UNIVERSITY OF NIS

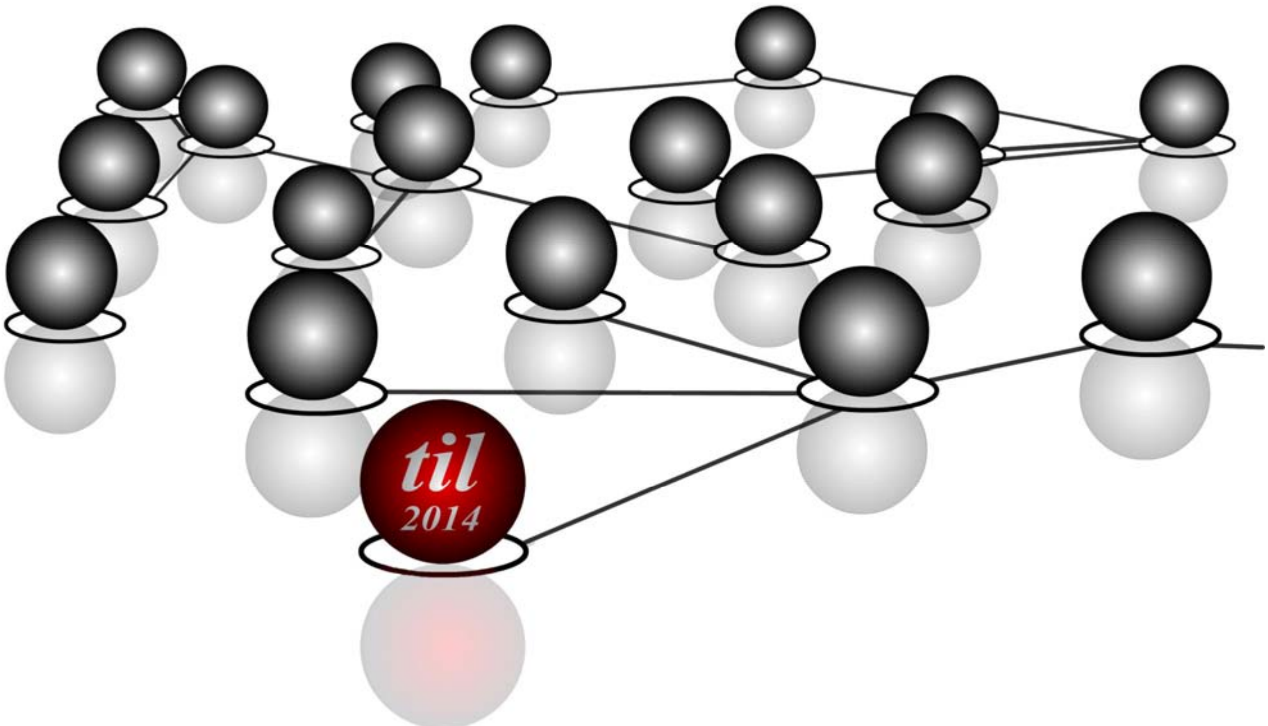
FACULTY OF MECHANICAL ENGINEERING

Department for material handling systems and logistics

5th INTERNATIONAL CONFERENCE

TRANSPORT AND LOGISTICS

PROCEEDINGS



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THE FIFTH INTERNATIONAL CONFERENCE

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FOREWORD TO THE FIFTH INTERNATIONAL CONFERENCE TIL 2014

In 2003, the Faculty of Mechanical Engineering, University of Niš, began to introduce multidisciplinary sciences by establishing the studies in engineering logistics. Multidisciplinarity is based on the scope of natural sciences studied within transportation engineering. The width of that educational scope is provided by classical mechanics of solid and compressible continuum, theoretical and experimental analysis of structures, sciences concerning processes such as stochastics, planning theory, simulation theory, economic theory, material flows, process optimization and information Internet technologies. This wealth of scientific values opens a path toward an easier acceptance of modern tasks in the wider engineering activity, which is one of the goals of academic work. Process studies within the area of industrial transportation are the scientific domain of modern engineering logistics. The Faculty of Mechanical Engineering, University of Niš, is the home of the Department of Transportation Engineering and Logistics which expands its knowledge on the Western European model of engineering logistics. These modern disciplines have been introduced through study visits by professors and assistants at the technical universities in Magdeburg, Dresden, Karlsruhe, Munich, Berlin and Vienna, as well as the visits of renowned European professors at the University of Niš, which have been taking place for the last 35 years.

The Fifth International Conference of the Faculty of Mechanical Engineering in Niš entitled Transportation and Logistics, TIL 2014, nurtures the disciplines of technical design of transportation machines and logistics directed toward the processes of exploitation of transportation systems. The Conference TIL 2014 has five topics: Plenary – shared, business logistics, transportation engineering, logistics of traffic engineering and industrial technology. The Program Committee has accepted 37 research papers as a thematic background for the dialogue. Current and logic ideas have attracted a number of scientific workers, students and professional experts to this scientific conference, which, above all, allows for the emancipation of the understanding of logistics and its introduction to the domestic educational and economic activity. Therefore, the Fifth International Conference includes thematic presentations by professional experts on current topics in Logistics, which take place on the second day of the Conference.

This and the previous conferences: TIL 2004, 2006, 2008, 2011, belong to the times of change in the economic model of national commerce from the socialist model to the liberal-capitalistic one. This process requires new knowledge and new professional structures which can enable the functioning of the market economy of the developed world. The professors of the University of Niš and Serbia believe that the need for more efficient work and new professional knowledge will be easily fulfilled by introducing new scientific disciplines and research. Moreover, new knowledge will lead to the new awareness in the people, and the return of the sensation of the beauty of being. The Faculty Board of the Faculty of Mechanical Engineering in Niš, by this act of dialogue and the support for the scientific conference TIL 2014, contributes to the changes in Serbia.

The help for the changes in the domestic educational system has continuously been provided by the Ministry of Education and Science of the Republic of Serbia and the sponsors of the Faculty of Mechanical Engineering who understand the times that we are living in. The Program and Organizing Committee of the Conference TIL 2014 would like to use this Conference Proceedings to extend their gratitude to the professors-founders, authors of papers, ministries, sponsors, the Serbian Logistics Association, the City of Niš and all other friends who have endorsed the previous conferences, thus contributing to the well-being of the future society.

Niš, 22 May 2014

President of the Program Committee TIL 2014
Professor Miomir LJ. Jovanović

Dr Zoran Marinković, a Full Professor at the Faculty of Mechanical Engineering, University of Niš, was born on 27.07.1948 in Beloljin, Prokuplje, Serbia. He finished elementary and high school in Prilep, Macedonia. He started studying mechanical engineering at the Technical Faculty in Niš in 1967. He graduated on 27.06.1972 with the grade point average 8.28 and a diploma thesis in the field of transportation engineering with grade 10. For the results achieved during the study, he received a university award for the best achievement in the third year of study at the Technical Faculty in Niš, Mechanical Engineering Department, as well as the Best Graduate Student of the Year 1971/72 Award at the Faculty of Mechanical Engineering in Niš. From January to December 1974, he worked as a production engineer in the Factory of cranes and steel structures, MIN Niš. This is how our colleague, Dr. Zoran Marinković, began a successful career in the scientific field of transport systems, to which he remained dedicated for the following 40 years. In 1975, he enrolled in postgraduate studies at the Faculty of Mechanical Engineering, University of Belgrade, where he studied the field of mechanization. He completed the studies with GPA 8.95 and successfully defended the magister thesis entitled *A contribution to the analysis of influential factors in determining the lifetime of drive mechanism in the development design of moving electric winch family* on 17.03.1983. He was fully employed at the Faculty of Mechanical Engineering in Niš from December 1974 to September 2013, starting at the beginning as a Teaching Assistant. In the year of 1986, he spent a three-month study period at the Department of Transport Technique of the Ruhr University in Bochum and in 1988 a two-month study period at the Department of Transport Technique of the Technical University Darmstadt. During these study visits, he studied the lifetime of crane drive components. The aim of these study visits was to provide the staff members of the University of Niš with adequate knowledge so that the industry in the region could be better developed. In this field of research, our colleague, Dr. Zoran Marinković, defended the doctoral dissertation entitled *Probabilistic - statistical model for lifetime calculation of crane drive mechanisms* on 05.07.1993 at the Faculty of Mechanical Engineering in Niš. In November 1993, he was appointed Assistant Professor at the Faculty of Mechanical Engineering in Niš in charge of the subjects *Transport Machines* and *Machines of Discontinuous Transport*. This is a period of his extensive professional scientific work characterized by the research of transport machine drive systems. In December 1998, he was appointed Associate Professor at the same faculty in charge of the subjects *Transport Machines* and *Machines of Discontinuous Transport*. Since 2001, in accordance with the new scientific requirements, Dr. Zoran Marinković has broadened his work in the field of transport and begun teaching subjects *Internal Transport and Storage* and *Container Transport*. In 2003, the Department of Transport Technology and Logistics was established at the Faculty of Mechanical Engineering, giving Dr. Zoran Marinković a great opportunity to fully express his knowledge: he took part in establishing the Department and the development of the first academic curricula for the new study profile. These first years of the novel study profile Transport and Logistics are characterized by 16 brand new courses, and Professor Dr. Zoran Marinković took a great part of the burden of a decade long activities until a steady educational activity in this area has been established. Apart from the aforementioned courses, Dr. Zoran Marinković introduced the subject *Storage Technique* and *Storage Logistics* and taught the *Technical Logistics* starting 2006. To be appointed a Full Professor at the Faculty of Mechanical Engineering in Niš, Dr. Zoran Marinković filed 125 scientific and professional papers, 22 strategic scientific projects, 30 projects conducted for the needs of industry, 5 published textbooks, 1 study and 1 research monograph. To date, the number exceeded 275 references which include 10 papers in the SCI list - Thomson Reuters categorization. It stands to reason that such great work would elicit recognition for the achievements and Dr. Zoran Marinković received Plaques in 1985 and 2011 from the Faculty of Mechanical Engineering in Niš for his contribution to the development of modern mechanical engineering studies. However, another significant contribution of our professor is related to the modern dynamics of transport machines, which he studied theoretically, by means of simulation, and experimentally. As a result of his work, the first industrial standards for transport machine drive mechanisms in Yugoslavia, based on the probabilistic - statistical lifetime model, were created between 1982 and 1988. This ended the period of inadequately designed transport machines with uneven lifetime of components. Through plenty of projects for the industry of southern Serbia, the modern mechanical engineering was elegantly introduced – essentially via products. Another important part of Professor Dr. Zoran Marinković's opus is his supervising work with students of mechanical engineering. He was a supervisor of two magister theses, more than 100 diploma (graduate) theses, and is now a supervisor of two doctoral theses. He has left the Department for Transport Technology and Logistics a legacy of the activities to which he has been dedicated all his life and the people who will continue his work. Today, after his retirement, he is still active in the field of technology of transport machines and works with students of master and doctoral studies. I strongly believe that the professional work of Dr. Zoran Marinković passed on to the Serbian academic and economic spheres is work based on optimistic and idealistic outlook on life.

May 2014 Members and associates of the Department for material handling systems and logistics

The Tenth Anniversary of the Department for Material handling systems and Logistics

Professor Miomir Jovanović, Faculty of Mechanical Engineering Niš

June 2013 marked the tenth anniversary of the establishment of the Department for Material handling systems and Logistics at the Faculty of Mechanical Engineering in Niš. During that period, 12 researchers had actively worked on the betterment of the Department and the development of new curricula and a new educational profile unlike any other in Serbia. Those ten years saw the subjects evolve into modern teaching disciplines, accredited and reaccredited. By educating young people in the country and abroad, a staff base was formed to pursue the fundamental scientific disciplines which are the backbone of the Department profile. The projects that were carried out in the last ten years resulted in over 200 scientific references and 15 papers on the SCI list. The adequately directed development of staff led to the preservation of the educational and scientific quality within the field of classical transportation engineering and the field of traffic and logistics. During the period of transformation of the educational system in Serbia, the technology and knowledge related to experimental and IT activities were retained. In that area researchers conducted interesting scientific experiments using the entire available experimental technology. The attractiveness of educational contents was expressed in the number of students who had applied for the module of Traffic Engineering, Transportation and Logistics. In the previous years (2002-2013), the Department profile was attended by 201 students (164+37), with 83 graduate engineers and 5 graduate managers. Five master's theses and one doctorate helped preserve the expert and scientific identity of the Department and the professional engineering degree awarded to the students. The fifth scientific conference represents the effort to organize a scientific dialogue at this Department and bring in the people from the practice and with academic knowledge of theoretical sciences.

C O N T E N T S

LOGISTICS (SESSION -4)

TRANSPORTING TECHNIQUE (SESSION -5)

TRAFFIC (SESSION -6)

INDUSTRIAL TEHNOLOGY (SESSION -7)

UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

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til 2014

TRENDS IN THE TECHNICAL LOGISTICS RESEARCH AND UNIVERSITY EDUCATION

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Faculty of German Engineering and Industrial Management
Technical University of Sofia

Abstract

The paper is dedicated to an actual understanding of logistics as a scientific discipline with cornerstones recently defined clearly, and the standing of technical logistics, particularly, in the science domain. The recent surveys on the trends in logistics and logistics research as well as the needed logistics taxonomy are discussed. After a brief presentation of the evolution in the university education in logistics, the actual trends for the development of curricula and the restrictions for the further growth of the discipline are argued

Keywords*: logistics, logistics research, logistics education*

1. INTRODUCTION

Logistics is an integral part of the world economy. Logistics costs are estimated to make between 9% of the Gross Domestic Product (GDP) in USA, 12% in EU and Japan, 15% in China and to 17% in Asia [1]. “Material handling and logistics are the backbone of the U.S. economy, Everything in our homes, businesses, malls and everything in between got there because of material handling and logistics” [2].“Logistics is the backbone of modern society. Logistics makes our world. ” This was the motto of the first International Logistics Science Conference (ILSC), on September 4th, 2013, in Dortmund/Germany. Logistics science is a recognized research area, which covers the different inquiry perspectives in its domain. Contrary to the expected maturity and stability of developments within such a broad area, over the last decade a considerable dynamics has been observed both in the fundamental issues of logistics as a discipline, and in the directions of research and teaching. As I was invited to present our point of view on the recent development in the area of technical logistics research and university education the first problem was, how to confine the subject in the variety of definitions of logistics. Consequently, the first section of this paper is dedicated to the comprehension of the Logistics, Logistics Engineering and Technical Logistics, in particular. The second one deals with global trends and their impact on logistics and research developments. Finally, the university education in Logistics Engineering and the obstacles standing in its way are represented, on the basis of our experience in the introduction of the Bachelor and Master’s degree courses in “Logistics Engineering” at the Technical University of Sofia in the last decade.

2. PROGRESS IN THE DEFINITION OF LOGISTICS

In 2010 Peter Klaus, editor-in-chief of Logistics Research commenced his editorial [3] with the rhetorical question: „ A science of logistics’: Is there any? And if so, is there one - or two, or even several? To answer these questions is not easy. We know that different members of the large worldwide logistics community … would have very different views”

The good old and very common understanding about logistics as “the art and science of moving things from one point to another and storing them along the way” , is akin to the definition of Materials Handling as „the art and science of moving storing, protecting and controlling materials“, but is unfortunately incomplete nowadays.

Logistics has a numerous different definitions because if the broad points of views on its activities. On the other hand, “these various definitions of logistics and their application in a particular environment demonstrate quite cleary the lack of general consensus among practitioners on what constitutes the exact nature of the discipline” [4]

The well-known “process definition” given by the Council of Supply Chain Management Professionals, cited by [5]: “Logistics is that part of the supply chain process that plans, implements, and controls the efficient, effective forward and reverse <u>flow and storage</u> of goods, services, and related information between the point of origin and the point of consumption in order to meet customers’ requirements.”

A resent common “scientific definition” was presented [6] on the results of an ambitious project by a working group of the Scientifically Advisory Board of German Logistics Association (BVL)[1] :

“Logistics is an application-oriented scientific discipline. It models and analyses economic systems as networks and flows of objects through time and space (specifically goods information, moneys, and people) which create value for people”. Five cornerstones are defined to an understanding of logistics as a science and its identity as an academic discipline:

1) The object of enquiry: flows in networks;
2) Logistical inquiry on consecutive levels of aggregation;
3) Interdisciplinary of logistics;
4) Unity within a variety of terminological, conceptual and methodological foundation through the network model;
5) Application orientation of logistics science.

“The fundamental principle is that the logistics takes a holistic view of all the activities, that belong to its domain

[1] Bundesvereinigung Logistik

[7] - inbound and outbound transportation, fleet management, materials handling, order fulfilment, logistics network design, warehousing, inventory management, supply/demand planning, and management of third-party logistics services providers, but also packaging, forecasting, procurement, return goods management, reverse logistics and global logistics.

Obviously, the logistics is an interdisciplinary applied science, with technical, information and business backgrounds and should not be observed as a bundle of engineering, business, information etc. logistics sciences. However, how much "business" and how much "engineering" remains vague. Marc Goetschalckx [8] claims that:

"Engineering logistics uses scientific principles, mathematical models, and information technology as fundamental tools to design supply chains, plan logistics processes, and operate logistics systems

Engineering logistics and business logistics are complimentary but fundamentally different. Business logistics is more focused on how to manage logistics processes and relationships. Practice assessments, behavioural propositions, and management concepts are typical outputs from business logistics research, while design concepts, decision support models and computer software are typical outputs from engineering logistics research. Educational programs for engineering logistics have evolved primarily in Industrial Engineering departments while educational programs for business logistics have evolved primarily in marketing departments. As a result, the two disciplines have traditionally approached logistics from very different perspectives.

Since 1990, there has been a dramatic increase in the implementation of information technology to support logistics functions. This has created a critical demand for new decision technology to take advantage of the increased information. It has also created a demand for people with both the engineering knowledge necessary to integrate this new technology into seamless logistics systems and the business knowledge needed to integrate this new technology with business practices. Hence, there is a need for business logistics and engineering logistics to coalesce around decision and information technology".

Logistics Engineering and Technical Logistics are often considered as synonyms. In accordance with the Charter of the German Science Society of Technical Logistics (WGTL)[2] "the Technical Logistics is the engineering science of planning, management and control of flows of materials, people, energy and information in systems. It covers mainly the task levels of planning and simulation, design and product development, automation, and operation and management. The annual colloquiums treat the following topics: Construction and mechanical design; Control and IT systems; Management, Organization and operations; Planning, analysis and simulation of logistics system

Therefore, Technical Logistics "expands" Logistics Engineering towards the areas of design, product development and automation of materials handling equipment. So Technical Logistics is also the study of the development, construction and the implementation of devices and equipment for moving and storage of goods and for the transport of persons (when the moving and transport take place over considerable distances within facilities). This is confirmed also by the numerous publications in the electronic magazine Logistics Journal, published by WGTL over the recent years.

3. GLOBAL TRENDS AND THE LOGISTICS RESEARCH

Global trends are a broadly discussed topic irrespective of their impact on logistics. Out of more than twenty global trends quoted in the literature, separate surveys use different sub-sets. The most frequently debated topics by the logistics community are:

Globalisation – A ten-fold increase of production in the last 60 years, with 30-fold increase of international trade at a drastic reduction of transport expenses - for instance, to deliver a bottle of wine at the price of 7.50 € from Australia to Europe, the transport expenses are calculated to be 12 euro cents.

Urbanisation – According to the United Nations forecasts in 2030 two-thirds of the population will be living in cities, whilst in the developed countries the reached boundary of 75% has been already crossed over and in them the percentage of city dwellers is expected to rise to more than 85% in 2050.

Climate change - Arctic Sea ice loss of more than 40% over the past 30 years, increasing greenhouse gases.

Demographic changes – Now over 20% of the European population is older then 60 years, with a forecast for 33% in 2050.

Technological Innovation and Digitalization

Sustainability - "development that meets the needs of the present, without compromising the ability of future generations to meet their own needs" (UN)

The much too broadened subject area of logistics presumes differentiation of the nature of impact of separate global trends on the different logistics prospects In [9] other subset of global trends is picked as most significant for intralogistics – Urbanisation, Individualisation, Demographic change, Climate change and environmental impact and Ubiquitous intelligence

Analysis, surveys and forecasts are conducted in industrial corporations, professionals' organisations (such as BVL in Germany and CSCMP in USA), in research institutes and in the universities – in scientific publications and PhD Thesis e.g. [10], [11].

The forecasts linked with the technical aspects of logistics, can be grouped in 2014 with respect to the time horizon they have set as:

Long-term – over 20 years [12], [13]

Mid-term – over 10 years [2]

Operational - 5-10 years. [14] [15] [16]

Long-term forecasts

The long-term forecasts deserve particular attention because they are not frequently discussed in the publications. A recent study [12] give a global long term (to 2050) forecast about the future environment for the

[2] Wissenschaftliche Gesellschaft für Technische Logistik

logistics. The identified megatrends, as commented from the point of view on the logistics research challenges [13] are partially quoted below:

- **Resource shortage and sustainability** – e.g. supply chains coping with oil prices up to US$1000 per barrel have to be designed and implemented;
- **Urbanization and new importance of urban logistics systems** – Logistics is expected to contribute to dies development e.g. by new city logistics and e-commerce distributions concepts, as well as new transportation systems) cargo streetcar, cargo bikes, parcel stations etc.);
- **Security concerns and problems within international transport systems** – will be a further major task and innovation expectation toward logistics – e.g. trough increasing technology implementation such as GPS tracking &tracing etc.;
- **Importance of demographic changes and knowledge management concepts** – the logistics systems will have to adapt sharply to such changes and implement rigorous qualification and training schemes as especially in developing countries, there are significant gaps;
- **Technological innovation** as e.g. RFID and GPS implementation as well as the Internet of Things with new steering mechanisms for logistics systems.

It is remarkable, that the German research cluster EffizienzCluster LogistikRuhr has defined the future major topics (project packages) in respect to identified global trends [13], as Changeable Logistics Systems, Logistics-as-a-service, Urban Logistics Systems, Transport Systems Management, Sustainable/Green Logistics, and Logistics Competence. This ambitious investigation initiative enclose 124 companies and 18 research and educational institutions with a project volume of € 106 million, with the objectives: the development of 103 products, patents and innovation, achievement of 25% saving of the logistics cost, the establishment of 4000 workplaces and generation of two billion euro market potential.

Mid-term forecasts

The, trends, followed in the recent MHI Roadmap for the next eleven years [2] closely correlate with the presented in the DHL survey, adding a few other technological aspects:

- The growth of e-commerce
- Relentless competition
- Mass personalization
- Urbanization
- Mobile and wearable computing
- Robotics and automation
- Sensors and the Internet of Things
- Big Data and predictive analytics
- The changing workforce
- Sustainability

The forecasts are grouped in 10 distinct organizational and technological groups and one educational domain: TOTAL SUPPLY CHAIN VISIBILITY, STANDARDIZATION, SENSORS AND THE INTERNET OF THINGS, PLANNING AND OPTIMIZATION, E-COMMERCE, HIGH-SPEED DELIVERY, COLLABORATION, URBAN LOGISTICS, TECHNOLOGY AND AUTOMATION, SUSTAINABILITY and PROFILE OF THE MATERIAL HANDLING AND LOGISTICS WORKFORCE.

A considerable part of the forecasts represent an ambitious road map for a present and future technical logistics research: Thus, for instance, the estimates for 2025 in the "Technology and automation" expectations are as follows:
„Significant new systems for storage, handling and order picking should be developed that allow companies to reconfigure their systems rapidly to accommodate changes (both up and down) in throughput, SKU velocity and product mix;
Significant advances in scalability should have been made in storage, handling and order picking systems;
Affordable robotic order picking systems should be available that support high-throughput, single-piece picking. These systems should be available in both part-to-picker and picker-to-part configurations;
Control and execution systems featuring wearable computing devices should be developed and widely deployed in transportation, warehousing and manufacturing;
Highly productive systems employing interactive computing devices and robots should emerge in the industry, particularly in order fulfilment and manufacturing systems;
Economical, high-speed automation to load and unload trucks should be available both at the carton and pallet level";

Operational forecasts

Assessing the worlds megatrends (continuing globalisation, global uncertainty, demographic changes and urbanisation, sustainability, changing competitive landscape, digitalization etc.) with the challenging new technologies (next-generation mobiles, hybrid IT &cloud computing, Encryption & Cryptography, Embedded technology etc.) a working group from DHL Solution & Innovation in cooperation with Detecon Int. Consulting derive ten key midterm trends for the logistics [14]. From point of view of Technical Logistics, the key technological trends of particular importance are:

Technology Trend	Impact	Relevance
Big Data/Data-as-a-Service	High	<5 years
Cloud Computing	High	<5 years
Autonomous Logistics	Medium	>5 years
3D Printing	Medium	>5 years
Robotics & Automation	Medium	<5 years
Internet of Things	Medium	<5 years
Next-generation Telematics	High	<5 years
Quantum Computing	Low	>5 years
Augmented-reality Logistics	Low	<5 years
Low-cost Sensor Technology	Medium	<5 years

Table 1 Key technology trends [14]

Big data analytics allows the use of immense amount of unstructured data and enables real time analytics e.g. for the real time routing or real time pick-up.
The paradigm of cloud computing and cloud-based services provide a new concepts of the logistics services for a globally distributed logistics networks and enterprises [17]

Autonomous logistics enables unmanned autonomous transfer of load units with such a devices as cellular transport systems, self-steering vehicles, etc.
3D-Printing is able to change dramatically the future logistics by involving new networks for materials delivery;
Robotics and automation gain new roles in the intralogistics e.g. with self-learning and adaptive systems
Internet of Things technologies (such as RFID) enable physical objects to interact in an Internet-like structures, enabling self-steering processes and new services such as event-driven solutions.
The next generation of telematics use real-time date and enable new solutions for dynamic routing and flexible delivery offerings
Quantum computing offers operational speeds far exceeding those in conventional computing; The quantum cryptography can make the information exchange more secure
The augment-reality-logistics adds virtual visual layers with specific information and provide new opportunities for the logistics planning, process execution, and visual analytics.
Low-cost-sensors reduce the investments and can provide a new sensitivity for the material handling equipment end for the control and management of a complex logistics networks.
The results from a Delphy-Survey [16] concerning the technological trends for the logistics till 2020 show that the "use of telematics applications" and "Fusion of logistics with information and communication systems "are seen by the respondents as most expected.

	A	B	C
Deployment of telematics applications	1	2	4
Fusion of logistics and information systems	1	3	3
Application of the GPS satellite navigation system	2	7	7
Traffic information systems for real-time routing control	3	3	5
electronic marketplaces for transport services	3	6	8
Networking and integration with IT systems	4	1	1
Real-time capability of traffic information systems	4	3	2
Use of Mobile Computing	5	8	9
Use of simulation models and techniques	6	5	6
Traffic information systems for the reduction of gas emissions	6	4	7

Table 2 Technological trends in the logistics [14]
A-feasibility; B-desirability; C-impact

Matter for reflection

The invariable positivism of many forecasts in the area of logistics evokes an air of boredom. Who remembers the forecasts defined prior to 2000 and were there any analyses, which of these are realized, to what extent, and more importantly, "why?" – There remain unanswered questions. The lack of sound scepticism and criticism is the salient characteristics of the projects of the science from that of business, where there is a clear-cut distinction – which enterprise is profitable and which is losing money.
The lack with respect to feedback is fundamental – whether the ambitious forecasts are realized in the expected terms, why are they changing, or the forecasts remain utopia, what is the contribution of research to our knowledge in the future, or the new realities in logistics have taken us aback with their emergence. Regardless of the fact that fusing informatics with logistics is the outstanding tendency in all investigations, even its evolution in the course of logistics development is not unequivocal. If we sought publications on the topic of cloud computing and its effect on the development of logistics some ten years ago, the answer would be obvious – there are none, but today we expect soon fundamental changes in the information environment of logistics. Fifteen years ago a lot of hope was allotted to the topic of RFID, but "the number of consumer goods manufacturers doing anything meaningful with RFID is still just a handful" [5]. Regardless of the efforts of GS1, the introduction of EPC on a world-wide scale is left to the future. The topic of Electronic Data Interchange has been enthusiastically commented over more than 30 years, yet the real introduction of exchange of ten/twenty messages in heterogeneous IT logistics environment is still a problem beyong separate industry sector.
A feedback is necessary as regards the forecasts, so that the direction of research can become pragmatically operative. A plausible example in this view are the forecasts by [18] [19], in which is seen an assessment of the progress with respect to the ambitious trends.
Endorsable are the recommendations of [5] about the necessity of feedback in scientific publications, which is worked out in parallel to the forecasts and state-of-art-surveys in the specialized scientific journals on the basis of the standardized taxonomy for logistics research which is still missing.

4. LOGISTICS ENGINEERING EDUCATION

A new dynamics is observed on a world-wide scale as regards the relatively conservative university education
After The Chinese government has identified logistics as one of the pillar industries to support economic growth, the number of schools that offer a major in logistics and the number of logistics programmes has increased steadily. Today there are about 280 universities offering logistics management majors and 60 universities providing majors in logistics engineering" [20]
Undergraduate, Graduate and doctoral level programs in logistics are offered on different structural levels – from University level (e.g. US Army Logistics University[3] in Fort Lee, Virginia, USA, Molde University College, founded in 1994;Norway), faculties (e.g. Logistics faculty[4] in Ohio-State-University, Ohio, USA, Logistics Faculty[5], Higher School of Economics, Moscow, Russia, Faculty of Logistics and Transport of St. Petersburg State Economics University and others) or hundreds of logistics

[3] http://www.alu.army.mil/
[4] http://fisher.osu.edu/ftmba/academics/faculty/operations,-logistics-and-supply-chain-management/
[5] http://logistics.hse.ru/

institutes – as major , as a core stud , as well as separate courses.
Despite the booming educational market in China in the last decade, the logistics education is driven mainly by the universities in USA and Europa.
With reference to USA, in 2000 Prof. Tully [4] realized that the logistics education has matured significantly over the past 40 years. The majority of the degree programs are in the area of business logistics U.S. News and World report ranks the top logistics degrees in the USA. In top ten are included: the Michigan State, the MIT, Arizona State, Ohio State, Pennsylvania State, Purdue University, University of Tennessee, Carnegie Mellon etc.
There are no overall statistical data about the university education in separate specialities in which Logistics is studied as a major. As a milestone can serve the data, provided by AASCB International from more than 600 universities [21] given in Table 3.

Logistics Education in Business Universities	2012-2013	Estimated number
Bachelor Degree Programs	13,3% from 638	~85
MBA	5,2% from 671	~35
Specialized Master Degree Programs	10,9% from 503	~55
Doctoral Programs	5,1% from 293	~15

Table 3 Logistics programs offered in 2012/13

The data obviously do not reflect the current situation in China and Europe

Logistics education in Europa

The range and the distribution of the logistics education in Europe nearly logically follow the volumes of the logistics market in the separate countries in Europe (Fig.1) . With a total logistics market size of approximately € 228 billion. and a transport volume of more than 3.4 bln. Tons in 2012, Germany is the largest logistics market in Europa [22]. The first seven countries cover 70% of the overall logistics turnover.

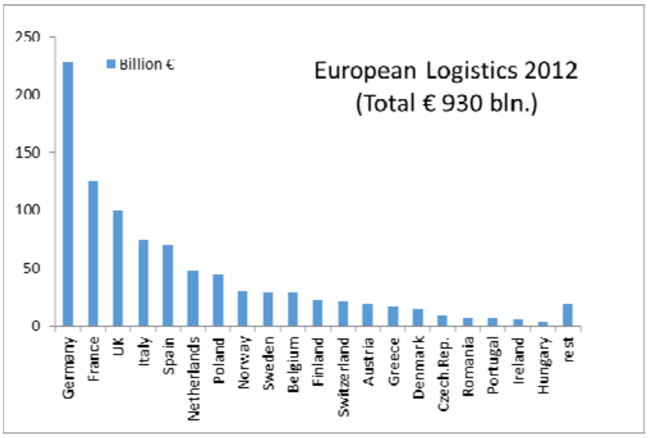

Fig. 1 Logistics Market in Europa

The extensive systematic survey about the logistics education programs in Europe was conducted within the framework of the project BESTLOG (www.bestlog.org) in the time February 2006 until May 2010, funded by the European Commission under the 6-th Framework Programme, collecting information from 27 EU Countries+ Switzerland, Norway, Russia and Turkey. Till 2008 there have been collected 866 educational programs [23]. In the survey are collected data on courses in vocational, undergraduate, postgraduate and executive levels, conducted in universities, universities of applied science and colleges of cooperative education. Trendsetters in the logistics education are the economically leading countieres.

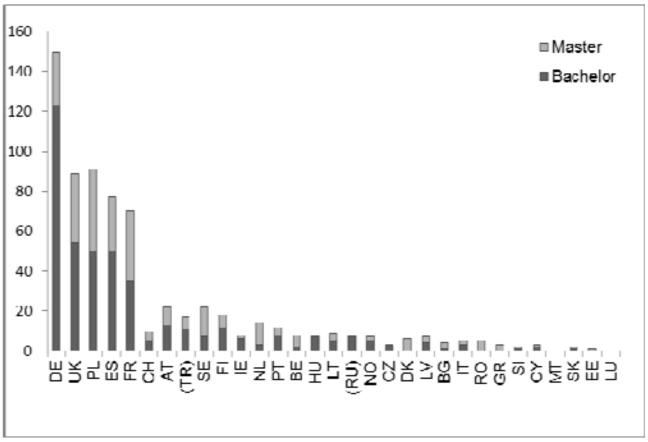

Fig. 2 Logistics Programms in Europa (on [23])

From collected in BESTLOG –Database programs 418 are classified as undergraduate, 262 as graduate, 54 as executive and 132 as vocational programs.
In the survey Germany take a leading position. In 2007 in Germany a total of 11600 students completed their studies with logistics background – 1300 with Major, 3500 with core study and 6800 with degree courses [24]
In Germany in 2007 a total of 11600 students completed their studies with logistics background – 1300 with major , 3500 with core study and 6800 with degree courses [24]
From the majors offered in Germany only 7% are in universities, 77% in universities of applied science and 16 % in colleges of cooperative education. The same resource shows the dynamics of the introduction of logistics specialities. Whereas in 2000 ten such specialities were offered, in 2007 they were 31, distributed in 7 universities, 18 universities of applied science и 6 colleges of cooperative education. Most of the degree programs are in the area of Business Logistics, followed by Logistics Engineering.

By comparing the results from different sources is seen some uncertainty. For example in BestLog for United Kingdom are identified 54 undergraduate and 35 postgraduate programs. But [25] reports 16 universities with 23 programs. Recent survey from 2013 [26] finds 41 postgraduate programs form 35 universities.
The overall number of programs in the survey is probably underestimated. So for “countries like Denmark, Italy and Greece seem to be somewhat underrepresented up to now in the bestLog-database” [23] Indeed, Dallarri reports in [27] about 4 undergraduate programms (Bolzano, Genova,

Napoli, Roma), 5 two-years postgraduate programs (Catania, Genova, Pisa, Roma, Trieste) and additionally 9 others one-year postgraduate programs.
Despite some inconsistencies, the creation of the common data base for the logistics majors in Europa is a significant step for the assessment of the evolution in the logistics education. These strongly indicate the need for systematic maintained statistics at the European level. Since the beginning of BESTLOG-Project the European logistics Association (ELA) has been engaged as a partner. ELabestlog website (www.elabestlog.org) was launched in 2010 as "emerging european platform for sharing best practice in logistics", unfortunately with modest activity.

In Bulgaria the logistics education as a Major is conducted at the Technical University of Sofia (Logistics Engineering - Bachelor and Master Level), Business University in Sofia (Business Logistics – Bachelor and Master), University of Shumen (Bachelor and Master). There are additional Supply Chain programmes at Sofia University, and in the High School of Transport.
The Technical University of Sofia introduced education in Bachelor and Master's degree courses in "Logistics Engineering" in the last decade. On average there are ca. 30 students registered on the Bachelor level and 15 on Master level. In collaboration with the University of Karlsruhe a core study in Logistics is provided in the German Faculty at the Technical University in Sofia.
The introduction of Engineering Logistics education would not have been possible in Bulgaria without the longstanding co-operation with, mainly, the Institute for Materials Handling and Logistics Systems (ILF), KIT-Karlsruhe, as well as the international cooperation with other universities from Central and Eastern Europa.

Obstacles in the logistics education

Many authors [26], [28],[29] discuss the obstacles to the growth of the discipline in the university education. The main of them can be summarized in 1) Lack of student awareness about the discipline; 2) Shortage in educators; 3) Disagreement with industry concerning an appopriate curriculum; 4) Lack of common standard guidelines for the logistics education. These topics are discussed briefly below.

1) Lack of student awareness about the discipline

In [25] was reported "At graduate levels, there are 10 degree programmes that have a direct logistics focus. However, it is reported that higher education institutions find it difficult to fill student places due to the poor image of the sector and lack of promotion of logistics as a career."
In the USA "from the schools that offer degrees in logistics, less than one-third require a course related to the discipline as part of the business core for all students … It is likely, therefore, that nearly 90 percent of business graduates leave their programs with little or no understanding of an area" [28]

2) Shortage in Educators

The research into logistics education [28], focused on the business area, indicate that:
„Since most programs are housed within departments with a larger program, the number of faculty with expertise in logistics/SCM usually is a small percentage (frequently about one-third or less) of the total number of faculty in the department. Many programs have only one or two professors devoted to the discipline, and even the larger programs are small relative to the host discipline. For example, the Ohio State University's logistics major, one of the largest and oldest logistics programs, is housed in the Department of Marketing and Logistics. That department has 17 tenure track faculty members: 11 (65 percent) in marketing and six (35 percent) in logistics. At the University of Arkansas's Walton College, there are 14 tenure track positions in the Department of Marketing and Logistics. Ten of those faculty positions are in marketing, and only four are assigned to logistics, less than 30 percent of the total. The same is true in most of the other programs, but often the number of (logistics) faculty is even smaller … Of the 27,676 full-time faculty in the United States, only 309 (1.1 percent) are in the field of supply chain management/transportation/logistics"
From European (and particularly from German) point of view, Professor ten Hompel makes in [30] a very impressive comparison of the academic situation in logistics with this in computer sciences. So "in the (German) industry almost €220 billion - from workforce of 2.7 million people- are generated from the logistics, and there are 59 university logistics departments, additional 90 departments in the universities of applied science. Comparing this with the computer science (€148 turnover, 0,85 million employees) one comes to the conclusion that there are 36 faculties and 28 departments with 961 professors. This discrepancy is not acceptable for the interdisciplinary field of logistics and Professor ten Hompel puts forward the establishment of a new European research centre for logistics. Similar ideas can be found in the U.S. Roadmap –" By 2025, there should be a Material Handling and Logistics Research Council with significant funding for academic research that has a strong potential to affect the industry" [2].

3) Disagreements with industry concerning a curriculum

Through a survey [31] 147 logistics professionals in Australia were asked how education programmes should be developed and conducted for the next 10 years. "the majority of responses (from the list of options provided) indicated that the industry should be involved in this process. In other words, providers should develop and conduct these programmes in consultation with logistics associations. In addition, respondents suggested that the development and execution of logistics education programmes should be supported by other business associations and that the educational programmes of other international universities should be consulted." The needs of coordinating bodies are recognized in the U.S. Roadmap too – "By 2025, a material handling and logistics education consortium should be actively working with community/technical colleges and four-year schools. This should expand the number of schools offering degrees, increase the number of core courses and the total number of graduates" [2]

4) Lack of common standards for the logistics education

“No studies have been undertaken to provide a framework for logistics higher education to help logistics educators to design, assess and improve their programms” [32].

The attempts for synchronization of Logistics education have been known for quite some time. Examples of direct transfer are Dual educational programs, such as:

„Atlanta – Singapore”: Dual master program in logistics, established in 1998 with a research emphasis between the National University of Singapore (NUS) and the Georgia Institute of Technology (GT) Atlanta, USA;

„MIT-Zaragoza” (The MIT-Zaragoza Masters of Engineering in Logistics and Supply Chain Management, created in 2004 between MIT and Zaragoza Logistics Center, Spain, held in Spain and English, dual degree within international MBA; PhD, engineering systems division),

‚Karlsruhe – Sofia (Dual bachelor and master program in Mechanical Engineering - with core study in Logistics Engineering- established in 1990 between the University of Karlsruhe (KIT) and Technical University of Sofia (TUS) , held in German, PhD, Engineering System Division).

„Berlin-Shnghai“ Established in 2009 dual post graduate programm in Master in Industrial Engineering (Logistics/SCM) between TU Berlin and Tongji University Shanghai. PhD dual promotion is provided.

Another alternative is through join educational projects e.g. in TEMPUS framework. In 2003-2006 within the framework of TEMPUS-Project JEP 17019-2002 „Development of new curricula in the Technical Logistics in University Nis, Serbia” carried out in collaboration among the universities of Magdeburg, Dresden, Munich, Karlsruhe, Vienna and Sofia with the Serbian universities in Nis and Novi Sad. The cooperation between the Technical University of Sofia and the University of Nis in the TEMPUS – Framework continues in further projects nowadays – e.g. in the project in progress 530577-TEMPUS-1-2012-1-RS-TEMPUS-JPCR, dedicated to improvement of Product Development studies. Noteworthy mentioning are also attempts at synchronisation of logistics education within the framework of University Logistics Networks, e.g. EUNiL, established in 1994 as a forum for universities interested in logistics education, which primary involved universities from Cardiff (United Kingdom), Dortmund (Germany), Eindhoven (The Netherlands), Lausanne (Switzerland) and Linköping (Sweden) [33] and European Logistics Association.

The lack of common standards can be overcome after the collaborative work on strong definitions of the desired skills. In this respect the idea of Prof. ten Hompel about the establishment of a new European Research Centre for Logistics deserves considerable attention and discussion in the logistics community. Similar idea for the USA is given in [28] – “The federal government should establish a national centre to advance logistics and supply chain education”. The centre should establish common European recommendations for the university logistics education. Perhaps it is necessary to synchronise the establishment of common standards with the standardisation of the desired skills in Logistics, based on the European Qualifications Framework (EQF), e.g. ELAQF Standards of competence, that lead to the ELAcertification., despite the fact that the EQF is seen as independent from higher education development.

4. IMPLICATIONS

Following inplications can be derived from the study:

1. “While there are valid and legitimate reasons for fractionalizing logistics programms into ... Business Logistics, or Logistics Engineering (or Technical logistics) , but there are many areas of mutual concern that transcend these parochial perspectives” [4]. The hosistic and global backbone of the logistics should not suffer from the fragmentation and regionalization
2. Despite the rapid development of the logistics science in the last 40 years, the work on the well-formed content structuring is not competed yet. It is esepcially evident in the area of Logistics Engineering.
3. A common taxonomy for the logistics research is still missing.
4. The academic logistics comunity needs a framework for coordination, which gives a systematic guidelines to support the educators in the development of the local curricula, and for a common policy on overcomming the identified obsacles.
5. Unanswered question remains - how to ensure the continuity in the implementation of results, respectively subsequent development for important expired projects, such as Bestlog. The stability can be achieved at common institutional level.
6. The academic logistics community comes to maturity to launch a constructive debate on the creation of a future European Logistics Institute.

5. CONCLUSIONS

Evidently there is no stagnation in the logistics research and logistics education. The last decade has seen some progress in the definition of logistics and its subject as a science. The impact of global trends onto separate perspectives in logistics is a hot topic both in scholarly research and in industrial studies. The expected trends in innovation over the next decades are basically influenced by the fusion of informatics and logistics. University education in the area of logistics has been expanding over the last ten years. The basic challenges and obstacles to its development are in the lagging availability of academic resources, alignment of educational programs with the requirements of the changing world and in the necessity for synchronization of its contents on European and world-wide scale.

REFERENCES

[1] CSCMP, 24-th Annual State of logistics Report, CSCMP, 2013

[2] K. Gue, E. Akcali, A. Erera, B. Ferrell und G. Forger, „Material Handling & Logistics U.S. Roadmap 2025 “, MHI, 2014

[3] P. Klaus, „Business logistics and logistics engineering: the rocky road “, Logistics Research 2010.Vol.2, 2010.

[4] P. F. Tully, „A Unified core curriculum for global logistics education “, International Review Volume.10, 2000, pp. 125-136.

[5] R. Farahani, N. Agari und H. Davarzani, „Overview," in Supply Chain and Logistics in National, International and Governmental Environment, Springer Verlag, 2009, pp. 1-20.

[6] W. Delfmann, W. Dangelmaier, W. Günthner, P. Klaus, L. Overmeyer, W. Rothengatter, J. Weber und J. Zentes, „Toward a science of logistics: cornerstones of a framework of understanding of logistics as an academic discipline ", Logistics Research Vol.2, pp. 57-63, 2010.

[7] M. Goetschalckx, Supply Chain Engineering, Springer Verlag, 2011.

[8] M. Goetschalckx, „Logistics", 2002. [Online]. Available: http://www2.isye.gatech.edu/~mgoetsch/cali/VEHICLE/VR1A005A.HTM

[9] G. Karting, B. Grösel und N. Zrnic, „Past, State-of-the-Art and Future of Intralogistics in Relation to Megatrends " FME Transactions, Volume 40 Nr. 4, 2012,pp. 193-200.

[10] H. A. von der Gracht, "The Future of Logistics: Scenarios for 2025", Wiesbaden: Gabler V., 2008.

[11] J. Fontius, Megatrends und Implikationen für Logistik, Dissertation, Berlin: Universitätsverlag TU Berlin, 2013.

[12] DHL, „Delivering tomorrow: Logistik 2050 Eine Szenariostudie ", Deutsche Post AG, Bonn, 2012.

[13] M. Klumpp, U. Clausen und M. ten Hompel, „Logistics Research and the Logistics World of 2050", in Efficiency and Logistics, Springer Verlag, 2013, pp. 1-6.

[14] DHL, „Logistics trend radar: Version 1: April 2013", DHL Customer Solutions & Innovation, Troisdorf, Germany, 2013.

[15] C. Kille, „Wir lieben Logistik "Verkehrsrundschau, Sonderheft Logistik 2013, pp. 26-29, 2013.

[16] A. Münchow-Küster und S. Zelewski, „Überblick über die Ergebnisse der Delphi-Studie: Trends in der Logistik in der Dekade 2010-202 ", Institut für Produktion und Industrielles Informationsmanagement, Universität Duisburg-Essen, Essen, 2012.

[17] W. Delfmann und F. Jaekel, „The Cloud-Logistics for the future? ", 2012. [Online]. Available: http://www.bvl.de/wissen/publikationen/positionspapiere/diskussionspapier-cloud-logistics.pdf

[18] D. J. Bowersox, D. J. Closs und T. P. Stank, „Ten mega-trends that will revolutionize supply chain logistics", Journal of Business Logistics Vol.21. Nr. 2, 2000, pp. 1-15.

[19] E. Sweeney, „Supply chain "mega-trends": current status and future trends", Journal of the Chartered Institute of Logistics and Transport (CILT) in Ireland, April 2013, pp. 31-34.

[20] Y. Shi und R. Handfield, „Talent management issues for multinational logistics companies in China," International Journal of Logistics : Research and Application Vol.15 No. 3, June 2012, pp. 163-179.

[21] AACSB, „Business school data guide 2014", Tampa, Florida, 2014.

[22] Fraunhofer Arbeitsgruppe für SCS, Top 100 in European Transport and Logistics Services 2013/2014, Nürnberg, 2014.

[23] BESTLOG, State of the Art Report III, 2009.

[24] W.-C. Hildebrand und A. Roth, „Führungskräfte für die Logistik - Akademische Ausbildung in Deutschland," in *Das Beste der Logistik*, Berlin, Springer Verlag., 2008, pp. 69-79.

[25] UKCES, Skills for logistics, (UK Commission for Employment and Skills), 2007.

[26] M. Bourlakis, M. S. Sodhi und B.-G. Son, „The relative emphasis on supply chain/logistics topics by UK industry in hiring postgraduates and by UK universities in teaching and research ", International Journal of Logistics: Research and Applications Vol.16 No.6, 2013, pp. 506-521.

[27] F. Dallari, "Come si creano i talenti? Lo stato della Formazione Universitaria in Italia", Milano, 2011. [Online]. Available:htto://www.luic.it/ricerca/clog/cm/upload/Dallari_Propeller_20110307.pdf

[28] J. Ozment und S. B. Keller, „The Future of logistics education," Transportation Journal, January Vol.50, 1, 2011.pp. 65-83

[29] S.Golicic, L.M.Bobbitt, R.Frankel, S.R.Clinton, "And who will teach them? An investigation of the Logistics PhD Market" in Journal of Education for Business, 80,1, 2004, pp.47-51.

[30] M. ten Hompel, „Corporate Academies in der Logistikqualifikation - Logistikqualifikation 2030 ", in Tagungsband: Logistikqualifikation 2012, FOM, Duisburg, 2012.

[31] Vinh V. Thai, „Competency requirements for professionals in logistics and SCM ", International Journal of Logistics Research and Application, 2012, pp. 109-126.

[32] J. Tong, "Managing logistics higher education using logical network analysis", International Journal of Innovation; Management and Technology, 2011, Vol.2, No.4, pp.309-314.

[33] M. Naim, C. Lalwani, L. Fortuin, H. Aronson und T. Schmidt, „A model for logistics systems engineering management education in Europa", European Journal of Engineering Education, Issue I, 2000, pp. 65-82.

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SOME ADVANCED STRUCTURAL DESIGN SOLUTIONS IN THE FIELD OF TRANSPORTATION

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Abstract

Transportation has always been one of the main impetuses to engineers by giving them a challenge to move the objects easier and faster. The challenge breaks down to very simple requirements, such as: make it lighter, stronger, more reliable and comfortable, safer, more robust, less expensive. These requirements have driven the development of novel structural materials and designs in the field of transportation, thus enabling solutions that classical structural materials and design could not comply with due to the imposed limitations. Advanced fiber-reinforced composites, as materials that offer the highest potential for weight reduction of traffic carriers, are in the focus of this paper. Reliable experimental testing, numerical simulation and characterization of these materials are discussed. Their potential is demonstrated on an example involving large deployable booms of concrete boom pumps. As a next level in structural design and behavior, the application of multifunctional materials with the idea of rendering structures active/adaptive and thus highly robust is elucidated. Some examples from the field of transportation are given.

Key words*: structural design, transport, concrete boom pumps, composite laminates, active structures, crane*

1. INTRODUCTION

Transportation as an engineering discipline has always been one of the major impetuses to engineers by giving them a challenge to make the structures and goods easier and less costly to move. The challenge breaks down to very simple requirements, such as: make it lighter, stronger, more reliable and comfortable, safer, more robust, less expensive.

Mass reduction for the improvement of energy consumption and emission as well as to meet certain legal regulations is one of the principal drivers in material selection for transportation. Over the past few decades, the use of composite materials in designs has seen enormous progress. It has opened new frontiers in optimization of structural design. The advantage of composites lies in their high strength to weight ratio, good stiffness and functionality as well as non-corrosive features, among others [1]. As a rather illustrative example of transport machinery, at which application of composite laminates has enabled to redefine the operative range, truck-mounted deployable concrete boom pumps are addressed in this work. This paper considers the aspects of design, simulation and testing of a boom section of concrete boom pumps made of composite laminates. Particularly, with regard to show that FE simulation is in the very heart of layout of the structure even for the manufacturing preparation. However, the main objective of a structural design of ensuring that a structure remains fit for the purpose and can sustain all loadings without failure makes testing still an indispensable element of the development of such parts.

As a next level in structural design and behavior, the idea of active/adaptive structures is considered. Adaptive structures have attracted a great deal of attention over the past two decades, with many researchers dedicating their work to this enticing field of research [2] – design of adaptive structures, their modeling, development of control laws, etc. Adaptive structures are characterized by the presence of sensors and actuators within the structure, coupled with each other by a controller that implements the control law, i.e. the strategy of structural behavior. The major application of adaptive structures is in the field of dynamics. Suppressing structural vibrations significantly increases safety and robustness of structures as well as the efficiency of machineries. The feasibility of adaptive structure approach will be demonstrated in this paper on the example involving vibration suppression of a tower crane's truss structure.

2. DEPLOYABLE CONCRETE BOOM PUMPS

Due to their high efficiency, flexible deployable concrete boom pumps belong to the essential items of heavy-duty equipment for the building industry, mining and tunnel construction and other major industrial projects [3]. Apart from many other criteria, which also include the adaptability to complicated construction site conditions, particularly the effective reach and coverage of the concrete distributor masts is a deciding competitive factor. Today concrete distributor masts provided with five or even six arm-segments and large operating range meet all expectations and requirements in civil engineering. Deployable booms are essential parts of concrete boom pumps. The overall length of the boom structure is a competitive edge because it commonly defines the area of operation (see Fig. 1). In particular with six boom segments, due to the relatively short lengths of each boom, the mast can be optimally adapted to an existing clearance of a structural level. The mast length available is converted by its flexibility at the same time without losses in reach and coverage depth. On the other hand, another very serious limitation must be considered. That is the axle load permitted on roads by legal rules, because the concrete boom pumps have to drive on the roads to get to the building sites. Hence, the restrictions in the registration approval make weight reduction of the overall equipment absolutely necessary.

Fig. 1. Mobile concrete boom pumps in operation

Along with optimal performance characteristics it places high demands on the design quality of such machines. If this industry would not place emphasis on further innovation, then the growth of the mast length would approach its ceiling. To get an increased boom length under these contradicting demands requires optimal lightweight construction based on extensive FE simulation. The use of high-alloy steels brought some potential for the boom design. For further substantial weight reduction as a pre-requisite for larger boom structures, a material with high stiffness to weight relation has to be sought. To that purpose carbon-fiber reinforced composite (CFRC) materials seem to be a suitable alternative.

3. COMPOSITE LAMINATES – MODELING, SIMULATION AND TESTING

The first priority in performance enhancement of concrete boom pumps is given to the increase of operational range and loading capacity along with an increase in speed of positioning and positioning accuracy and discharge of concrete with simultaneous improvement of stability against overturning. At present, the material steel takes for various reasons undisputedly the top position among all imaginable construction materials and will remain for most of the design. However, at somewhat lower stressed areas near the mast tip, strength problems have taken a back seat compared to stability problems. Adequate solution for this problem requires application of innovative materials. Outstanding examples of innovative materials are the various fiber composite materials based on carbon fibers, glass or aramide fibers to the natural fibers. Through the years, the use of composites materials in design has seen enormous progress. The advantage of composites lies in their high strength to weight ratio, good stiffness, functionality, non-corrosive features. Laminates represent a common form of CFR composites that offers many possibilities for tailoring the material properties.

3.1 Modeling of composite laminates

Quite generally speaking, composite materials are formed by combining two or more already existing materials with different properties. The aim is to form a material with unique new properties, which are actually a combination of advantageous properties of the constituents. The most common architecture of carbon fiber reinforced composite materials is laminate, which consists of a number of layers with different orientations of fibers and certain sequence (Fig. 2).

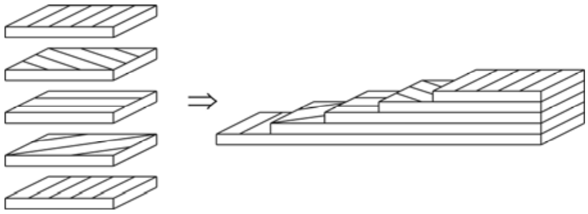

Fig. 2. CFRC laminate with unidirectional layers

For the simulation of the global behavior of composite materials, homogenization methods are used. They allow the calculation of composite effective properties knowing the topology of the composite representative unit cell. In this manner, the composite material is modeled as "equivalent" homogeneous medium to resolve the global behavior. However, in performing homogenization, it has to be taken into account that, due to manufacturing process, there are uncertainties in material properties of a composite. For this purpose, an approach has been developed [4] for spatially correlated simulation of parameter distribution owing to the process of manufacturing or other causes, which is suitable to be included in the FE analysis. Such descriptions (generations) employed within the FE modal analysis are for example the central part of *Monte-Carlo-Methods*. A *Variogram* type material property model has been introduced to predict the spatially distributed material properties (like Young's modulus) over the entire structure.

Effective modeling and simulation of thin-walled structures made of fiber-reinforced laminates are driven by the recognition that the nature of their general behavior allows the condensation of the complex 3D-field to the essential ingredients of the structural response described by a 2D approach. Two major first-order theories are used: the Kirchhoff-Love and the Mindlin-Reissner theory. Without going into details of the theories, it can be said that the essential difference between the two is in the consideration of transverse shear stresses. Modern finite element (FE) software packages offer rich element libraries and, thus, the engineers are provided with appropriate choice of elements implementing one of the two theories and sometimes even some theories of higher order. This reduces significantly the effort required for the modeling process and improves the efficiency of the model. The appropriate choice is a matter of engineering judgment.

3.2 FEM modal analysis of a CFC arm segment

The finite element method (FEM) has imposed itself as the state of the art method in the field of structural analysis. FEM simulations are supposed to reduce the overall manufacturing costs by providing the possibility to reach the suitable design much faster and with less need for testing. This is particularly valid for structures with composite laminates involved as a structural material. A great number of possible material combinations and layer sequences render testing of all possible solutions prohibitively expensive. For the purpose of simulation, we use commercially available finite element software packages, such as ABAQUS, NASTRAN, etc., but we also have developed our own finite element codes that provide certain features typically not included in commercial packages [5]. The aim of this subsection is to exemplify the FEM simulation for the investigated type of structures. In order to do that, an arm segment of a mobile concrete boom pump is considered.

Modal analysis is of utmost importance in structural analysis and, furthermore, for our method of non-destructive detection of failures in composites. Therefore, a FEM modal analysis has been conducted in this work. The considered arm web segment (Fig. 3) is made of a CFRC laminate consisting of 70 layers and has an overall thickness of 1.65 cm, with the total length of the arm web segment of approximately 1.6 m. Each layer is made of the same CFRC material with long unidirectional fibers, but the orientation of fibers, as well as the thickness of layers differs from layer to layer. It was necessary to introduce three local coordinate systems in order to define the sequence of layers in three different areas of the arm web segment. The areas are distinguishable on the right-hand side of Fig. 3, where the discretized model with approximately 1000 quadratic shell finite elements is depicted.

Fig. 3. *Arm web segment of a concrete boom pump*

Besides the accurate description of geometry and material properties, for high quality modal analysis it is also necessary to include all the attached masses in the model, since the eigenmodes and eigenfrequencies are significantly affected by them. As seen in the middle of Fig. 3, there are metal bushings placed at the holes. Their mass is included in the model as distributed mass around the holes. As for the boundary conditions, the edge of the upper hole is considered to be clamped, since this was the closest match for the actual boundary conditions applied in the test.

3.3 Experimental modal analysis of the CFC arm segment

An experimental modal analysis of the investigated composite web structure is performed with a state of the art laser scanning vibrometer (Polytech). For this purpose, the structure has been excited by means of a shaker within certain frequency range. The scanning-software provides the results in the form of frequency response diagrams, from which eigenfrequencies and modal damping can be extracted. It also provides structural vibration forms to each of the excitation frequencies and therewith also the eigenmodes.

Although the laser scanning vibrometer facilitates the extraction of modal data, its usage brings also certain problems for further processing. The scanning-software defines its own mesh of measurement points over the real structure. For processing and comparing the measured and numerical modal data, the measurement points should be

a) b)

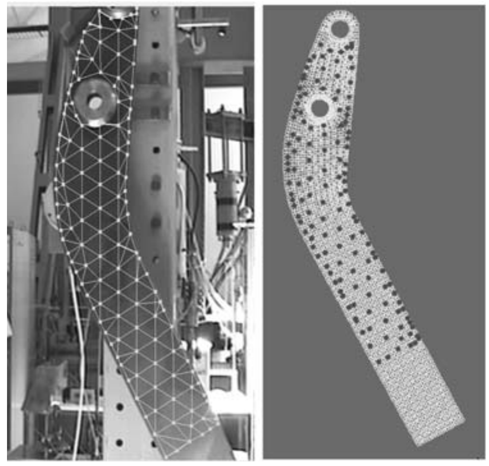

Fig. 4. *CFC arm: a) real structure with scanning mesh b) FEM model with matched scan points*

ideally coincident with nodal points within the FE model, which is in practice not always easy to achieve. Furthermore, the number of scanning points is limited. Fig. 4a depicts the real test object with the generated scanning mesh (as generated and taken by the scanning vibrometer). In comparison, Fig. 4b shows the FE model, with its much finer mesh, whereby the marked points depict the FE mesh nodes that closely match the measurement points. For determination of those FE nodes, originally developed software has been used.

3.4 Comparison of simulation and experimental results

The measured modal data and those from the FE simulation have shown good agreement, although some differences are notable. This is expectable due to the idealizations included in the computational FE model. The real boom web does not have exactly constant thickness over the length as it was laminated by hand. Furthermore, as seen before, the metal bushings are only tackled as secondary components in the FE model. Finally, on the upper bushing, the structure is fixed during testing, but this is definitely not an ideal clamp of the structure, as considered by the FEM-model.

Fig. 5 shows the second (top) and third (bottom) measured and calculated eigenmode, with two-colored representation chosen to clearly depict the nodal lines of the modes (lines with zero amplitude). The allocation of the measured and computed modes is done by Modal Assurance Criterion (MAC) analysis, which compares calculated ith mode, φ_{ci}, with experimentally determined jth mode, φ_{ej} (Table 1):

$$MAC_{ij} = \frac{\left(\varphi_{ci}^T \, \varphi_{ej}\right)^2}{\left(\varphi_{ci}^T \, \varphi_{ci}\right)\left(\varphi_{ej}^T \, \varphi_{ej}\right)} \qquad (1)$$

Despite the idealizations implemented in the model, one may notice high values of MACs for the considered frequency range. Not for all of the modes calculated by numerical simulation (A-modes in Table 1) corresponding experimental modes have been determined. This is attributed to the position of the shaker during the experiment. Later analysis revealed that the shaker position was quite close to the nodal lines of the experimentally undetected modes. Obviously, those modes could not be excited by the shaker. Table 1 gives only the first several experimentally determined (first row) and numerically computed (first column) modes and their correlation by means of MACs.

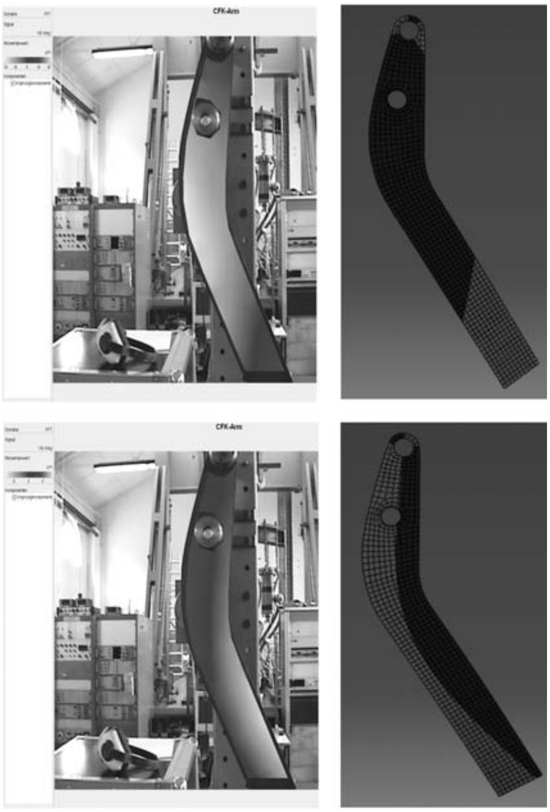

Fig. 5. Eigenmodes – experimental (left) and simulation (right) results

Table 1 *Modal Assurance Criterion (MAC)*

		Measurement				
	MACs	E-Mode 1 7.9 Hz	E-Mode 2 35 Hz	E-Mode 3 97 Hz	E-Mode 4 182.9 Hz	E-Mode 5 213.1Hz
FEM calculation	A-Mode 1 7.25Hz	**0.997**	0.159	0.207	0.019	0.013
	A-Mode 2 35.5Hz	0.191	**0.98998**	0.045	0.219	0.042
	A-Mode 3 68.7Hz	0.058	0.034	0.689	0.009	0.08
	A-Mode 4 91.9Hz	0.18	0.05	**0.947**	0.008	0.092
	A-Mode 5 94.3Hz	0.076	0.001	0.0036	0.005	0.0095
	A-Mode 6 174.3Hz	0.016	0.25	0.051	**0.951**	0.023
	A-Mode 7 217.5Hz	0.014	0.0003	0.17	0.0029	**0.8999**

3.5 Detection of failures in composite laminates

The commonly used techniques for non-destructive testing of materials are X-ray and ultrasonic measuring. Those are extensive and complex procedures, regardless if they are to be applied only to built-in components or they have to cover complex structures entirely. The approach we adopt is to assume that the detection of potentially faulty areas can be obtained with combination of modal data from measurement and FE analysis.

One of the major causes of composite material damages is related to delaminating. Delamination may be caused by impact loads, fatigue or poor fabrication. If it occurs and if the state of the damage has not progressed too much, the natural frequencies and mode shapes do not change remarkably and can, therefore, alone not be used to detect faulty areas of the structure. However, a measurable change in certain parameters of vibration motion according to different modes is expected to be observed.

The presence of damage in a composite laminate gives rise to certain nonlinear effects in structural vibration. Hence, investigations of the nonlinear response seem to be promising for localization and to quantify the size of the damage on a global basis. Actually, vibration of delaminated composite laminates leads to a non-smooth dynamic system due to continuously developing impact-like contacts along the delamination. Therefore, the nonlinearity arises from the local contact phenomenon – clapping. The delaminated layer and the remaining part of the structure periodically strike against each other during the vibration and this results in visible differences in the frequency response functions compared to the same of the undamaged part.

The general idea of our method is to determine modal clapping factors and perform their superposition [6]. This is done both by means of the FE-model, which yields a reference result for an undamaged structure, and for the actual damaged structure by means of experiment. The comparison between the obtained distributions of the superposed modal clapping factors is supposed to spot damage/delamination in the structure. The development of this method is still work in progress.

4. THE IDEA OF ADAPTIVE STRUCTURES IN TRANSPORTATION

Significant attention has been given to active/adaptive structures over the past two decades. It is their intrinsic property to mimic the behavior of natural systems that serves as an impetus for researchers to steadily broaden the area of application of adaptive systems [2]. The general idea consists in using advanced multifunctional materials in order to design and integrate active elements, i.e. sensors and actuators, into structures and thus provide the means for their active behavior. Active elements can also be added as additional devices, if such a design better suits the structure. A structure with active elements only, i.e. sensors and actuators, is denoted as *active structure*. Sensors provide signals that typically contain information about the state of the structure. The sensor signals are transmitted to a controller that implements the control law, i.e. the desired structural behavior. In other words, the controller processes the sensor signals and determines what action should be performed by actuators in order to produce a desired structural behavior. The corresponding signal is then sent to actuators. Hence, by coupling active elements, sensors with actuators, by means of a controller, an active structure becomes *adaptive* – it can actively react to external excitations in order to adapt its response.

In the case of adaptive car roof depicted in Fig. 6, the adaptive behavior of the roof is used to suppress its vibrations with the final objective of diminishing noise in the car and thus improving driving comfort of passengers.

Fig. 6. Adaptive car roof

4.1 Adaptive behavior of a tower crane

Although the adaptive structural behavior can be used with many different objectives, vibration suppression belongs to the most common ones. It improves many aspects of their dynamic behavior, ranging from comfort to robustness and safety.

To exemplify the general idea of adaptive structural behavior, the truss structure of a tower crane depicted in Fig. 7 is considered. Without going into details of possible solutions for sensors and actuators, they will be idealized here simply by assuming that the sensors can measure desired quantities related to truss elements and that the actuators can produce desired forces that act along truss elements. To meet the observability and controllability conditions [2], it will be assumed that the coupled sensors and actuators are collocated, i.e. positioned in the same truss elements.

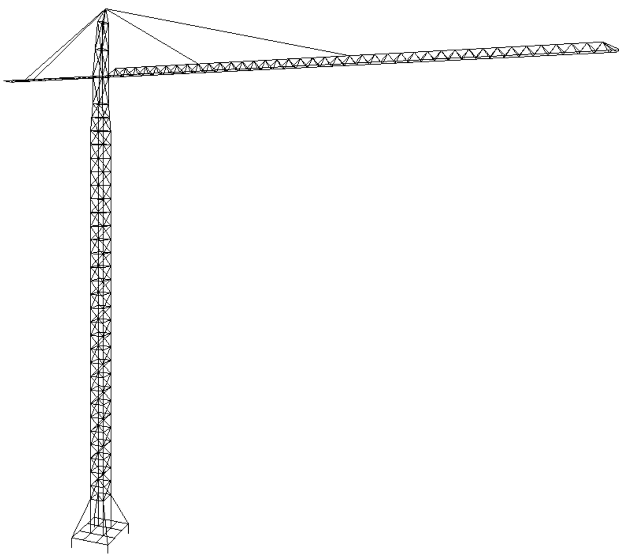

Fig. 7. Truss structure of a tower crane

A very simple logic will be applied to achieve vibration suppression. It is for a good reason that damping, although being a rather complex effect, is quite often modeled in dynamics as viscous, i.e. velocity proportional. Since velocity proportional forces bring structure to rest (when acting in opposite direction to velocity) the idea is to use sensors to determine the strain rate of selected truss elements and then the corresponding actuator force that acts along the very same truss element so as to damp the vibration out in them. This should further suppress the vibration of the whole crane structure.

The optimal position of active elements is a very important aspect. There are different approaches depending on the objective of adaptive behavior. As already elaborated, the objective in this specific case is vibration suppression. Control of complex systems with a large number of degrees of freedom is a prohibitively expensive task. An elegant idea to resolve the problem is to perform control within specific frequency range and, in doing that, to put focus onto the structural eigenmodes, which are then regarded as degrees of freedom to be controlled. The optimal position of active elements is then determined as locations with the largest strain energy density. Hence, the strain energy density is determined for each eigenmode. Furthermore, the eigenmodes are given weight factors according to their importance in the overall structural behavior and control. Finally, the weighted modal strain energy densities are superposed. This simple procedure reveals in which truss elements the control would have the largest impact onto the structural vibrations.

Now, considering the crane structure in Fig. 7, upon limiting the number of active truss elements to four and the number of eigenmodes of interest to ten, this procedure yields the truss elements shown in Fig. 8 as optimal for active elements (sensors and actuators).

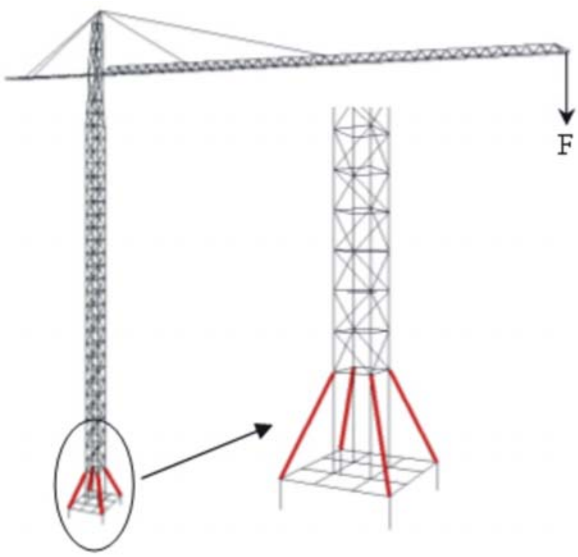

Fig. 8. Tower crane with active elements

Over the course of simulation, the strain rate in those elements is determined and used to compute directly proportional actuator forces by means of a predetermined coefficient.

In the simulation, the crane is exposed to an external impact excitation in duration of 0.3 s acting at the tip of the crane jib (F in Fig. 8). The vertical displacement of the very same point is observed as a representative structural response. The internal structural damping is assumed to be relatively small. The obtained results are summarized in Fig. 9. Fig. 9a gives the jib tip deflection without the active control applied and the decrease in amplitudes is the consequence of internal damping only. On the other hand, Figs. 9b, 9c and 9d show the response when the active control is turned on 15 s, 10 s and 5 s, respectively, after the excitation. The effect of active control, which can be interpreted as active damping in this case, is obvious.

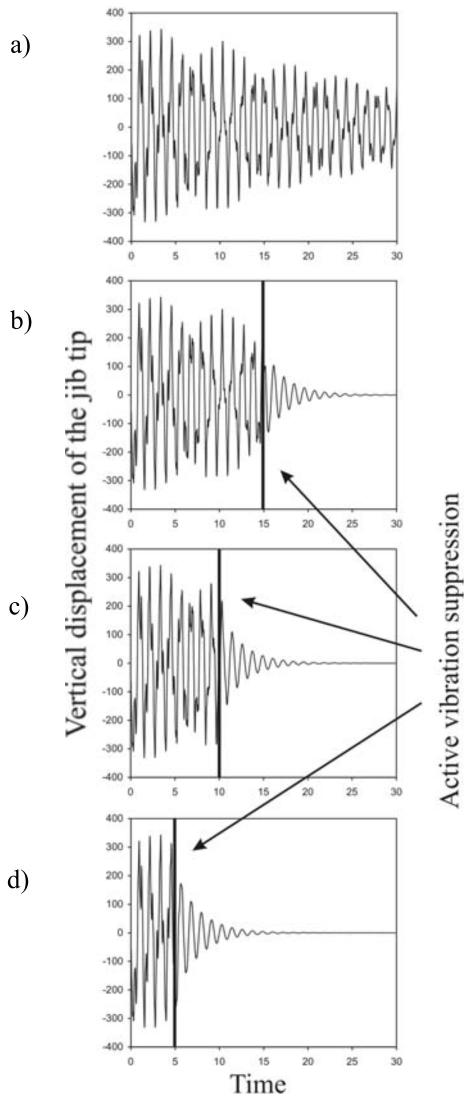

Fig. 9. Vertical deflection of the crane's jib tip: a) no active damping; and with active damping started after: b) 15 s; c) 10 s; d) 5 s

5. CONCLUSIONS

Transportation as an engineering discipline requires innovative solutions that push the leading edge of technology and challenge the expected. Innovations in both materials and design solutions are performed to meet these objectives.

Heavy-duty operations performed by truck-mounted concrete boom pumps make design of their structures a very responsible task. The tendency to steadily improve the performances of those machines imposed the need for application of innovative structural materials. The paper tackles the aspects of using state of the art structural materials in the design of those structures as well as how this aspect is reflected in the need for numerical simulation and experimental testing. The paper has demonstrated that, despite all the complexities and uncertainties of CFRC materials, simulations based on FEM models can be successfully performed, resulting in rather reliable and accurate results. Tests are quite expensive, in certain cases even prohibitively expensive, but are also inevitability that provides the ultimate check on suitability of the structural design and developed models. Beside the fact that it represents the means of model updating, experimental modal analysis is also a crucial element of the presented promising approach to failure detection in composite laminates.

Over the past few decades, the idea of adaptive structures has progressed from almost an engineering curiosity to a new generation of high-performance structural and mechanical systems with integrated sensing, actuating and control capabilities. Their application becomes wider every day covering many areas of engineering, transportation being among the most important ones. Their attractiveness originates from numerous advantages they offer over passive systems. The presented examples are illustrative but certainly not exhaustive. Many aspects are idealized in the tower crane example with the objective to demonstrate the feasibility of the idea of adaptive structures. The current adaptive systems are a mere skeleton compared to the anatomy perceived in not-too-far future. We strongly believe that they will have a great impact on our lifestyles.

ACKNOWLEDGMENT

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REFERENCES

[1] J.-M. Berthelot, **"Composite materials – mechanical behavior and structural analysis"**, Mechanical engineering series, Springer-Verlag, New York, 1999.

[2] A. Preumont, **"Vibration Control of Active Structures – An Introduction"**, 3rd edition, Springer Verlag, Berlin, Heidelberg, 2011.

[3] **Putzmeister Post. Das Magazin für unsere Kunden und Freunde.** Several Issues. Herausgeber: Putzmeister AG, Aichtal.

[4] M. Zehn, G. Machina, **"Modelling and Influence of Manufacturing Induced Material Imperfections on the Buckling Behaviour of Thin-walled CFRC Structures"** NAFEMS World Congress 2007 on "Engineering Simulation: Innovation Leads to Competitive Advantage", Vancouver, Canada, 2007.

[5] D. Marinković, **"A new finite composite shell element for piezoelectric active structures"**, Ph.D. thesis, Otto-von-Guericke Universität Magdeburg, Fortschritt-Berichte VDI, Reihe 20: Rechnerunterstützte Verfahren, Nr. 406, VDI Verlag, Düsseldorf, 2007.

[6] T. Rademacher, M. W. Zehn, **"Schadensidentifikation an Bauteilen aus Faserverbundwerkstoffen durch Kopplung von linearer und nichtlinearer Schwingungsantwort"** 3. VDI-Fachtagung Schwingungs-analyse & Identifikation 2013, pp. 77-87, 2013.

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DEVELOPMENT CHRONOLOGY OF THE "TRET" AND "SCREEN CONTACT" METHODOLOGIES

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Abstract

*One of the most important activities in science is to find new and more effective methods which can offer one or multiple advantages in comparison to the traditional methods and principles. This paper has a goal to present the main characteristics of both methodologies "**Tret**" and "**Screen Contact**" which were created almost three decades ago, as well as their chronological usage in education projects, design and development of complex mechanisms used in mechanical engineering, with specific projects. The both computer based methodologies have considerably different calculation approach vie-a-vis traditional methods in mechanics. Their advantages are remarkable in the most complex multi-body mechanisms.*

This paper will illustrate the possibility and capability of those methods which are intended for analysis of the multi-body mechanisms, and also mechanisms of higher kinematical pairs.

Key words: *mechanisms, machines, computer, excavators, loaders*

1. INTRODUCTION

The increasing trends in many areas of the science and technology give opportunities for other branches. The most considerable development can be seen in computer technology and telecommunications. For mechanical engineering where complex systems are used, it is of essential importance to make structures with best performances. So, the new improved methodologies for calculation are really required. How these methodologies were chronologically used in wide projects, according the computer performance levels, and also levels in other branches, will be presented in this work.

The processor speed of a computer, and also graphical performances are fundamental for the creation of software in which modules based on the "**Tret**" and "**Screen Contact**" principles are built-in. The projects are actually dealing with construction and mining machines like excavators, loader, cranes, crushers, as well as common systems like chains, gear reducers, hydraulic vane and gear pumps, blowers etc.

2. CREATION AND USING THE "TRET" METHODOLOGY

The best representative of the complex mechanical structures which are very difficult to calculate, due to their multi-body construction are excavators and loaders. It was a great challenge for many engineers and scientists to create some method for faster and shorter calculations with particular accuracy. It was conveyed with computers, but the results in most cases were very low. The animation give the best comparisons between the different methods. If the animation was smooth (without flicking), it was considered as good animation with very fast calculation. Traditional methods of theory of mechanisms and machine (which are taught on the faculties of mechanical engineering) were complex and in different projects very confusing. Computer programs based on these methods required very long calculation time between the subsequent positions of the mechanism. So, this way it was impossible the animation to be realized /completed. For this reason computer programs which calculate many positions of the mechanism were often created, to save these positions in the discs or in the RAM arrays, and after that execute the animation (that method is usually used in cartoon movies).

The initial idea for "**Tret**" methodology was born on January 25th 1984. This methodology consists of several equations which always appeared in the complex link-bar mechanisms (excavators, loader, hydraulic cranes, robots, jaw-crushers and many other working link-bar mechanisms in mechanization). In the subsequent years, the modules incorporated in computer programs for excavators and loaders, (in the computer languages Fortran and Basic) were created. The methodology was operational for working mechanisms of all types, without exceptions (fig.1 and fig.2), and programs executed very fast. The animations were always without blinking. The programs were created from 1988 to 1992:

- **BAGER** (program in Basic, using CGA and later EGA/VGA graphics, 1988),
- **HBOL** (hydraulic backhoe excavator - trajectory and complete working zone, 1988),
- **BAGER 1 to 8** (program in Basic on microcomputer Commodore plus/4, 1988-90),
- **DROB** (Simulation of jaw crusher, Hercules graphic card, 1990, Basic, later rewritten in C),
- **CONV** (Chain conveyors simulation - Commodore plus/4, 1989),
- **HBCK** (hydraulic shovel excavator - Basic - PC 286, and Commodore plus/4, 1990), etc...

On the fig.2 two common schematics of hydraulic excavators are shown, and on fig.3 the multi-body loader with grapple used in forestry (Volvo BM L160- Sweden). After 1989 almost all programs written in the Basic language, were rewritten in the excellent program language C (Turbo C). Simultaneously, with the increasing of the computer processor frequency and also with the improvement of the graphic resolutions, the programs became faster and it was an opportunity to insert additional modules (calculation of velocities, accelerations, reaction forces etc.).

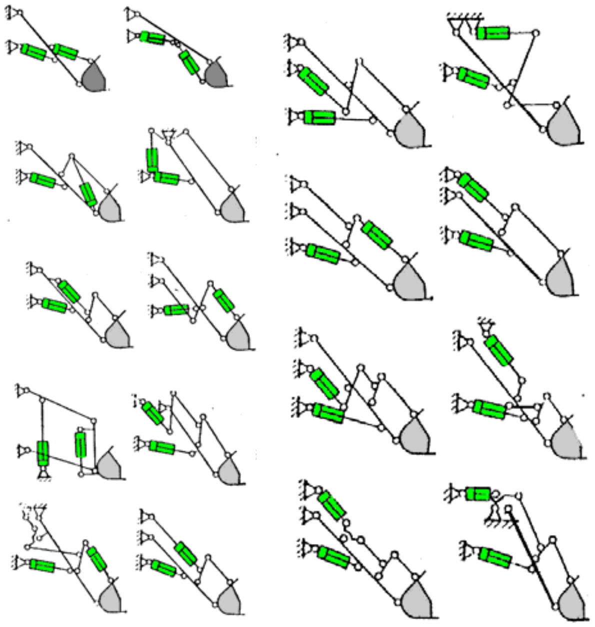

Fig.1. Concepts of working mechanisms of the loaders (complex link-bar mechanical systems)

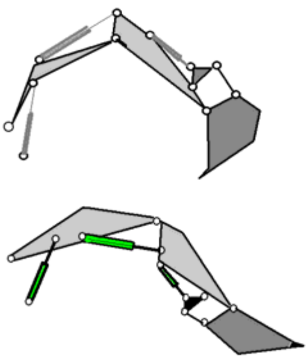

Fig.2 Working mechanisms of hydraulic excavators

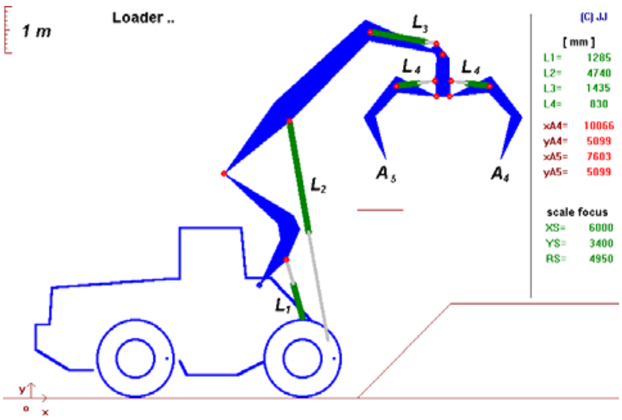

Fig.3. One working position of loader Volvo BM L160 (Program VL160.EXE,1995 based on the "Tret" methodologies)

The next illustrations show some concepts of complex working mechanisms in sequences of computer animation. The animations were executed with programs which use program modules based on "**Tre**t" methodology.

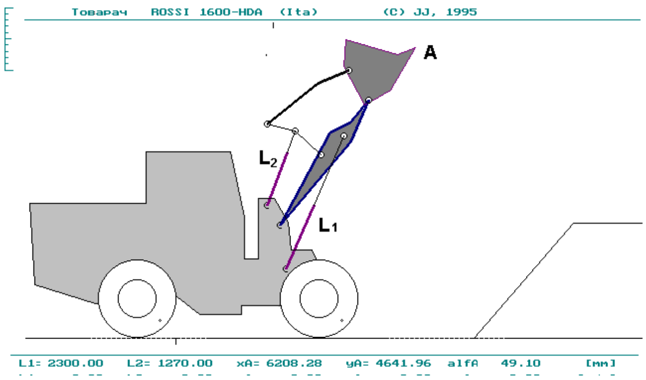

Fig.4. Loader ROSSI 1600-HDA (Ita) (DOS Program ROSSI.EXE, 1995 based on the "Tret" methodology)

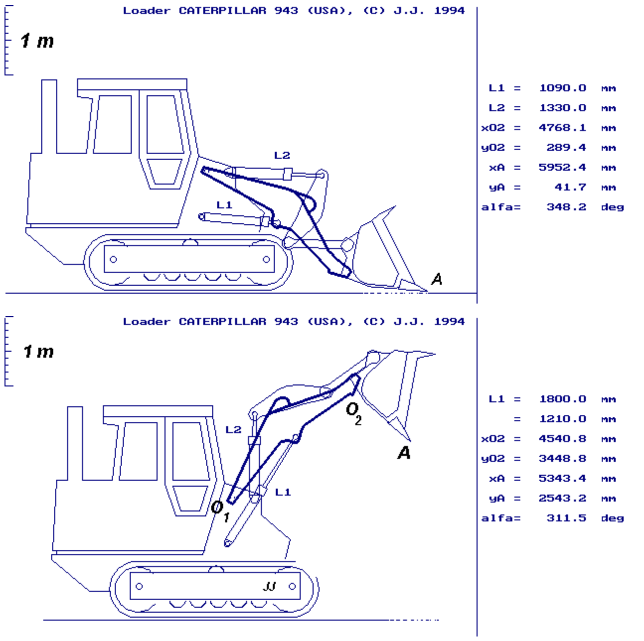

Fig.5. Two positions of the Loader CAT 943 (USA), (DOS Program CAT.EXE,1994 based on the "Tret" .)

The increasing of the speed (frequency) of computer processors enables to include additional modules in programs based on "**Tret**" methodology. So, the computer has enough time to execute the additional calculations, for example reaction forces, stresses, pressure in hydraulic installation etc., without "flicking (blinking) during animations.

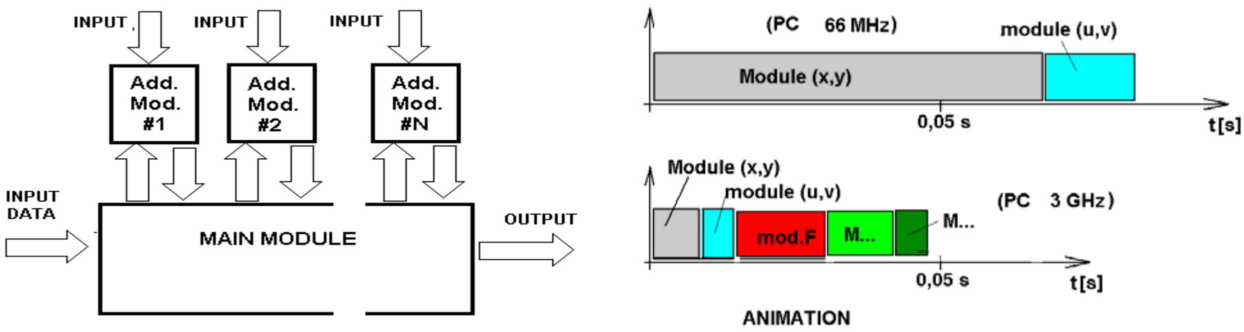

Fig.6. Including additional modules into programs when the processors are fast, doesen't disturb the animation

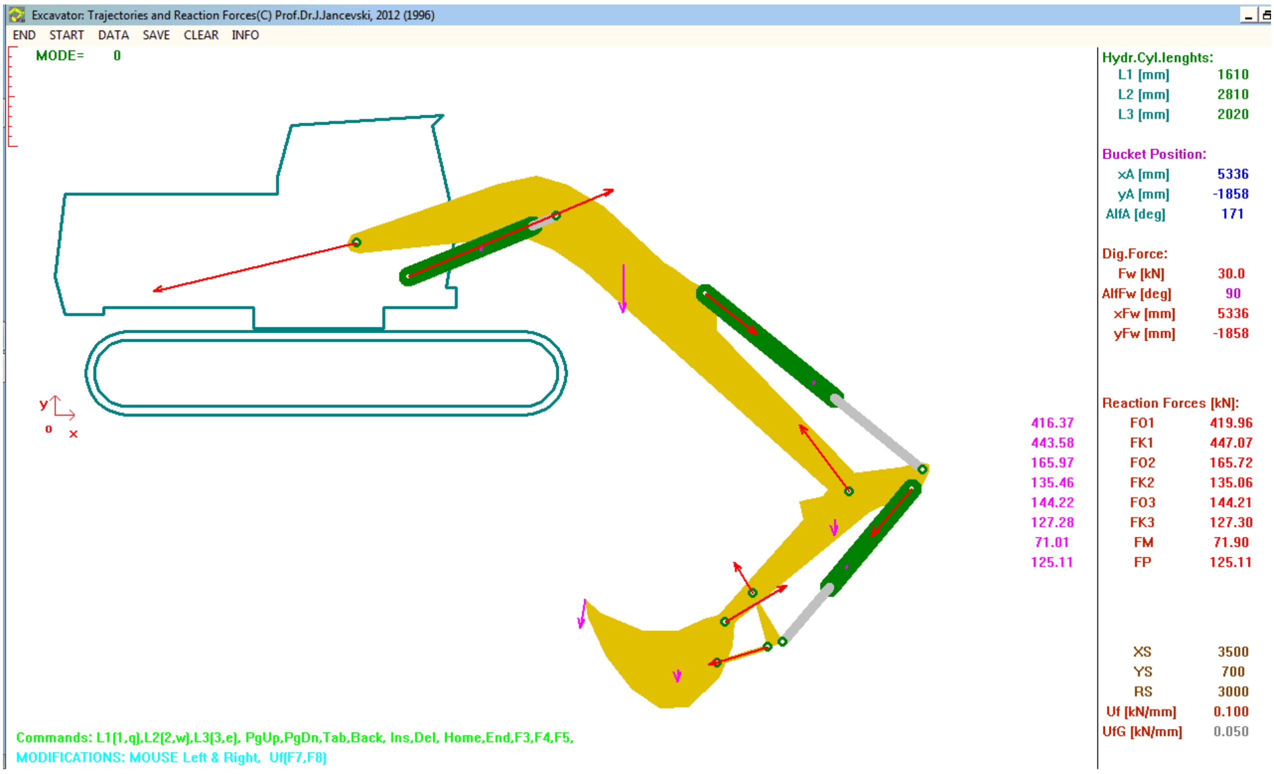

Fig.7. Position of working mechanism of a hydraulic excavator Liebherr 922 - Ger,(program LIEB922.exe) (Two modules for calculation of the Reaction forces and trajectories are included, animation is normal)

3. CREATION AND USING THE "SCREEN CONTACT" METHODOLOGY

The "**Screen Contact**" methodology was created after 1992. Some of the complex mechanisms are impossible to calculate with traditional methods even with "**Tret**" method. The mechanisms which are consisted of kinematic group of 3rd class (**Triada**) in some loaders (for example Volvo L120 - fig.8), as well as shovel excavators like Tri-Power (for example Orenstein-Koppel - fig.9), and others (Caterpillar, Komatsu, etc), all of them are able to calculate the position during the work using only iterative methods.

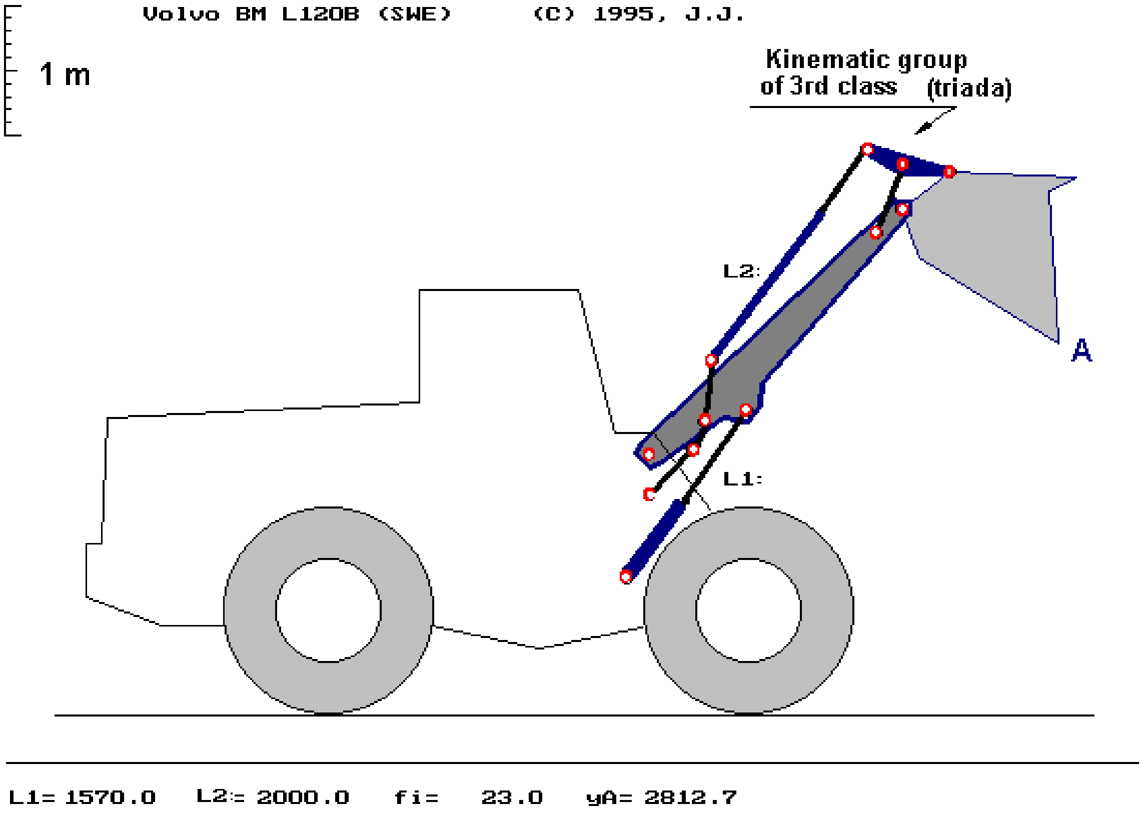

Fig.8. Loader VOLVO BM L120B (Swe) , consists of kinematic group of 3rd class (triada). (Prog.VL120.EXE - based on the Screen Contact Methodology)

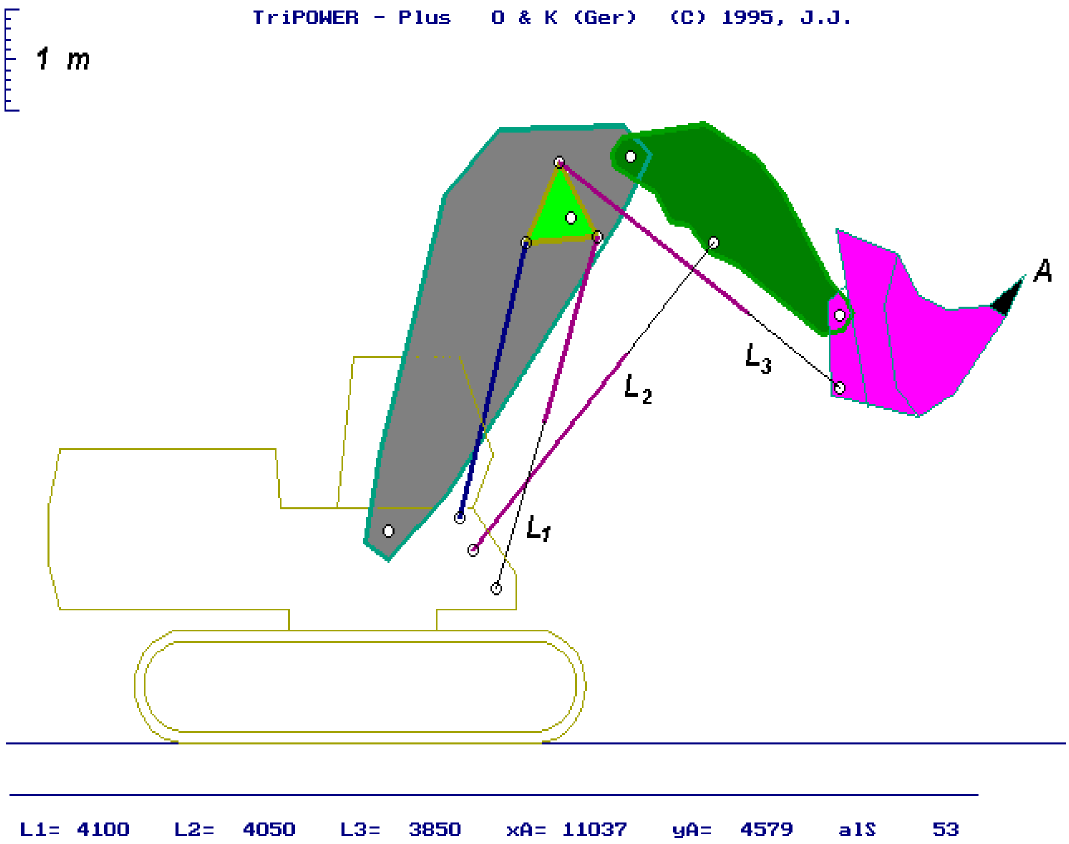

Fig.9.Tri-Power excavator with kinematic group of 3rd class (triada). (DOS Prog.TRIPOW.EXE. - based on the Screen Contact Methodology)

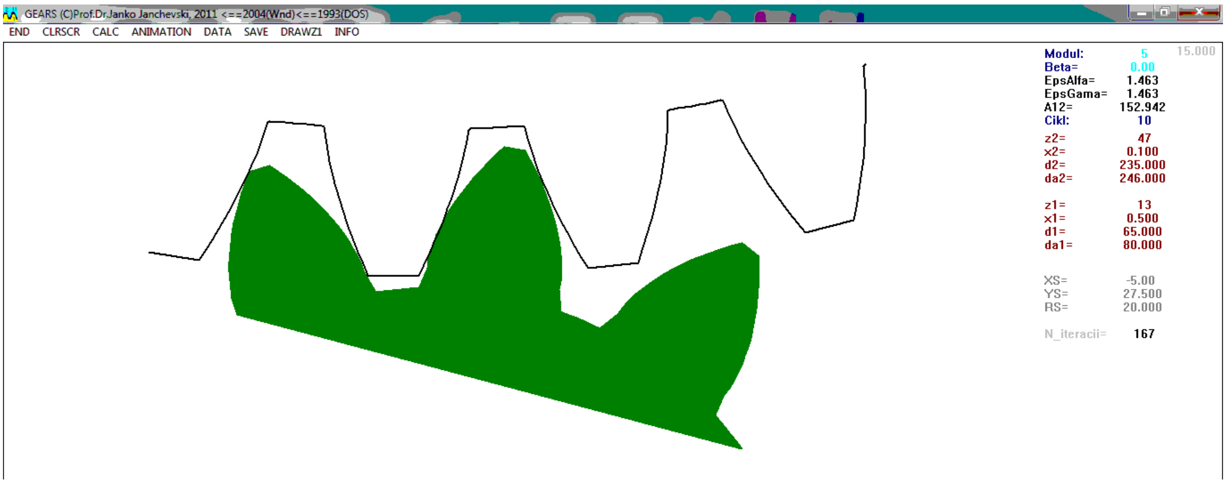

Fig.10.Animation - computer simulation of working process of gears (prog.ZAP.EXE- windows app.2011, based on DOS prog.ZAP2.exe of 1993, use ScreenContact methodology)

The "Screen Contact" is an iterative method based on the contact of the pixels (point) of two or more elements of the mechanism. This method was used after 1993 in GEARS program, a computer simulation of two involute spur gears (fig.10.). After that, programs for computer simulation of chains on the conveyors, and also vane-pumps were created.

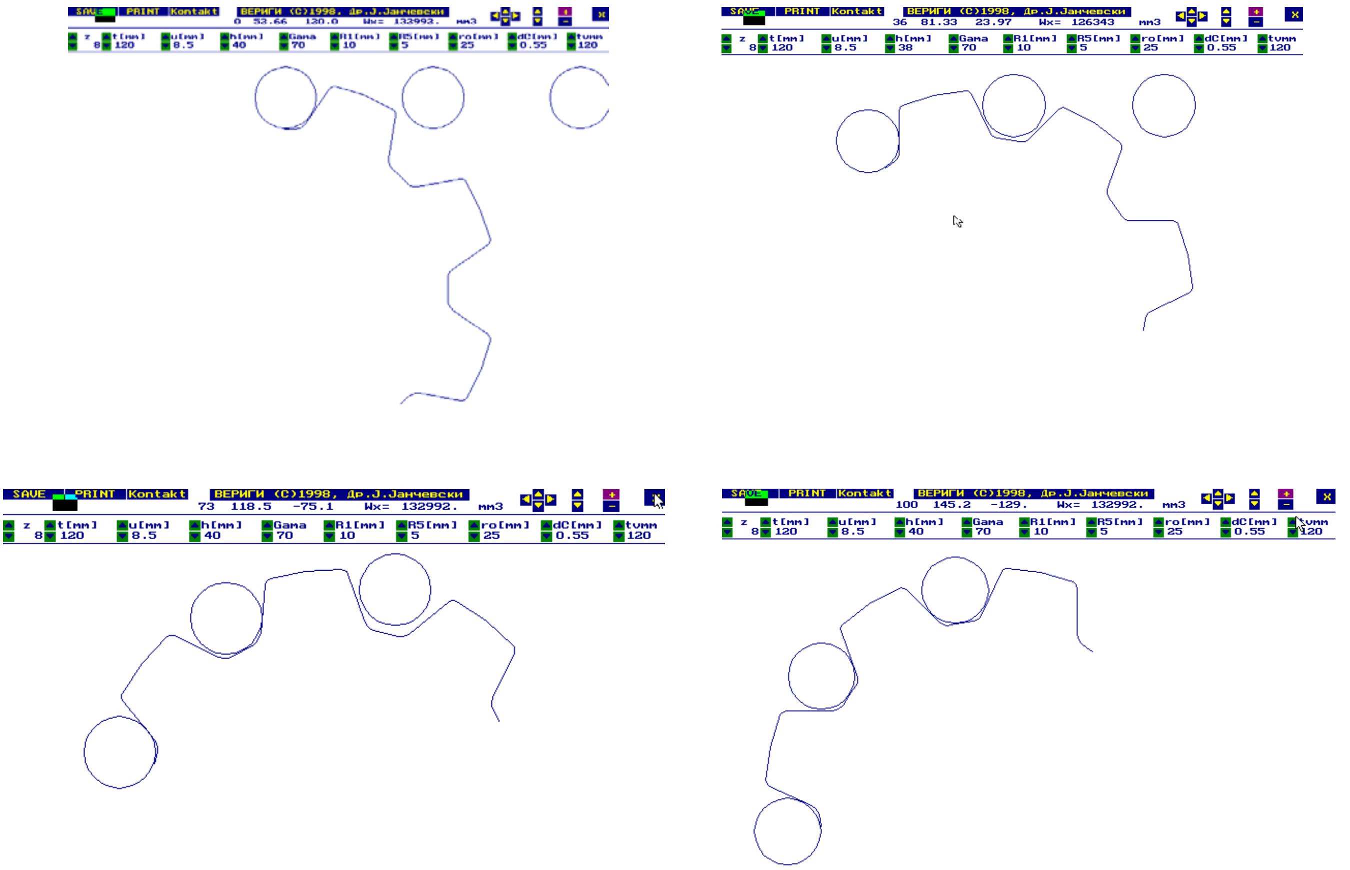

Fig.11.Animation of the chain-sprocket mechanism used in chain conveyors (DOS Prog.VERIGI.EXE (1998) based on the Screen Contact Methodology)

After that, programs for computer simulation of chains on the conveyors, and also vane-pumps were created. Using the "**Screen Contact**" methodology for position calculation f chain-sprocket mechanisms used in chain conveyors is shown on the fig.11. [3].

4. ADDITIONAL DEVELOPMENT

Both methods are officially introduced in the dissertation [1], where the usefulness of both methodologies on all concepts of loaders and excavators was proven. In [1] it is also presented a simulation of extremely complex mechanism consisted of kinematic group of 4th class.

After 1996 almost all programs created in program language C for DOS operating system, were rewritten for Windows operating system in C/C++.

The period between 1993 and 2000 was marked with the creation of new programs which use "**Screen contact**" methodology. Some of those programs used the methodology in some different manner. Such program is "**TMI.EXE**", where variants of "**Pixel counting on the screen**" were introduced. The program was able to calculate geometrical characteristics of complex cross-sections of the machine parts, like moments of inertia, gravity position etc. Fig.12. [6]. Pixel counting on the screen can be used in many different areas (chemistry, biology, mathematics etc.).

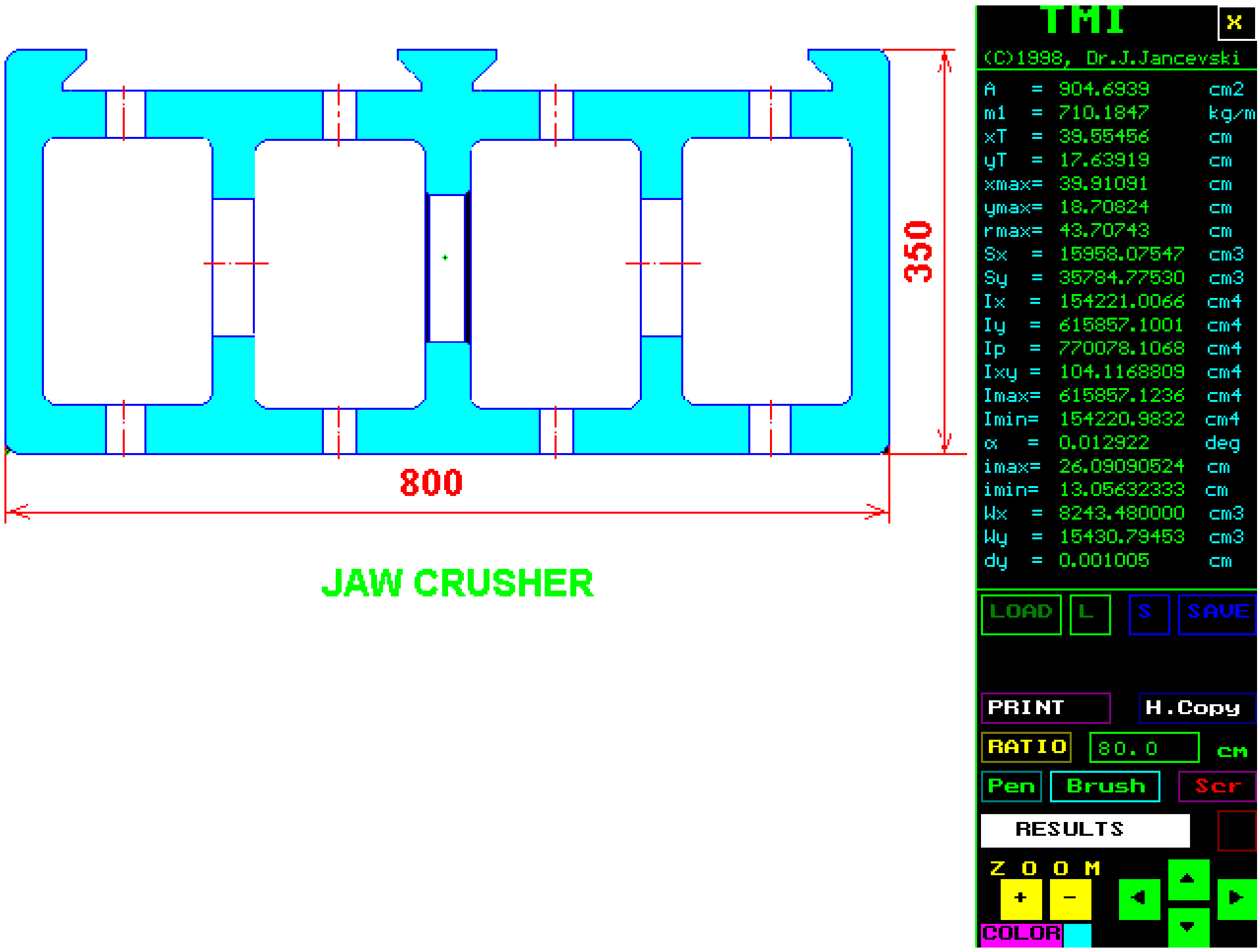

Fig.12. Calculation gravity centre, axial, polar and resistance moments of inertia for machine parts with complex cross section (prog. TMI.EXE - 1998)

One of the major features of both methods is to move the mechanisms on the projected complex trajectories fig.13 and fig.14. This is very important for robotics and special machines with open structure [2], [4].

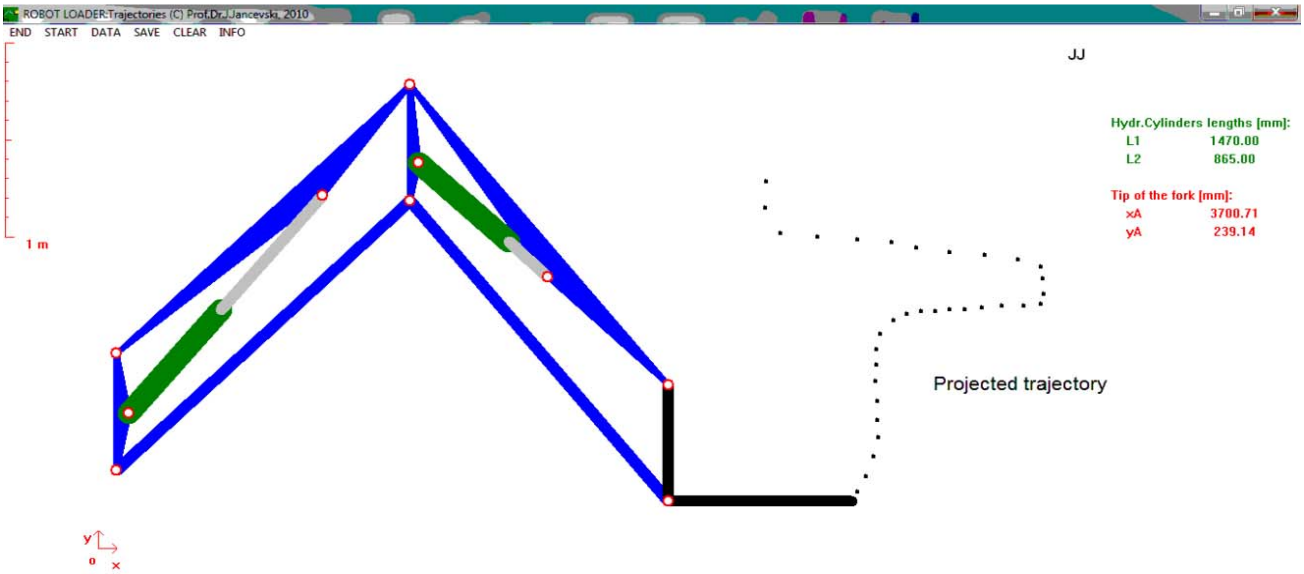

Fig.13. Loading manipulator should go through the Projected trajectory

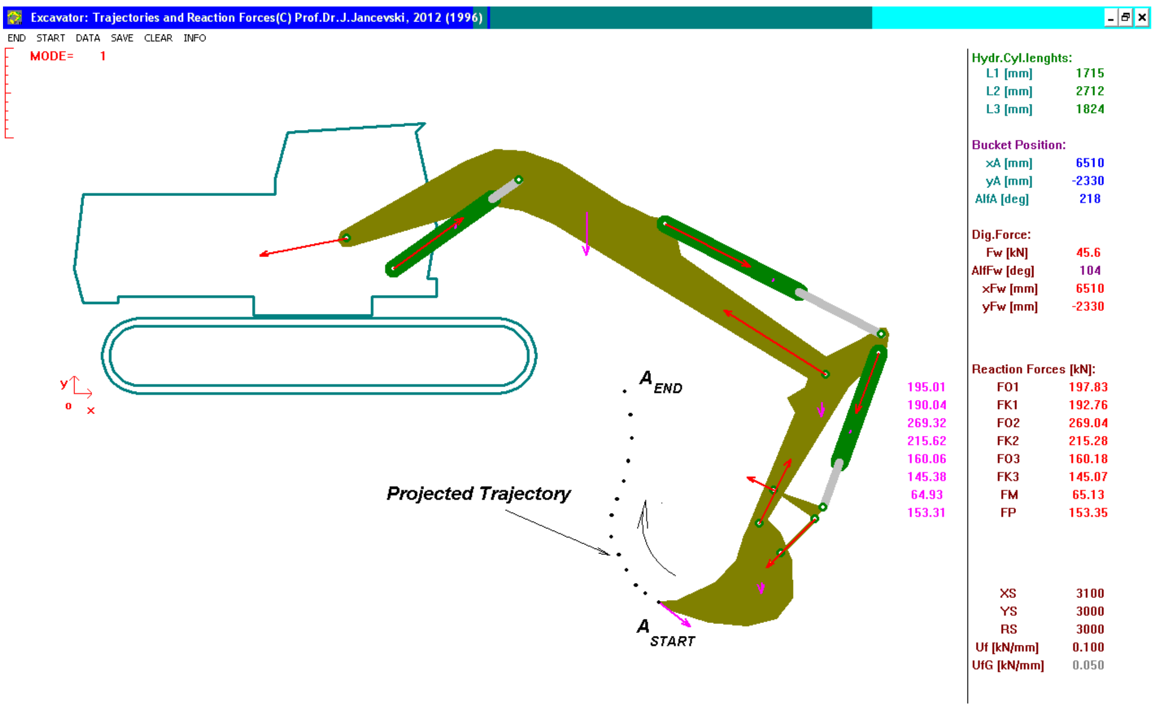

Fig.14. Excavator bucket tooth should touch every point of projected trajectory

5 CONCLUSION

The intention of this overview is to present the diversity of usage of the methods "**Tret**" and "**Screen Contact**" on variety of different projects, and especially in mechanical engineering. For some reason, the rapid increasing of computer hardware as well as software are insufficient signals to make significant improvements in other disciplines. For example, heavy machinery in mining and farm machinery, robotics and others, is actually improved only with additional electronic equipment (computers for control of some mechanisms, signalization, security, GPS, remote control etc.). Mechanical structures are the same, or with a few slight modifications. However, many parts of a machine are optimised (less weight, higher speed and bigger capacity), but also the prices are higher.

Finally, most of the calculation methods used in the past as well as those used today are usually traditional, often without any innovations. Only the more and more complex system of equations is now calculated with modern computers with high-speed processors. However, methodologies as "**Tret**' and "**Screen Contact"** can include more additional modules for some complex calculation which were impossible to use in case of computers with slower processors' frequencies.

REFERENCES

[1] Janchevski J., *Algorithm Approach of Synthesis and Analysis of Working Mechanisms of Loaders*, **Dissertation**, Faculty of Mechanical Engineering, University "Ss. Cyril and Methoduis" - 1996, Skopje

[2] Janchevski J., *Projects Using The "Tret" And "Screen Contact" Methodologies* -10th. International Science Symposium - Project learning, Portoroz, Slovenia, Apr.2012

[3] Janchevski J., *Complex Projected Trajectories of Hydraulic Excavators with Buckets or Grapples*, XX International Conference on "MATERIAL HANDLING, CONSTRUCTIONS AND LOGISTICS, Belgrade, Oct.2012.

[4] Janchevski J., *Trajectory Computer Control of the Complex Mechanical Systems,* 9 th. International Science Symposium - Project learning, Portoroz, Slovenia, Apr.2011

[5] Janchevski J., *Opredeluvanje na glavnite geometriski parametri na hidraulicnite bageri*, Zbornik MF, No.7/88, Skopje. 1988

[6] Janchevski J.: *Principles of Interactive Software for Complex Working Mechanisms*, ***Keynote paper***, XVIII International Conference on "MATERIAL HANDLING, CONSTRUCTIONS AND LOGISTICS, Pages: 107 - 112, Belgrade, Oct.2006,

[7] Janchevski J., Ivanovski H., Vetadokovska E., 1997, *A Visual Computer Simulation of the Spur Gear Wheels and Disc Cam Mechanisms*, Conference of Intelligent Motion Control, Power Transmission and Tribology (IMPT –100), Tokio, Japan, July, 1997.

[8] Windows Programming C, API, 1999.

[9] Ammeraal L., Graphic programming in Turbo C, Chichester, John Wiley & Sons Ltd, 1990.

[10] Hall A.S., McAree P.R. " Robust bucket position tracking for a large hydraulic excavator", Mechanism and Machine Theory, Volume 40, Issue 1, January 2005, Pages 1–16

[11] Jin Chen, Fei Qing, Xiaoping Pang: Mechanism optimal design of backhoe hydraulic excavator working device based on digging pats. Journal of Mechanical Science and Technology, The State Key Laboratory of Mechanical Transmission, Chongquin University, China (2013).

[12] Ren-Chung Soong , Sun-Li Wu, Design of Variable Coupler Curve Four-bar Mechanisms, Journal of the Chinese Society of Mechanical Engineers, Vol.30, No.3, pp.249~257 (2009) ;

[13] Vaidya A. M., Padole P. M,: A Performance Evaluation of Four Bar Mechanism Considering Flexibility of Links and Joints Stiffness , The Open Mechanical Engineering Journal, (2010), 4, 16-28 ,1874-155X/10 2010 Bentham Open Department of Mechanical Engineering, Visvesvaraya National Institute of Technology, Nagpur, India.

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DAHAR EU SEE PROJECT AS AN INCENTIVE TO THE DEVELOPMENT OF LOGISTICS IN THE DANUBE REGION

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Abstract

Starting from the Danube Strategy, which states that there is 11 times more goods on the Rhine than on the Danube, the paper provides conclusions from the DaHar project (EU SEE research project). The research included analysis of the Danube partner ports from: Austria, Slovakia, Hungary, Serbia, Bulgaria and Romania. The results of the research are included in the five master plans developed in relation to the following five thematic pillars: ports; hinterland connections; development of container and RoRo liner services; RIS; Navigability and environmental protection. As a conclusion of the research related to the given five thematic pillars, the paper gives the DaHar Policy recommendations to the decision makers, which contain the necessary steps to encourage the development of logistics in the Danube region.

Keywords*: Danube, logistics, master plans, policy recommendations*

1. INTRODUCTION

Danube Inland Harbour Development (DaHar) is a transnational project financed by the South East Europe Transnational Cooperation Programme. The project brought together 13 partners from 7 Danube countries. The DaHar partnership represents small and medium sized Danube cities with ports and cities of international importance, with an idea that economic development and participation in the economic circulation of these cities could be enhanced through the optimal utilization of port development in the frame of enhancing waterway cargo transport on the Danube in a transnational context. [1]

The project is developed on the five thematic pillars:

- Logistical infrastructure of ports and port operation models;
- Enhancing hinterland connections related to transport linkages between inland waterways and road and rail;
- Integration of ports of small and medium-sized cities in the development of Danube container and Ro-Ro liner services;
- RIS related to cargo transport management;
- Navigability and environmental protection.

One of the most important outcomes of the project is the Integrated Strategy for Functional Specialization of the Danube Ports in the Logistic Chain (in further text Strategy).

The Strategy is a strategic document based on the 5 Master Plans developed as a result of the Thematic Groups analysis related to the 5 DaHar pillars and a joint vision of the logistics development in the Danube region from the point of DaHar project partners (PP) view. [3]

The development of the Strategy started with the problem description, having in mind the idea of economy and ports development through the introduction of additional, logistics value added services, mainly initiated with the goal to attract growing container transport. After the problem description, based on the five DaHar pillars, suggestions and recommendations for the problem solving are elaborated. This paper is writen following the structure of the Strategy.

2. PROBLEM DESCRIPTION

In an environment of galloping globalization, there is a trend of constant increase in cargo flows and demand for long-distance transport services. On the other side, issue of the fossil fuels and environmental protection has become an imperative. In that ambient facilitating constantly increasing cargo flows by using environmentally friendly modes of transport was set to be one of the top priorities worldwide.

In past two decades, the containerized cargo had the highest increase. According to the Review of Maritime Transport 2012 [5], containerized cargo represents approximately 17 % of world seaborne trade by volume and 52 % by value.

The biggest containerized cargo flows are from Asia to USA and Europe, more than two times bigger than the flows from Europe and USA to Asia. The containers flows are forecasted to increase in the future. Starting from the 13.5 million TEUs from Asia to Europe in 2010 and forecasts of annual growth of containers throughput given by the Global Insight of 6.1 % and 5 %, it is to expect about 22.9 million TEUs on this route in 2020, what is an increase of 9.4 million TEUs in 10 years time frame.

The trend of constant growth in maritime transport has been becoming increasingly concentrated on just a few major maritime hubs, partly because of the increase in vessel size. For the future, although experts are generally optimistic about the capacity of these ports to accommodate ships and about the development of associated services on major maritime routes, there is concern of over congestion and saturation problems that are steadily becoming more apparent in land access to ports, despite the fact that transshipment to *feeder ships* seems to be quite efficient.

Facilitation of these flows will be primarily realized in the European sea ports (North Sea, Mediterranean, Adriatic or Black sea ports). Currently, the largest European container port is Rotterdam with 11.9 million TEUs in 2012. Compared to this port, the Romanian Black Sea port Constanta may still seem insignificant, but its performance in the past years has been very impressive.

Main expectations regarding the development of the container transport through the Port of Constanta are based on the 4500 km shorter route from Asia to Western Europe (*Fig. 1*). At the same time, this navigable route considers the Danube as a hinterland connection of the Port of Constanta that provides the Central European landlocked countries access to a maritime point, shorter transit times and CO_2 emission reductions.

Fig. 1 Asia Europe sea routes (source: Port of Constanta)

Unfortunately, despite the named advantages, the potential of the IWT on the Danube as a hinterland connection of the Port of Constanta is not enough exploited. In 2005, the volume transported on the Austrian Danube was around 5000 TEU, what corresponds to approximately1 % of Austria's imports and exports via sea ports.

Possible reasons for the low number of container shipments on the Danube in the last two decades are:

- The two crises in former Yugoslavia, due to which the Danube and the Rhine Main Danube waterway has become a trans-European route first after 2000, with the bridge in Novi Sad, which is still a problem in the higher water levels periods;
- Nautical difficulties for inland navigation in the western direction (long transport times to ARA-ports passing through more than 60 locks)
- Nautical difficulties for inland navigation in the Lower Danube section due to the low water levels and periods with limited navigation of up to two months per year,
- Economic difficulties in the transition countries in the Danube area;
- Hinterland logistics in the Danube basin;
- Logistic competitiveness of the Mediterranean ports and
- Lacking in liner services that should be supported by the comprehensive and reliable logistics services in the Danube ports.

The listed indicates that the incentive for the development of logistics of the Danube represents a complex problem, which has:

- Strategic - political dimension, which involves regional cooperation of all Danube countries in the field of: the maintenance of the waterway and the development of the economy and infrastructure;
- Transitional - educational dimension in pointing to the logistics industry that encourages growth and creates jobs.

EU Danube Strategy is the unique instrument that can bring progress on all grounds.

3. DAHAR POLICY RECOMMENDATIONS

Starting from the detected problems and their causes, within the DaHar project, from the point of the five topics, an analysis of the required steps and actions has been carried out and resulted with definition of the Policy recommendations related to the five issues. The recommendations are listed below.

3.1 Logistic infrastructure of DaHar ports and port operation models

The EU Strategy for the Danube Region (COM/2010/0715) aims at the achievement of higher economy standards, better regional development and integration of the countries along the Danube River, including:

- improvement of transport connectivity and access of regions from the Danube macro-region,
- conducting joint policy with regard to the intermodal cargo.

For realizing the first aim:

Regarding the *blue banana phenomenon*, distribution activities are still centered in the western part of Europe but as the Centre of gravity of the EU shifts eastwards logistic sector intends to follow.

Distribution Centers (DCs) in some DaHar countries have relatively low population density and existing DCs are built to act in mainly road and rail sectors of transportation. IWT have to be taken into account when choosing the locations of newly established DCs for realizing improved access by means of IWT therefore

Transformation of inland waterway ports into logistics hubs (in form of DCs) have to be supported by means of ensuring appropriate economic conditions for such investments.

For realizing the second aim:

There are different regulations and administrative procedures exist regarding the traffic on inland waterways and transshipment operations as well as customs and border crossing procedures almost in every Danube riparian Country nowadays. This situation causes delays in transport times and inappropriate working conditions at inland waterway ports accordingly it sets backwards the competitiveness of the IWT.

Therefore the initiatives of "Same river –same rules" have to be supported by EU regulations or at least in form of EU directives in all Danube riparian Country.

3.2 Port hinterland connections

The EU policy regarding ports hinterland connection is based on:

- WHITE PAPER - Roadmap to a Single European Transport Area,
- TEN-T - Trans-European Networks and the Railway package,
- IWW - Inland waterways/NAIADES,

and can be defined as *accessibility by integration over EU space and further to neighboring countries*.

Starting from that point of view, it has to be pointed out that all Danube ports have at least a road/rail connection but often, these connections are not a part of a TEN-T corridor.

With a few exceptions like Budapest and Bratislava which are crossing points for more than one *core corridor*, the only core corridor connections for all DaHar ports is the Danube. This is not enough to be integrated into logistic freight and passenger flows. That's why, for these ports, even that they are playing an important role for their regions, they will not be exploited efficient.

Therefore, in order to increase accessibility of the Danube region:

- The Danube ports need to be connected by efficient rail (double electrified tracks) or road (an express way) to, at least, one core TEN-T corridor;
- The DANUBE financing program should give more support to those actions that enable integration of small and medium Danube ports into logistic chains, mostly to prepare other projects than those included into selected priority projects from the TEN-T list;
- Integrating inland waterways into the multimodal logistic chains.

3.3 Container and RoRo liner services

Having in mind that an introduction and sustainability of liner services, require fullfilment of high number of prerequisits, the Policy recommendations related to that subject are rather comprehensive and include eight main points:

1. Ensuring state of technology fairway maintenance and operation of locks:
   - All waterway administrations have to ensure and guarantee minimum standards in waterway maintenance which **are 2.5 m fairway depth** at LWRL;
   - Highest attention must be paid to improve current situation due to missing short & mid-term maintenance concepts, unclear political will and/or lack of public budget;
2. Elimination of strategic infrastructure bottlenecks:
   - Implementation of defined TEN T projects for elimination of shallow water bottlenecks with target of 2.5 m draught according UNECE/AGN
   - Potential conflicts of interest economic development – environmental protection can be solved by applying principles of *Joint Statement for Environment & Waterway Development* (ICPDR);
3. Elaboration and implementation of a dedicated transnational Danube Port development strategy together with long-term Action Plans as part of the future EU regional & economic development policy:
   - Development and implementation of (cross-border) regional development plans and related projects
   - Definition & implementation of State Aid Schemes for port & terminal investment similar to programs in Western Europe / back-financing of these State Aid Schemes via Structural Funds in period 2014 – 2020 in EU member states with Operational Programs; special attention to ports in EU support programs for Servia, Moldova and Ukraine;
4. Modernization of Danube fleet:
   - Financial support for the modernization of the fleet from EU programs and national State Aid Schemes for Danube barge operators;
5. Identification and elimination of administrative barriers:
   - Measures should be tackled in a joint working group of navigation, customs and immigration authorities in close co-operation with inland navigation businesses in the framework of EUSDR/PA1A;
6. Full deployment of River Information Services in all Danube states;
7. Development and marketing of integrated intermodal Danube waterway – rail liner services:
   - Requirement of pre-planned backup solution by rail/trucking in case of restrictions of navigations which endanger the guaranteed time schedule;
   - Port of Constanta as well as the maritime Danube ports, in particular Galati and Giurgiulesti could function as intermodal hubs for cargo flows connecting them with industrial centers along the Danube;
8. Strong mandate for future TEN T coordinator:
   - The improvement of the current poor infrastructure situation in the Danube ports as well as with regard to the waterway itself requires a strong coordination of the EU services. Essential will be the selection of an energetic personality for a the future TEN T coordinator
   - The future TEN T coordinator must be supported by a Steering Committee of the Member States which involves them on decision making level. The coordinator also must be supported by a sufficiently staffed implementation unit.

3.4 River Information Services

In order to support traffic and transport management in inland navigation and its interaction with other transport modes the following development of RIS is required:

- Implementation and application of basic RIS for navigation along the entire Danube;
- That state borders do not represent any barriers to the RIS information flows;
- Deployment of RIS on the German section of the Danube and on the entire Rhine, in order to create a unique information system on the EU's Rhine – Danube Corridor.
- The requirements can be ensured with:
- Equipping all vessels with Inland AIS Transponders and basic RIS equipment, so that RIS is used for the navigation on the Danube and its navigable tributaries;
- Equipping all ports (port authorities) with computers and softwares so that they represent periphery of the RIS centers in order to monitor ships coming into ports, including: Alarm zones and Calculation of the expected time of arrival;
- A new EU Directive that defines the minimum set of data to be exchanged about the cargo that are not in conflict with the interests of privacy and to adopt that the defined set of data has to be included in the RIS information flow;
- Providing logistics users access to governmentally operated RIS infrastructure, as far as legally possible;

- Development of practically oriented legal and technical framework for the exchange of RIS data along the Rhine – Danube corridor;
- Development of a European masterplan for the further development of RIS for logistics, including a clear time schedule for implementation and the required financial framework.

Introduction and implementation of the DaHar RIS Transport Logistics Service (TLS) platform, as an extension of the basic RIS, on a regular base in SC-s (Supply Chain) in the Danube region, it is required:

- At present: Application of the DaHar RIS TLS web based platform for general SC, with guarantees for privacy of information flows.
- In the future: Upgrade of the DaHar RIS TLS web based platform to a Cloud Computing System RIS TLS CCS as a part of the Cloud Logistics Services in the EU;

A single point of reporting through the RIS TLS platform in order to minimise the administrative burdens (e.g. customs declarations, transport documents), giving mutual access to the competent authorities and logistics users and therewith enabling and ensuring paperless flows of information following cargo flows in SC.

3.5 Navigability and environmental protection

Inland waterway transport can contribute to the sustainability of the transport system, as recommended by the European Commission's White Paper: European Transport Policy for 2010

Slogan:„**Time to Decide**".

Make it clear: **The Danube works for Europe**

Environmental protection and navigability are one of the most important factors which affect the competitiveness of inland navigation.

The European Union would like to motivate the stakeholders to prefer inland navigation rather than other transportation modes. On one hand, inland waterway transport is considered as the most environmental friendly method of delivering goods. This transportation mode consumes the least fuel pro ton per kilometre. Thereby fewer pollutants and CO_2 are emitted. On the other hand, the vessels should be refitted with most modern engines. The modernization of the vessel would help to protect the environment from pollutants.

In case of navigability, one policy recommendation was formulated. Accordance with the directives set out by European Agreement on Main Inland Waterways of International Importance (UNECE - AGN) inland navigability should be ensured.

We must plan the major works on the achievement of minimum recommended fairway parameters, hydro-technical and other facilities and improvements on the Danube. (loaded draught of 2.5 m).

Installation of the necessary national and cross-border coordination procedures in order to implement effective response actions, in extraordinary circumstances (low water, ice, floods).

Continuous and proper communication of up-dated fairway situation. (National administrations River Information Services provider's waterway users.)

With the above steps safe and cost-efficient transport can be ensured if all Danube States respect the existing international regulations.

These minimum standards can not be compensated by fleet innovation, therefore the slogan:

adapt the vessels to the river and not the river to the vessels

creates a dangerous fiction and ignores basic economic facts.

The Danube - as the 2nd longest and biggest river of the continent - qualified by the following international institutions:

- Danube Commission
- UNECE
- European Commission
- International Transport Forum – ex CEMT,

requires imediately PROPER FAIRWAY MAINTENANCE AND GUARANTED MINIMUM FAIRWAY DEPTHS OF AT LEAST 2.5 m!

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Therefore, it is important to mention that, although formulated by the two listed autors, this paper represents a product of joint cooperation of all project partners.

REFERENCES

[1] www.dahar.eu

[2] www.dahar.rs

[3] Integrated Strategy for Functional Specialization of the Danube Ports in the Logistic Chain, DaHar project, http://www.dahar.eu/webfm_send/189

[4] The application of the information technologies in the ports of Srbia from the monitoring of machines to the networked system with the EU inviroment. The project funded by the Ministry of Science of the Republic of Serbia, TR 35036, 2011-2014.

[5] The Review of Maritime Transport 2012, United Nations Conference on Trade and Development, United Nations, New York, 2012.

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APPLICATIONS OF MATRIX-ANALYTIC METHODS AND PHASE-TYPE DISTRIBUTIONS IN STOCHASTIC LOGISTIC PROBLEMS MODELING

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Abstract

The goal of this paper is to present a variety of applications of matrix-analytic methods (MAMs) and phase-type (PH) distributions to logistic models with random variables. We first provide an overview of different types of PH distributions as advanced analytic techniques for the solution of non-Markovian state-space based models. In the latter part of the paper, we illustrate these techniques by means of some logistic examples dealing with exponential and non-exponential stochastic processes and random values. The ultimate goal of this paper is to provide a reference for logistic researchers and students in state-space modeling.

Keywords*: matrix-analytic methods, phase-type distributions, logistic problems, modeling.*

1. INTRODUCTION

Logistic planning and management largely focus on problems of material flows in transportation systems. The very complex processes of transport, within the material flow analysis, are usually represented by simple models in order to find solutions to practical problems. Processes in real material flow systems, the movement of transport units or changes in inventories at warehouses, can be modeled as changes in characteristic system values over time. These system values can be interpreted as random variables and their changes over time as stochastic processes. In this sense, discrete and continuous probability distributions are the basis for analytical study and simulation of transportation processes with dynamic behavior.

The most important random variables in a material flow analysis, as a major category of logistics processes, are:

• results in time intervals, for example number of transportation orders, number of operating cycles for a period, total number of failures, number of transportation units necessary for the movement of the product, number of arrivals per unit time, etc.,

• time interval between events, for example interarrival time, sojourn time, service time, waiting time in front of server, time gaps, lead time and cycle time, etc.,

• distance traveled during a time interval, for example length of road of FTS vehicles or trucks in external transport, length of transportation networks, etc.,

• the amount of material to be handling in a given time interval, for example in the manufacture and storage of goods in distribution centers of logistics chains, etc [1].

In general, random variable can be defined as a numerical outcome that results from an experiment. Discrete random variable can take on only a finite or countably infinite set of outcomes (the first group of the above examples - total number of failures). On the other hand, continuous random variable can take on any value along a continuum or infinite set of outcomes (the second group of the above examples - interarrival time).

In view of the above presented facts that changes in characteristic system values over time have stochastic character, effective managing of logistics processes, particularly in terms of optimization, requires the involvement of probability theory and stochastic process, as well as reliability theory. On this basis, it is possible to define appropriate mathematical models that would adequately interpret complex logistic processes and that are very important for optimal system management.

2. LOGISTIC PROCESS WITH NON-EXPONENTIAL BEHAVIOR

In modeling different logistic processes the basic idea is to graphically describe the real-time dynamical evens or flows by state-space diagrams that may be further transformed into mathematical models for which solution mathematical tools and procedures are well known. A standard form for state-space diagram is directed graph or digraph **G**(**V**,**E**) composed of the following elements **V** – set of nodes (vertex) and **E** – set of edges (links between vertices). Nodes represents the different states of the domain (i.e. cities in the transportation problem) and edges represents the transitions from a state to another. Each edge is a pair (*i*,*j*), where *i* and *j* belongs to V. If the edge pair is ordered, the edge is called directed and thus the graph is directed graph. Otherwise, the graph is called undirected and it's rarely encountered in usual logistical problems. Very often, an edge has a component called edge cost (or weight).

It is generally known that the state-space diagram can be simply represented by *Markov processes* (a kind of a stochastic processes) if transition probabilities, from a state to another, have constant values (do not depend on time) and if future states of the system depend only on the present state (not on any past states). This means that the time spent in a state *i*, before the system moves to the next state *j*, takes non-negative real values and has an exponential distribution which further defines transition probability, from state *i* to state *j* as:

$$p_{ij} = \frac{1}{E(t)} = const., \tag{1}$$

where $E(t)$ denote expected value of the time spent in state i.
If it's necessary to model random variables (processes) which are characterized by general distribution (non-exponential) functions, such models are called non-Markovian. This class of models can be solved using several different approaches:
- Markov renewal theory [2]
  - Markov renewal sequences,
  - semi-Markov processes
  - Markov regenerative processes,
- method of additional variables [3],
- matrix-analytic methods (MAMs) and their part phase-type (PH) distributions [4].

The most important advantage of using PH distributions is their mathematical tractability, which is primarily reflected in the possibility of approximation of arbitrary continuous probability distributions with arbitrary precision. Namely, an increase in the number of phase (stages) causes an increase in precision of approximation. In contrast, the application of additional variables method or Markov renewal theory is very limited in practical problems [5].
The fact that some general distribution or an empirical data set can be approximated by two or more exponential distributions is very often used in logistic models where transition processes have non-exponential behaviour.

3. MOSTLY USED CONTINUOUS PHASE-TYPE DISTRIBUTIONS

PH distributions are based on the method of stages technique introduced by A. K. Erlang (1917.) [6] and later (1981) generalized by M. F. Neuts [4]. Since their introduction PH distributions have been used in a wide range of stochastic modelling applications in different areas such as: telecommunications, finance, biostatistics, queueing theory, reliability theory, survival analysis, etc [7]. Neuts defined PH distribution as the distribution of the time until absorption in a Markov process with a finite number n of transient states and one absorbing state, state n+1 [4]. The key idea is to model random time intervals (with non-exponential distribution) as being made up of a number of exponentially distributed segments and to exploit the resulting Markovian structure to simplify the analysis.
Let $X(t)$, $t \geq 0$, be a time-homogeneous Markov process with discrete state space $\{1, ..., n, n+1\}$ and infinitesimal generator (hereinafter only generator) Λ:

$$\mathbf{\Lambda} = \begin{pmatrix} \mathbf{\Theta} & \boldsymbol{\theta} \\ \mathbf{0} & 0 \end{pmatrix}, \tag{2}$$

where $\mathbf{\Theta}$ is a $n \times n$ square matrix (generator restricted to the transient states), $\boldsymbol{\theta}$ column vector and $\mathbf{0}$ row vector of order n. The initial probability vector of process $X(t)$ is denoted by $\acute{\boldsymbol{\alpha}} = (\boldsymbol{\alpha}, \alpha_{n+1})$ where $\boldsymbol{\alpha}$ is a row vector of size n. The states $\{1, ..., n\}$ are referred to the transient states and n+1 is an absorbing state. Let Z:= inf $\{t \geq 0 : X(t) = n+1\}$ be the time until absorption of the process $X(t)$ in state n+1. The distribution of Z is called phase-type (PH) distribution with parameters $\boldsymbol{\alpha}$ and $\mathbf{\Theta}$ and is denoted by PH($\boldsymbol{\alpha}$,$\mathbf{\Theta}$). Dimension n of matrix $\mathbf{\Theta}$ is order of PH distribution and represents the number of phases or stages. The basic distributional characteristics of PH distribution (the cumulative distribution function (3), the density function (4) and the rth moment (5)) are:

$$F(t) := \mathrm{P}(Z \leq t) = 1 - \boldsymbol{\alpha} e^{\mathbf{\Theta} t} \mathbf{e}, \tag{3}$$

$$f(t) = \boldsymbol{\alpha} e^{\mathbf{\Theta} t} \boldsymbol{\theta}, \tag{4}$$

$$m_r = (-1)^r r! \boldsymbol{\alpha} \mathbf{\Theta}^{-r} \mathbf{e}, \tag{5}$$

where $e = (1,...,1)^T$ is a column vector of ones and r is ordinal number of a moment.
According to form of matrix $\mathbf{\Theta}$ and initial probability vector $\boldsymbol{\alpha}$ it is possible to classify different types of PH distributions: exponential distribution (one phase PH distribution), Erlang distribution (two or more identical phases in sequence), hypoexponential distribution (two or more non necessarily identical phases in sequence – series connection), hyperexponential distribution (two or more non necessarily identical phases - parallel connection), Coxian distribution (two or more not necessarily identical phases in sequence, but with a probability of transitioning to the absorbing state after each phase), etc.
The basic indicator in selecting one of these distributions to represent a non-exponential distribution is the coefficient of variation. The coefficient of variation CV is a measure of deviation from the exponential distribution (CV = 1) [5]. Table 1 shows the intervals of the coefficient of variation for some types of PH distributions.

Table 1 Koefficient of variation for some types of PH distributions

coefficient of variation CV	Type of PH distribution
> 1	hyperexponential
1	exponential
< 1	hypoexponential
0	deterministic distribution

PH distributions capture a wide range of statistical characteristics including high variability. Note that PH distributions do not capture long-range dependence or self similar behavior. There is another set of processes known as Markovian arrival processes that are still based on the method of stages and capture long-range dependence in a data set. PH distributions are a special case of Markovian arrival processes [8].
The following probability distributions are considered as special cases of a continuous PH distribution. Moreover, each of them has been used widely in literatures.

3.1 Exponential distribution

Exponential distribution is one of the most important continuous theoretical distribution which describe many natural phenomena. The density function of exponential distribution is:

$$f(t) = \begin{cases} \lambda \cdot e^{-\lambda \cdot t} & \text{za} \quad 0 \leq t \leq \infty \\ 0 & \text{za} \quad t < 0 \end{cases}, \tag{6}$$

where parameter λ determines the "rate" at which events occur. The cumulative distribution function is defined as:

$$F(t) = \begin{cases} 1 - e^{-\lambda \cdot t} & \text{za} \quad 0 \le t \le \infty \\ 0 & \text{za} \quad t < 0 \end{cases} \tag{7}$$

In general, any exponentially distributed random variable $t \sim \mathrm{Exp}(\lambda)$, with parameter λ, has the following properties:

- expected value $E(t) = 1/\lambda$,
- moment about zero $m_r = r!/\lambda^r$,
- variance $Var(t) = 1/\lambda^2$,
- coefficient of variation CV = 1,
- skewness $\alpha 3 = 2$,
- kurtosis $\alpha 4 = 6$,
- transient generator $\Theta = [-\lambda]$.

It is easy to observe that an exponential distribution is also a phase-type distribution which has only one phase. Consequently, processing time till the absorbing state is just moving from initial state to the absorbing state.

Exponential distributions dominant feature is "ease-to-use" character in practical engineering situations. Applying the exponential distribution is relative simply in stochastic modeling because there is only one parameter λ. The great significance of this distribution is in the fact that it is unique continuous theoretical distribution with so called memory less property. The memory less property enables simple expressions for many performance measures of stochastic logistic models. The third important feature of exponential distribution is its relation to the Poisson distribution. This distribution is used to measure the time intervals between events according to Poisson process.

Exponential distribution has many important features that often provide analytical solutions of the problem. On the other hand, it is not always the ideal approximation of the observed phenomena in nature. Coefficients of variation of many important processes and random variables have values which are significantly more or less than one. This means that it is necessary to define some other PH distributions which can be better approximation of non-exponential processes.

3.2 Hypo - exponential distribution

Hypoexponential distribution or generalized Erlang distribution is the probability distribution of time to absorption in Markov process with two or more non necessarily identical, series-connected, exponentially distributed phases (states). The continuous, non-negative random variable $t \sim \mathrm{Hypo}(k, \lambda_i)$ has hypoexponential distribution if its density function has a form:

$$f(t) = \sum_{i=1}^{k} \prod_{i \ne j} \frac{\lambda_j}{\lambda_j - \lambda_i} \cdot \lambda_i \cdot e^{-\lambda_i \cdot t}, \tag{8}$$

where k is the number of phases and λ_i is transition rate from the i-th phase. The cumulative distribution function is defined as:

$$F(t) = \sum_{i=1}^{k} \prod_{i \ne j} \frac{\lambda_j}{\lambda_j - \lambda_i} \cdot e^{-\lambda_i \cdot t}. \tag{9}$$

Figure 1 shows a state transition diagram – graph of hypoexponential distribution.

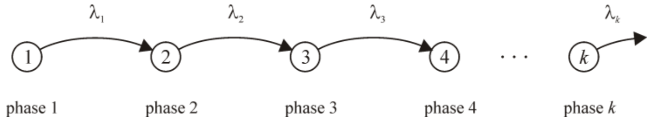

Fig. 1 State transition diagram of hypo - distribution

Random variable $t \sim \mathrm{Hypo}(k, \lambda_i)$ has the following properties:

- expected value $E(X) = \sum_{i=1}^{k} 1/\lambda_i$,
- moment about zero do not exist in closed form
- variance $Var(X) = \sum_{i=1}^{k} 1/\lambda_i^2$,
- coefficient of variation CV < 1,
- skewness $\alpha_3 = \dfrac{2 \cdot \sum_{i=1}^{k} \frac{1}{\lambda_i^3}}{(\sum_{i=1}^{k} \frac{1}{\lambda_i^2})^{3/2}}$,
- kurtosis do not exist in closed form
- transient generator

$$\Theta = \begin{bmatrix} -\lambda_1 & \lambda_1 & 0 & \dots & 0 & 0 \\ 0 & -\lambda_2 & \lambda_2 & \dots & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & -\lambda_{k-2} & \lambda_{k-2} & 0 \\ 0 & 0 & \dots & 0 & -\lambda_{k-1} & \lambda_{k-1} \\ 0 & 0 & \dots & 0 & 0 & -\lambda_k \end{bmatrix}.$$

- initial probability vector $\alpha = (1, 0, ..., 0)$.

While the Erlang distribution is a series of k exponential distributed phases all with rate λ, the hypoexponential is a series of k exponential distributions each with their own rate λ_i.

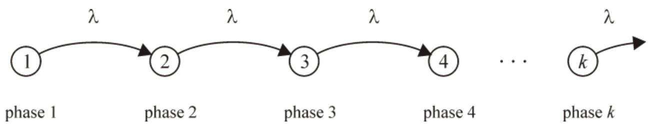

Fig. 2 State transition diagram of Erlang distribution

As a result of that, Erlang distribution can be considered as a special case of the hypoexponential distribution.

3.3 Hyper - exponential distribution

Hiperexponential distribution is the probability distribution of time from initial state to absorption in Markov process with two or more non necessarily identical, parallel-connected, mutually exclusive, exponentially distributed phases (states). The continuous, non-negative random variable $t \sim \mathrm{Hyper}(k, \alpha_i, \lambda_i)$ is distributed according to hyperexponential distribution if its density function is defined as:

$$f(t) = \sum_{i=1}^{k} \alpha_i \cdot \lambda_i \cdot e^{-\lambda_i \cdot t}, \tag{10}$$

where k is the number of phases, λ_i is transition rate from the i-th phase and α_i is probability of transition to the i-th phase (component of initial probability vector). The cumulative distribution function is defined as:

$$F(t) = 1 - \sum_{i=1}^{k} \alpha_i \cdot e^{-\lambda_i \cdot t} . \tag{11}$$

Figure 3 shows a state transition diagram – graph of hyperexponential distribution.

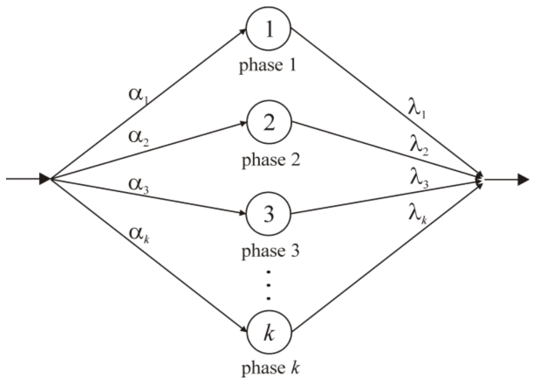

Fig. 3 State transition diagram of hyper - distribution

Random variable t~Hyper(k, α_i, λ_i) has the following properties:

- expected value $E(X) = \sum_{i=1}^{k} \alpha_i / \lambda_i$,
- moment about zero $m_r = r! \cdot \sum_{i=1}^{k} \alpha_i / \lambda_i^r$,
- variance $Var(X) = \sum_{i=1}^{k} \frac{2\alpha_i - \alpha_i^2}{\lambda_i^2}$,
- coefficient of variation CV > 1,
- skewness do not exist in closed form
- kurtosis do not exist in closed form
- transient generator

$$\mathbf{\Theta} = \begin{bmatrix} -\lambda_1 & 0 & \ldots & 0 \\ 0 & -\lambda_2 & \ldots & 0 \\ \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & \ldots & -\lambda_k \end{bmatrix},$$

- initial probability vector $\boldsymbol{\alpha} = (\alpha_1, \alpha_2, ..., \alpha_k)$, .

  of order k where $\sum_{i=1}^{k} \alpha_i = 1$.

The hyperexponential distribution exhibits more variability than the exponential (CV > 1). Typical examples of application are CPU service-time distribution in a computer system and the failure density of a product manufactured in several parallel assembly lines which outputs are merged.

4. MATRIX-ANALYTIC METHODS FOR MODELING GENERALLY DISTRIBUTED TIMES IN LOGISTIC SYSTEMS

Recent applications of matrix-analytic methods in queueing theory, reliability and availability, telecommunications, civil engineering, finance, computer science [9], among others, shows the power of these techniques in different areas. In this paper we focus on the applications of matrix-analytic methods in two very importante areas and we present the concepts and the modeling approach of real-life logistics problems.

4.1 Matrix-analytic methods in queuing theory

The first example is model described in the paper *Application of the Markov theory to queuing networks* by Petrovic et al. [10]. This paper presents an application of the matrix-analytic methods to the model of networked transport system which consists of two subsystems, namely PS1 i PS2 (Fig. 4). Transport units (TU) enter subsystem PS1 and are processed. In part they depart from the system, while partly, they come to the second subsystem PS2. At the entrance of the subsystem PS2 the units coming from the outside are included too. After being processed in subsystem 2, the units depart from the system. The aim is to determine average number of transport units in each subsystem as well as average time of keeping the unit within each subsystem.

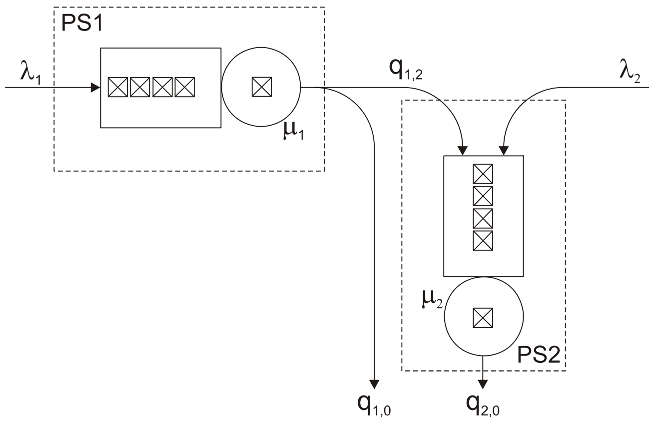

Fig. 4 Model of Real Transport System

Number of transport units entering subsystems PS1 is modeled by Poisson's distribution with parameter λ_1, while the TU processing time in subsystem PS1 is defined by exponential distribution with parameter μ_1. Number of TUs departing from the system is defined by parameter $q_{1,0}$, while the number of units entering into queue of subsystem PS2 is defined by parameter $q_{1,2}$. The queue of subsystem PS2 also includes the units coming from the environment by Poisson's distribution with parameter λ_2. TUs leave subsystem PS2 after the processing which is defined by exponential distribution of service time with parameter μ_2. Thus defined numerical example represents an open network of the queuing system for whose modeling methodology described in previous sections is applied.

The set model represented in the form of the graph of states is given in Fig. 5. If the capacity of both subsystems PS1 and PS2 are S_1=S_2=5 then the transient generator matrix gets the form shown by expression 13, where -Σi represents negative sum of all the elements in i-th row. Also, initial probability vector has a form:

$$\boldsymbol{\alpha} = (1, 0, ..., 0). \tag{12}$$

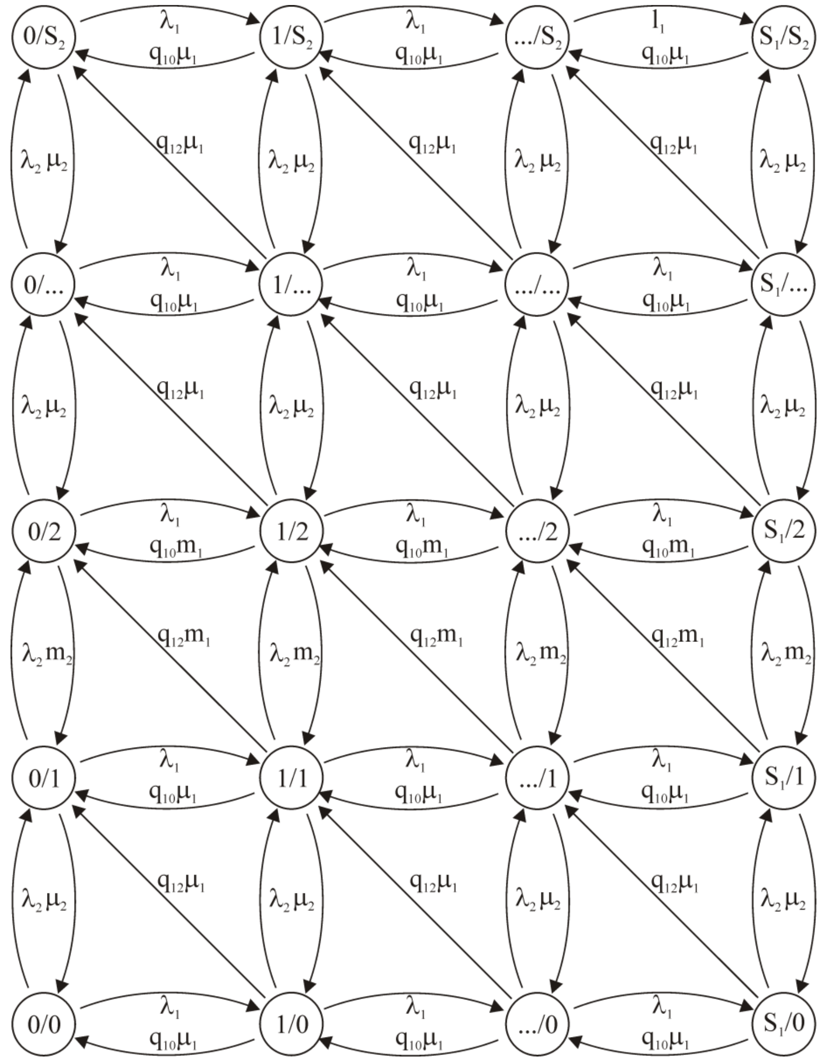

Fig. 5 Model represented in the form of the graph

$$
\Theta = \begin{array}{c|ccccccccccccccccc|}
 & (0,0) & (1,0) & (2,0) & (3,0) & (4,0) & (5,0) & (0,1) & (1,1) & (2,1) & (3,1) & (4,1) & (5,1) & (0,2) & (1,2) & \cdots & (4,5) & (5,5) \\
\hline
(0,0) & -\Sigma_1 & \lambda_1 & 0 & 0 & 0 & 0 & \lambda_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & & 0 & 0 \\
(1,0) & q_{10}\mu_1 & -\Sigma_2 & \lambda_1 & 0 & 0 & 0 & q_{12}\mu_1 & \lambda_2 & 0 & 0 & 0 & 0 & 0 & 0 & & 0 & 0 \\
(2,0) & 0 & q_{10}\mu_1 & -\Sigma_3 & \lambda_1 & 0 & 0 & 0 & q_{12}\mu_1 & \lambda_2 & 0 & 0 & 0 & 0 & 0 & & 0 & 0 \\
(3,0) & 0 & 0 & q_{10}\mu_1 & -\Sigma_4 & \lambda_1 & 0 & 0 & 0 & q_{12}\mu_1 & \lambda_2 & 0 & 0 & 0 & 0 & & 0 & 0 \\
(4,0) & 0 & 0 & 0 & q_{10}\mu_1 & -\Sigma_5 & \lambda_1 & 0 & 0 & 0 & q_{12}\mu_1 & \lambda_2 & 0 & 0 & 0 & & 0 & 0 \\
(5,0) & 0 & 0 & 0 & 0 & q_{10}\mu_1 & -\Sigma_6 & 0 & 0 & 0 & 0 & q_{12}\mu_1 & \lambda_2 & 0 & 0 & & 0 & 0 \\
(0,1) & \mu_2 & 0 & 0 & 0 & 0 & 0 & -\Sigma_7 & \lambda_1 & 0 & 0 & 0 & 0 & \lambda_2 & 0 & & 0 & 0 \\
(1,1) & 0 & \mu_2 & 0 & 0 & 0 & 0 & q_{10}\mu_1 & -\Sigma_8 & \lambda_1 & 0 & 0 & 0 & q_{12}\mu_1 & \lambda_2 & \cdots & 0 & 0 \\
(2,1) & 0 & 0 & \mu_2 & 0 & 0 & 0 & 0 & q_{10}\mu_1 & -\Sigma_9 & \lambda_1 & 0 & 0 & 0 & q_{12}\mu_1 & & 0 & 0 \\
(3,1) & 0 & 0 & 0 & \mu_2 & 0 & 0 & 0 & 0 & q_{10}\mu_1 & -\Sigma_{10} & \lambda_1 & 0 & 0 & 0 & & 0 & 0 \\
(4,1) & 0 & 0 & 0 & 0 & \mu_2 & 0 & 0 & 0 & 0 & q_{10}\mu_1 & -\Sigma_{11} & \lambda_1 & 0 & 0 & & 0 & 0 \\
(5,1) & 0 & 0 & 0 & 0 & 0 & \mu_2 & 0 & 0 & 0 & 0 & q_{10}\mu_1 & -\Sigma_{12} & 0 & 0 & & 0 & 0 \\
(0,2) & 0 & 0 & 0 & 0 & 0 & 0 & \mu_2 & 0 & 0 & 0 & 0 & 0 & -\Sigma_{13} & \lambda_1 & & 0 & 0 \\
(1,2) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \mu_2 & 0 & 0 & 0 & 0 & q_{10}\mu_1 & -\Sigma_{14} & & 0 & 0 \\
\cdots & & & & & & & & & \cdots & & & & & & & & \\
(4,5) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & & -\Sigma_{35} & \lambda_1 \\
(5,5) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & & q_{10}\mu_1 & -\Sigma_{36}
\end{array} \qquad (13)
$$

4.2 Phase-Type Distribution for modeling failure rate function

The problem analized in reference [9] is shown here as the second example of matrix-analytic methods in logistics. In order to study system performance throughout its life cycle, method of multi – state degradation analysis was introduced [11]. Degradation is a continuous random process in time, and generally, it can be modeled by a continuous probabilistic function. However, in practice, the description of the system operating (technical) condition is accomplished through a finite number of system states, and hence, the continuous degradation path is simplified by dividing it into a number of different discrete states [12].

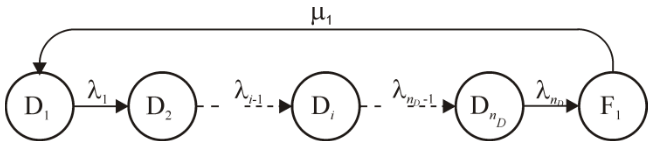

Fig. 6 System degradation path:
D_i – degradation states, F_1 – degradation failure

Degradation state D_i (degradation level or cluster) can be introduced as a system state with relevant technical conditions at similar level of operating ability. Because of that, failure rate function has close relationship with degradation process and in a specific degradation level, system failure rate is assumed to have a constant value λ_i, i=1÷n_D. The final area (degradation level n_D) represents the state of the system with a strong increase in failure rate function (approximated with value λ_{nD}) when the degradation failure F_1 occurs. Time to degradation failure F_1, in mathematical sense, represents the generalized Erlang or hypoexponential distribution as a special case of PH distribution. The last process necessary to complete the model is replacement/repair of failed system. After degradation failure the system will be replaced or repaired to a state D_1 which is "as good as new" state. Time of replacement or repair is exponentially distributed E(μ_1). If corrective maintenance time, after degradation failure, is not exponentially distributed, process can be modeled (similarly to degradation process) as another hypoexponential distribution. The aim is to determine working state probabilities (availability) as well as probability of failure state.

The transient generator matrix ($\boldsymbol{\Theta}$) and initial probability vector ($\boldsymbol{\alpha}$), for system degradation model through n_D states, with degradation failure and corective maintenance can be represented expressions (14) and (15) respectively:

$$\boldsymbol{\Theta} = \begin{bmatrix} -\lambda_1 & \lambda_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\lambda_2 & \lambda_2 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & \cdots & & & & & \\ & & & \cdots & & & & & \\ 0 & 0 & 0 & & -\lambda_i & \lambda_i & 0 & 0 & 0 \\ & & & & & & \cdots & & \\ & & & & & & \cdots & & \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\lambda_{n_D} & \lambda_{n_D} \\ \mu_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\mu_1 \end{bmatrix}, \qquad (14)$$

$$\boldsymbol{\alpha} = (1, 0, ..., 0). \qquad (15)$$

5. CONCLUSION

Markov models are a well known modeling technique in industrial and academic applications. Aim of this paper was to present applications of matrix-analytic methods and phase-type distributions to logistic models with random variables.

The presented methodology enables a rapid increase in the size of the problems that can be effectively handled by Markov models. It offers a new possibility of dealing with non-exponential processes and variables. Matrix-analytic methods and phase-type distributions represents flexible and effective modeling method and the author's intent is that this paper will be an encouragement to logistic researchers and students in state-space modeling.

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REFERENCES

[1] D. Arnold, K. Furmans, "Materialfluss in Logistiksysteme" Berlin: Springer, 2009.
[2] N. Limnios, G. Oprisan, "Semi-Markov Processes and Reliability", Birkhäuser Boston, 2001.
[3] D.R. Cox, "The analysis of non-Markovian stochastic processes by the inclusion of supplementary variables", Proceedings of the Cambridge Philosophical Society, 51(3), 1955, pp. 433-441.
[4] M. Neuts, "Matrix-geometric solutions in stochastic models", Dover Publications, New York, 1981.
[5] S. Distefano, K.S.Trivedi, "Non-Markovian state-space models in dependability evaluation", Quality and Reliability Eng. Int. 29(2), 2013, pp. 225-239.
[6] E. Brockmeyer, H.L. Halstrøm, J. Arne, "The Life and Works of A.K. Erlang", Transactions of the Danish Academy of Technical Sciences, No. 2, 1948.
[7] G. Latouche, V. Ramaswami, "Introduction to Matrix Analytic Methods in Stochastic Modeling", ASA SIAM, Philadelphia, 1999.
[8] A. Riska, V. Diev, E. Smirni, "An EM-based technique for approximating long-tailed data sets with PH distributions", Performance Evaluation 55, 2004, pp. 147-164.
[9] G. Petrović, "Multi-objective optimization of technical systems maintenance process based on probability methods and artificial intelligence", doctoral dissertation, University of Niš, Faculty of Mechanical Engineering in Niš, 2013.
[10] G. Petrović, N. Petrović, Z. Marinković, "Application of Markov's Theory to Queuing Networks", The Scientific journal FACTA UNIVERZITATIS, Series Mechanical Engineering, 6(1), 2008, pp. 45-56.
[11] H. Wang, H. Pham, "Reliability and Optimal Maintenance", Springer – Verlag, London, 2006.
[12] G. Petrović, Ž. Ćojbašić, "Comparison of clustering methods for failure data analysis: a real life application", XV International Scientific Conference on Industrial Systems (IS'11), Proceeding, University of Novi Sad, Faculty of Technical Sciences, Serbia, 2011, pp. 297-300.

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ANALYSIS OF LOGISTICS CHAINS IN DAIRY INDUSTRY

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Abstract

This paper outlines some basic remarks on logistics chains, particularly in the dairy industry, starting from the technology of production, via collection, processing and distribution to sales of milk and dairy products. In particular, the analysis of costs at all stages of milk production from raw milk to the final product, UHT milk, is given. The analysis was done for the region of Zaječar in order to determine the final retail price of milk at the store. It was concluded that any logistics chain, therefore the one in the dairy industry as well, has to make a profit, and that the profit needs to be adequately distributed among participants according to their costs and labor expended. Any solution implying that certain participants operate with losses, while others make high profits at the expense of others, is not good. This is often the case in our region, due to disordered relationships and monopolies in the economy.

Key words: *logistics, transport chains, milk, costs, profit.*

1. INTRODUCTION

Today, the modern concept of global economy is based on logistics. It is supported by the emergence of integrated logistics networks and the rapid development of the market by using e-business. This business concept requires the provision of necessary raw materials for production (supply logistics), production of material goods (production logistics) and marketing of those goods (market logistics). Besides manufacturer companies, this approach to economy also implies inclusion of other specialized service companies that provide manufacturers with raw materials and distribute final products to the end users (customers) and also inclusion of public utilities for waste treatment. All of these companies together with the market and the customers make logistics chains in certain areas of the economy. Their physical connectivity has been achieved by an extensive transportation network consisting of roads of different types of transport and logistics centers with public warehouses and terminals [1, 2, 3, 4].

The aim of this paper is to highlight the importance of the implementation of supply chains in the modern concept of business in order to achieve a more efficient, cost-effective and safer operations for the benefit of all the participants in the chain and its users. Special attention is given to the analysis of the supply chain in the dairy industry of Zaječar region and certain measures for improvements in the chain are recommended [5].

2. THE BASICS ON SUPPLY CHAINS

Literature provides a large number of papers on supply chains that offer a number of definitions and consider various aspects. The supply chain is described as a system, a network of organizations, a number of activities, integrated process, etc., which include material, information and financial flows [2, 3, 4].

In principle, the supply chain consists of a number of enterprises (companies) involved (directly or indirectly) in the process of meeting the demands of customers (consumers). This chain includes not only the manufacturers and suppliers (distributors), but also the transport companies, warehouses, retailers and customers. Within each of the supply, production, distribution and sale, the supply chain includes all functions related to meeting the demands of consumers. In the supply chain, the constant flow of information, materials (goods and products) and money between different enterprises is manifested. Each company in the chain performs a variety of activities (processes) and is associated with other companies in the chain. The basic purpose of any supply chain is to meet the needs of the customer, whereby a profit is made [2].

Therefore, any logistics chain is supposed to make a profit, which should be adequately distributed among the participants according to their costs and labor expended. Any solution implying that certain participants operate with losses, while others make high profits at the expense of others, is not good.

A typical supply chain may include more participants, whereby the most important are: suppliers, manufacturers, distributors, retailers and customers (Fig. 1).

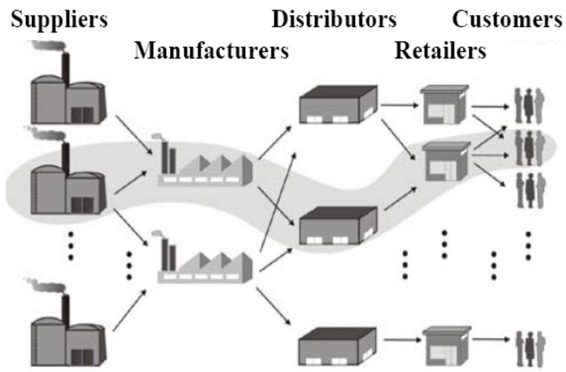

Fig. 1. Supply chain participants

A number of papers categorize the supply chains into traditional and contemporary, according to the development phases [4]. At first they were traditional, but upon the introduction of the concept of control, they have become modern and very popular in certain branches of the economy and significantly affect the development of the country.

3. SUPPLY CHAIN IN DAIRYING OF ZAJEČAR REGION

High nutritional values of milk were known even in ancient times. It is assumed that the man first used milk some 6-10 thousand years ago, when he began the domestication of animals. Only in the second half of the 19th century, with the development of the industry, the rapid development of dairying begins. The rapid development of microbiology and chemistry provides an opportunity to learn more complex microbiological and biochemical processes occurring during storage and processing of milk into a range of dairy products.
Today, milk is a product that has great significance in human nutrition and is important in daily use. This is supported by the fact that bread and milk belong to the most consumed groceries on daily basis. The ultimate aim is the production of high-quality and healthy dairy products.
Zaječar region (Timočka Krajina) is a hilly area, mostly with mountain slopes and hills of 200-800 meters above the sea level. Slightly more than half the total area of the district is either agricultural land on which animal feed, or can be converted into it. The favorable conditions have made livestock farming one of the dominant economic activities of the rural population of the region for centuries. Thanks to such conditions, a long tradition of raising cattle, producing meat, milk and high quality natural offspring (Timok Simmental cattle) has developed [5].
The organized milk processing in Timok Krajina began between 1930 and 1932 close to Zaječar, and on the 1st April, 1964, the dairy factory of Zaječar - "IMPAZ" officially started its work. In the Zaječar region, this induced a period of organized and continuous action to constantly improve animal husbandry, production and purchase of milk, which still takes constant modernization in order to adapt to new market needs with the aim of providing permanent economic security and stability in the production of milk and dairy products. In 2003, in the process of privatization, the dairy factory from Belgrade "IMLEK" became the majority owner of "IMPAZ" with a great assortment of dairy products [5].
In general, dairy has six main factors in its logistic chain and they are:

- the manufacturer of raw milk (farm),
- purchaser of raw milk,
- processors of milk into dairy products,
- distributor (wholesaler) of milk and dairy products,
- stores, where milk and dairy products are sold,
- consumer of dairy products.

In this case, the logistics chain in dairying of Zaječar region contains three main parts, as shown in Fig. 2.

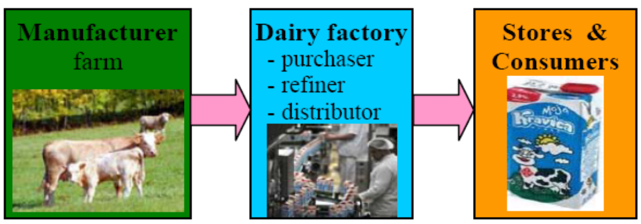

Fig. 2. The logistics chain in dairying of Zaječar region

The manufacturers of raw milk are in the first group and they usually represent rural households with small farms with up to 15 cows. The dairy factory renders the second group, which deals with the purchase of raw milk, processing and distribution of finished product. The third group consists of stores (retail) and customers. The goal of any organized chain, hence the one in dairying as well, is to make profit, which is to be proportionally distributed among the chain participants.

4. ANALYSIS OF COSTS OF PRODUCTION, PROCESSING AND DISTRIBUTION OF MILK

The conducted analysis considers the best sold dairy product of "IMLEK" – the 1L package of UHT milk with 2.8% milk fat. The aim of the analysis is to determine the costs of production, processing and distribution of milk as well as the retail price of milk, and therewith to determine the participation in the overall costs of each logistics chain participant.
The following factors influence the overall cost of production of raw milk on farms: cow nutrition, animal husbandry measures, veterinary services, hygienic-sanitary measures, energy, insurance, maintenance and depreciation, etc.
The nutritional costs were calculated for a cow weighing 600 kg and producing 25 liters of milk daily, whereby the cattle is kept stationary in the barn. The chemical quality of milk received must meet the following parameters: 3.72% fat, 3.20% protein, 8.75% non-fat dry matter and 8.40% lactose.
The nutrition cost per cow is shown in Table 1 [5]. From the description, it is evident that the cost of food per cow giving an average of 25 liters of milk per day is 400.30 RSD (Serbian Dinar $\Rightarrow$ din.). Thus, the nutrition cost per one liter of milk is given as: $T_1 = 400.3/25 = 16.01 \approx 16.00$ din/lit.

Table 1. *The nutrition cost per cow*

SORT OF NUTRITION	amount (kg)	price (din.)	cost (din.)
corn silage	20	3.5	70
alfalfa hay	4.5	25	112.5
dry sugar beet chips	1	12	12
hominy	3	18	54
corn meal	2.25	11	24.75
soybean meal 44%	1	58.5	58.5
sunflower meal 33%	1	29	29
premix (synthesized preparations)	0.2	160	32
animal salt	0.07	15	1.05
1€ = 115.5 RSD (din.)		Sum	400.3

Other costs of raw milk production are determined on an annual basis to sample farm with 15 cows, which in the period of lactation during the year give an average of 6,500 liters of milk per cow. These costs, which are given in Table 2 [5], imply the following costs: artificial insemination, treatment, preventive udder care, keeping the register (pedigree), mandatory veterinary health analysis, insurance, hygienic supplies, depreciation and current maintenance, salaries (wages of workers on the farm), electricity, water, utilities, energy (fuels and lubricants) and other unforeseen expenses.
From this table, it is noted that other annual total costs of production of raw milk at the farm with 15 cows amounts to 2,436,250.00 din. The total annual average production of raw milk at this farm, where cows give an average of 6,500 liters, is 6500 x 15 = 97,500 liters/year. Hence, the costs per liter of raw milk are: $T_2 = 2.436.250,00/97500 = 24.987 \approx 25$ din/lit.

***Table 2.** Other expenses for the year in the production of raw milk at the farm with 15 cows*

Expense	din.	Times a year	overall (din)
insemination	4000	30	120000
treatment	12000	15	180000
preventive udder care	2000	15	30000
keeping the register	5000	15	75000
veterinary health analysis	25000	2	50000
insurance	8000	15	120000
hygienic supplies	500	365	182500
depreciation	20000	4	80000
salaries	40000	12	480000
hay	250	365	91250
electric energy	22000	12	264000
water	5000	12	60000
utilities	1000	12	12000
fuels and lubricants	1500	365	547500
unforeseen expenses	12000	12	144000
		Sum	2.436.250,00

The total overall cost of the raw milk producers, as the sum of the two previous costs, T1 and T2, yields:

$T_{sum} = T_1 + T_2 = 16 + 25 = 41$ din/lit.

At this point, the maximum purchase price in our country for a liter of raw milk per European standard is around 39 dinars. For poorer quality milk, the purchase price is slightly lower. This price is usually 48% of the manufacturing cost of a liter of UHT milk. In this case, the average purchase price of raw milk for the dairy factory "IMPAZ" from Zaječar, i.e. "IMLEK", as a buyer, processor and distributor, is 34.74 din. The purchase price differs from the cost of production of raw milk by 6.26 dinars, which causes a loss of farmers and discourages the production of raw milk.
The conclusion can be drawn that, in the framework of the logistics chain in dairying, the raw milk producer (farmer) cannot even cover his costs. This is not the case only in our country, but it also happens in developed countries. Therefore, the state must allocate the money for premiums for milk and to provide subsidies in order to maintain this important branch of the economy.
The producer price of dairy factory "IMLEK" for a liter of UHT milk with 2.8% fat is 78 dinars. We see immediately that the purchase price of raw milk should be 78 x 0.48 = 37.44 dinars, yielding a difference of 2.7 dinars to the detriment of farmers - producers of raw milk (34.74 din.), who already operate with a loss of 6.26 dinars per liter of raw milk.
The costs of the producer of UHT milk, the dairy factory "IMLEK", except for the purchase price of 34.74 dinars, include additionally 12% for packaging and 34% for the purchase, distribution (transport) and processing of milk (fuel, wages, interest, contributions, etc.) of the producer price (78 din.). This means that the cost of packaging is 78 x 0.12 = 9.36 din. and of processing 78 x 0.34 = 26.42 din, yielding a total cost of 34.74 + 9.36 + 26.52 = 70.62 din. From this, it is clear that the dairy makes a profit of 7.38 dinars per liter of milk (9.46% of the producer price of 78 dinars).
It is known that the retail chains sell 1 liter of milk at the price of 95 dinars. Reducing the price for the amount of value-added tax (VAT), which is 8%, i.e. 7.6 dinars, the so-called wholesale price of 87.4 dinars is obtained. The dealer margin is easily determined as 95 - 87.4 = 7.6 din. At this price, the retailers receive an additional discount from the manufacturer of 3.8%.
Milk and dairy products, as well as all other products, are most expensive in small shops (mini markets), where the margin reaches as much as 25%, a quarter of the retail price. With the approved manufacturer's discount, the trading share is even higher.
From the analysis of logistics chain costs, it is clear that only the direct manufacturer of raw milk is without a profit, and even worse – he operates with a loss. It is not a good solution when some participants make profit, while others operate with losses. In this case, the manufacturer of raw milk cannot plan any expansion of capacities or business improvements. Therefore, on the basis of this analysis, it is necessary to consider and propose specific measures in order to implement an efficient and cost-effective logistics chain in the dairy industry.

5. MEASURES OF IMPROVEMENT OF LOGISTICS CHAINS [5]

Proposed measures to improve the business within the analyzed logistics chain in the dairy of the Zaječar region and to reduce the total cost of milk production, involve:

- changing the organizational structure of the existing logistics chain, which now has three main factors,
- the business of individual participants in the logistics chain, such as direct producers of raw milk (farms) and logistics company for the collection of raw milk and the distribution of finished goods to the retails.

Regarding the organizational structure of the existing logistics chain in the dairy of Zaječar region (Fig. 2), which has three main factors, it is suggested that the activities of collecting raw milk and distribution of processed milk and dairy products are separated from the dairy factories. This means that the dairy does not deal with these activities, but only with the development of the primary activity – production of high quality milk and dairy products.
These activities would be done by a specialized company that is dealing with the logistics activities for the dairy and grocery stores. This concept of relocating logistics services to specialized logistics executives (providers) is known as logistics outsourcing. Thus, the new organizational structure of the logistics chain would have four participants, one more than at present, and that is the logistics provider that would supply the raw milk to the dairy factories and distribute the finished product to the stores, or the final customer (Fig. 3).

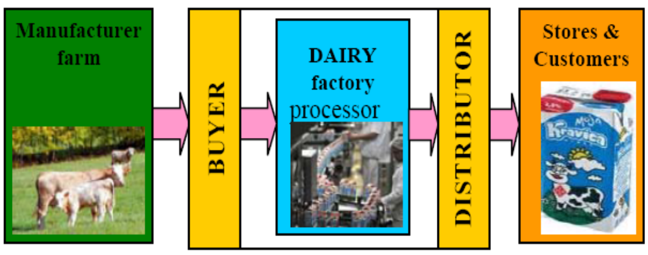

Fig. 3. The new logistics chain in the dairy

This does not mean that these two activities cannot be assigned to two separate providers, one that would only deal with the collection and supply of raw milk, and the other one only with the distribution of final products to stores and customers. In such a case, the logistic chain given in Fig. 2 would have 5 separate primary factors.

In the analysis of the milk production costs, it was clearly shown that the producer of raw milk within the logistics chain (farm) operates with losses. A possible solution in this case is premiums and subsidies that the government should provide to the producers to maintain and improve the production. However, in order to improve the production of raw milk, farmers should consider measures they can implement on their own in order to achieve better and cheaper production of raw milk.

One such measure is the transition from the system of keeping cows in barns onto a system of keeping cows freely on pasture during feeding, which is mostly used in Switzerland, Netherlands and other countries with developed livestock. This system has a number of advantages. It contributes to better health and longevity of cows, because they have healthier legs and udders, which are important in their cultivation and exploitation.

In principle, several different types of this system can be distinguished, firstly: barns with and without stalls. Common to both types is the separation of functions of lying and movement. Further differences between the types are in the way of handling manure and the use of bedding (with or without it).

Barns with stall area offer advantages over other systems of keeping cows. They offer each cow a properly sized and framed stall. They can be either with thin bedding or even without it. As with the systems of tied keeping, these barns include feeding aisle, stalls, enough room for feeding and bedding.

The feeding aisle in these barns has a width of about 4 m, because of the necessary barn volume depending on the number of cows and the need for mechanized food distribution. The aisle is mostly in the same plane level as the stall, although it does not have to be.

The means of mechanized cow feeding need to meet certain conditions, such as:

- optimal forming of feeding place,
- distribution of food with moderate labor and energy,
- rational individual distribution of concentrated food according to productivity.

In feeding cows, particularly dairy cows, it is most important to achieve low losses in nutrients and make a proper distribution of food to cows. Cow feeding is a very important job that takes up a very high percentage (30%) of the total amount of labor. In addition, quite significant quantities of food need to be delivered to cows. The annual food consumption per livestock unit is about 12 t.

Cows need to be fed from a specially defined area or place. Cows need to freely take food, i.e. food must be easily accessible to the cows. This is supported by the requirement that the food must be placed at 15 cm above the floor level, which defines the depth of the stall. From the middle of the space where they stand, cows need to be provided the minimum of 55 cm to both, left and right side. This requirement defines the width of stall.

During feeding, the cows scatter food significantly. If it comes to hay, the wastage can be as high as 20%. In addition to the loss of food, such dispersal may completely undermine the principle of functioning of manure if the liquid manure in used.

The food wastage is mainly caused by movements during feeding. These movements are different in feeding with hay (long food pieces) or silage (chopped food). The wastage is lower with chopped food because there is less movement.

With long food pieces, a cow takes a bite, steps back and then starts chewing. In this movement, significant food losses are made. With chopped food, cows rich deep into the food looking for pieces of food they prefer, especially if the food is of poor quality. This results in food scattering outside the space allocated for feeding.

A barn with this type of keeping and feeding of 30 cows is shown in Fig. 4 [5].

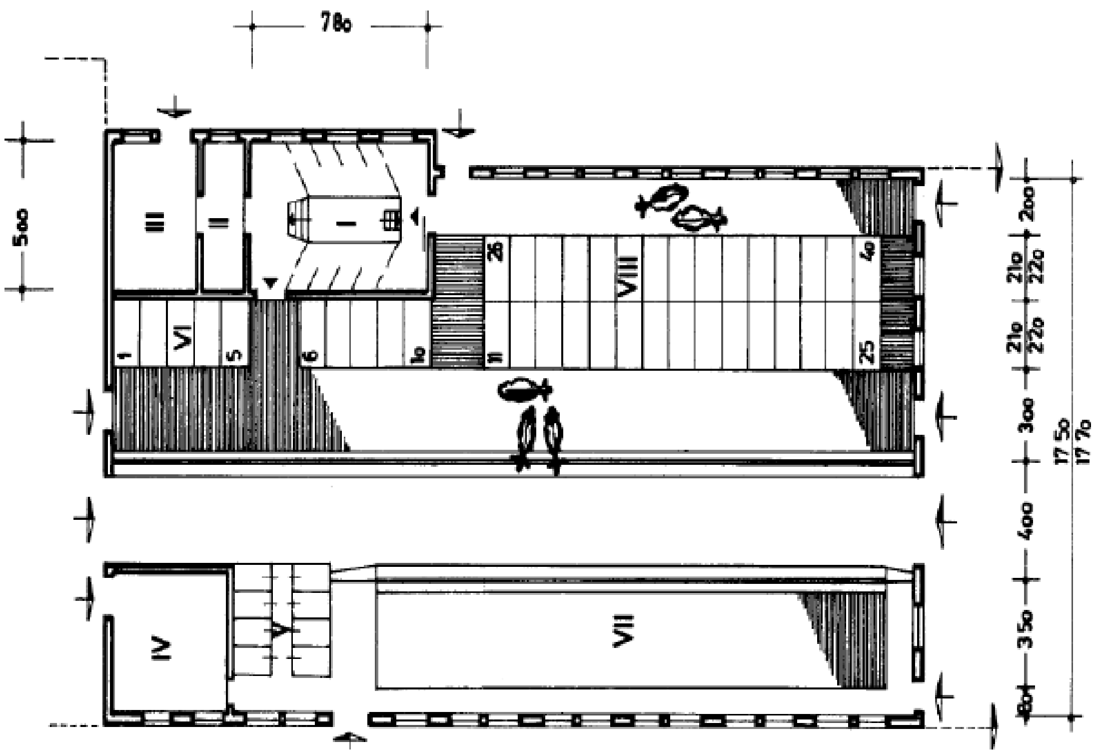

Fig. 4. The layout of a barn for 30 cows

Cow feeding can be individual or in groups.
With the tied system of keeping cows, feeding is individual. Food is given 2-3 times a day. Cows take food as it is served, which might have a positive impact on reducing wastage. Therefore, this type of feeding is suitable for all types of food, especially for concentrates. However, this type of feeding requires high investments in the construction of buildings and significant labor in feeding.
Feeding in groups enables food intake during the whole day at will (ad libitum) and requires sufficient amounts of food. Due to the constant presence of food in the stall, the cows may take it as they feel the need to. This type of feeding at will is suitable for forages or a complete meal.
The requests related to the mechanization in feeding are not significant. However, if feeding implies serving a complete meal, then the appropriate means of machinery must be applied so that such a meal can be prepared and distributed (a mixer-distributor trailer).
For the construction and equipment of such a barn (Fig. 4) some 5,000,000 dinars are needed. Due to bad parity prices of milk, feed and other costs, which have already been analyzed, such a facility can be built only with the help of a loan (interest of 6%, as a state subsidy) which would further burden the milk production by about 52,000 dinars per month, if the loan is to be paid back in 96 installments (8 years).
This investment would increase the number of cows to 30, which would increase the milk production to 195,000 liters per year. Other costs would be increased to 4,812,900 dinars, which is sustainable with the price of milk at 34 dinars and state incentive of 7 dinars per liter. Sustainability can only be jeopardized in case of irregular payments for milk and incentives.
The modern concept of economy implies that the supply of raw materials to manufacturing companies and the distribution of final products to the market are done by service companies, as proposed in this paper. These highly specialized companies will certainly perform their services more efficiently, economically and safely compared to the previous model used by the manufacturing companies.
In the presented case of the logistics chain organization in the dairy of Zaječar region (Fig. 3), it is implied that the existing purchase locations and the available equipment remain in the already developed transport network, while the optimization of route planning is to be done in order to minimize the costs of collecting raw milk.
In order to improve the process of distribution of final products to the market, it is planned to relocate the dispatching warehouse of dairy factories to the central distribution center, from where regional centers and retail stores will be supplied.

6. CONCLUSIONS

Based on the conducted analysis of the logistics chain in the dairy of Zaječar region, some general conclusions as well as some specific ones can be made:

- milk is a product of a great importance in the human nutrition, and it is also an important ingredient in everyday use
- the Zaječar region, with its mountainous landscape and favorable climate conditions, has good overall conditions and a tradition of cattle breeding and milk production,
- the logistics chain in the dairy of Zaječar region consists of three basic entities (farms, dairies and stores) and must make a profit in its business, which should be properly distributed to each participant according to the costs and labor expended,
- in this chain, the only participant without a profit is the raw milk producer, who actually operates with losses; this is not good for the development of animal husbandry in the Zaječar region,
- subsidies for milk and incentives for livestock, provided by the state, are important for the sustainability of this economy branch,
- proposed measures to improve the production of raw milk on farms will certainly contribute to more efficient and economical production and eliminate losses, thus making profit,
- the idea of assigning specialized companies the tasks of supplying the raw milk to the dairies and distribution of final products from the dairies should also contribute to higher quality operations within the chain,
- the logistics chain in the dairy industry should be constantly modernized to adapt to the market needs for assuring lasting economic security and stability in the production of milk and dairy products.

REFERENCES

[1] C. Lippolt, **"Lager-und Distributationssysteme"**, Vorlesung, IFL, Universitaet Karlsruhe, Karlsruhe, 2005.

[2] N. Barac, G. Milovanović, **"Strategijski menadžment logistike"**, Studenski kulturni centar Niš, Niš, 2006,

[3] M. Bukumirović, **"Urbana logistika"**, Mašinski fakultet Kraljevo, Univerzitet u Kragujevcu, Kraljevo, 2009.

[4] J. Vlajić, M. Vidović, M. Miljuš, **"Supply chains – defining and performances"**, The International Journal of TRANSPORT & LOGISTICS, vol. 09, 2005, pp. 85-112.

[5] S. Đorđević, **"Logistički lanac u mlekarstvu zaječarskog okruga"**, diplomski rad, Mašinski fakultet Univerziteta u Nišu, Niš, 2013,

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MODERN BUSINESS MODELS OF LOW-COST AIRLINES AS A COMPETITION FACTOR ON THE AIR-TRAFFIC MARKET

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Abstract

Two recessions, terrorism, oil prices, intense competition, financial restructuring and consolidation are transformed air traffic last ten years. In 2008, the global economic crisis had a major impact on all business entities, as well as the low-cost airlines that is forced to adapt their business models to new market demands. By the beginning of the global economic crisis, low-cost airlines have their operations were based on basic elements of a low-cost model. However, during the global economic crisis in order to survive the low-cost airlines have implemented elements of the business model of traditional airlines where they formed a hybrid business models. In this paper, the authors will pay special attention to the characteristics of low-cost, traditional and hybrid business model of airlines.

Keywords: *low-cost airlines, business model, hybrid model*

1. INTRODUCTION

The airline industry is a sector vital to the world`s transportation infrastructure and has been in the throes of a life-and-death struggle between the so-called network or original, older companies and relatively new low-cost airline [3]. When in 1978 the deregulation of the aviation market was introduced in the United States the way was opened for a new era of airline services. Airline companies were able to reorganize their management structure in order to survival and development. The South-West Airlines was the first company to start by providing a new form of services respectively less services but offering cheaper prices to its travelers. Becoming a successful competitor on the air transportation market in the US, South-West Airlines settled the basics for what nowadays is called the low-cost airline.

Also in Europe after deregulation in 1993, new airline services were set up by ways of a copy of the South-West Airlines model. This "Southwest's business model" has contributed to during the last few years; low-cost airlines become very important participants in European lines, with a market share that is growing. EasyJet and Ryanair were among the first to organize such a low-cost service structure. These two companies have been Europe's leading low-cost airlines, but the low-cost services have been increasing rapidly around the Europe.

As a starting point studies reviewed from Button & Vega [4], Francis et al. [8] and Van der Zwan [12] brought arguments to formulate a definition of low-cost airlines and classify them into several types, which gave more insight in the low-cost operation methods. Francis et al. also provided background for understanding the low-cost model and the development of its operations. Also Barret's article [2] provided a useful study about the low-cost model and the use of secondary airports. In his paper, Dobruszkes [6] gave more insight in the dimensions between the low-cost model and the selection of airports. Both also touched upon the subject of competition between full-service and low-cost airlines.

Many studies have analyzed the factors of successful operation of low-cost airlines in which they indicated that low-cost of model is the most important factor in their business [1, 7, 9]. The containment of costs is only one of the reasons for the success of a low-cost carrier.

The business model of low-cost airlines which ensured doing business with 50% less expenses compared to the business of traditional airlines proved to be unsustainable in new conditions. In order to keep their airline market share in medium-haul flights, traditional airlines launched new products, reorganised their business activities, decreased expenses and taxes for their services. This had an impact on low-cost airlines which had to adjust their business models to new changes on the turbulent market.

2. CHARACTERISTICS OF LOW-COST AIRLINE DEVELOPMENT

The emergence of low-cost air-companies is a consequence of air-traffic deregulation, globalisation as well as information technology development and application [12]. Increasing the number of low-cost airlines and their market share in Europe greatly influenced the development of air traffic. Due to the success of this model, low-cost airlines expanded their networks, increased the number of lines for providing services and thus increased the number of passengers. In ten years, they significantly transformed air market - changed travelling habits, opened new direct lines to European cities which were unavailable to traditional airlines, stimulated traditional airlines to change their business models and increased the number of passengers at secondary and regional airports. What is necessary to point out is the significant role of low-cost airlines as employers and generators of both economic growth and local community development owing to secondary and regional airports.

The foundation and development of low-cost airlines contributed to the development of new segments within the air market. That development is based on the increase in the number of passengers travelling between European cities. The choice of low-cost airlines to connect secondary airports enabled an optimal use of these airports as well as lower airport costs and decreased occurrence of flight delays.

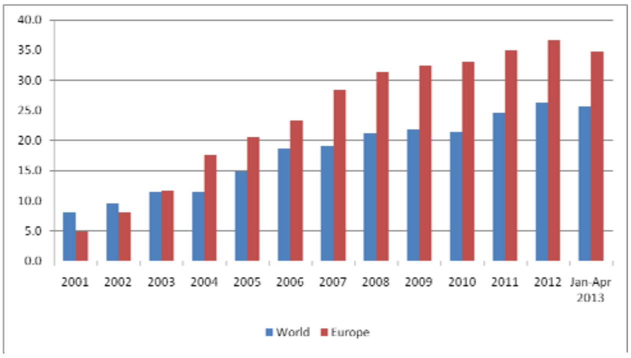

Fig. 1 Low-cost market share according to available seats (u %)

After being founded on the European market during the nineties of the previous century, low-cost airlines managed to increase their market share significantly, which forced traditional airlines to change and adjust their business models for medium-haul flights. The market share of low-cost airlines in the period from 2001 to 2012 increased from 4.9 to 36.6% in Europe and from 8.0 to 26.2% in the world. In the period from January to April 2013, they realised the market share of 25.6% in the world and 34.8% in Europe. However, their market share has no longer as significant growth as it was the case a few years ago.

3. BUSINESS MODELS OF TRADITIONAL AND LOW-COST AIRLINES

Increasing the number of low-cost airlines and their participation in the air traffic market was enabled by their ability to adapt to new conditions on the market. They applied different methods of decreasing expenses with the aim to offer lower prices. Their activities were based on the continual elimination of nonprofitable and the introduction of new profitable lines.

There is not an airline which in itself represents a low-cost airline. It is actually a model based on which an airline does business. Having that in mind, it is necessary to pay special attention to the low-cost business model consisting of the elements which enable the decrease of business expenses.
Business policy of low-cost airline is focused on maximum reduction of average costs, low cost of airline tickets and the maximum level of capacity utilization. In order to reduce average costs of business low-cost airlines are trying to maximize profits by applying a business model with the following characteristics:

- unification fleet (preferably by only one type of airplane);
- use of "point to point" traffic structure instead of complex network "hub and spokes";
- there is no free meals and drinks on the plane - all are charged;
- only one class of passengers with reduced comfort -the maximum number of seats in the cabin;
- there are no programs to increase loyalty - the only stimulation is low ticket price;
- higher productivity of low-cost airlines in relation to traditional;
- seats on the plane are with no markings;
- do not use services of global distribution system.

Table 1 - Diference between business model elements of low-cost and traditional airlines

Product features	Low cost airline	Traditional airline
Brand	One brand: low fare	Brand extensions: fare+service
Fares	Simplified: fare structure	Complex fare: structure+yield mgt
Distribution	Online and direct booking	Online, direct, travel agent
Check-in	Ticketless	Ticketless, IATA ticket contract
Airports	Secondary (mostly)	Primary
Connections	Point-to-point	Interlining, code share, global alliances
Class segmentation	One class (high density)	Two class (dilution of seating capacity)
Inflight	Pay for amenities	Complementary extras
Aircraft utilisation	Very high	Medium to high: union contracts
Turnaround time	25 min turnarounds	Low turnaround: congestion/labour
Product	One product: low fare	Multiple integrated products
Ancillary revenue	Advertising, on-board sales	Focus on the primary product
Aircraft	Single type: commonality	Multiple types: scheduling complexities
Seating	Small pitch, no assignment	Generous pitch, offers seat assignment
Customer service	Generally under performs	Full service, offers reliability
Operational activities	Focus on core (flying)	Extensions: e.g., maintenance, cargo

Table 1 shows the main differences between the business model elements of traditional and low-cost airlines which contribute to the variance in business expenses. The greatest advantage of low-cost airlines is seen in using point-to-point system. Short-haul direct line flights increase the degree of using airplanes which eliminates the need for additional services necessary on long-haul flights. This system decreases the possibility of losing luggage to a minimum.

Lower working costs greatly contribute to decreasing expenses of low-cost airlines in relation to the traditional ones. According to some research, the income of a pilot is on average 28% lower with low-cost airlines than with the traditional ones although their working hours, i.e. flight length is 25% longer.

Low-cost airlines most often use secondary airports characterised by a small capacity utilisation rate. Secondary and regional airports attract attention of these companies with lower airport charges. Using secondary airports also means providing services in a shorter period, i.e. in 25 minutes on average. In this way, maximum level of plane capacity utilisation is ensured.

One of the most important factors which influences the decrease of expenses relates to the users of transport service. Low-cost airlines do not provide free additional services such as food and drinks. The maximum allowed weight of luggage is lower than the weight allowed by traditional airlines.

Reducing expenses connected to maintenance and managing is achieved by the use of smaller planes. Low-cost airlines use new types of planes which are more economic and which incur lower maintenance costs.

They most often offer only one class without the possibility of booking a seat which in turn decreases the time necessary for both boarding a plane and spending the time on the ground. One more advantage can be seen in checking-in which is simpler since, by abolishing tickets, you only need to turn up at the desk with the number of reservation. About 97% of the overall sale of low-cost airline tickets is done via the Internet. In this way, low-cost airlines avoid selling tickets through tourist agencies and GDS which charge commission for the sale.

4. HYBRID BUSINESS MODEL OF LOW-COST AIRLINE

The basic business models of low-cost airlines are to operate with lowest possible costs. Distribution tickets through indirect channels, frequent flyer programs, partnerships and other measures aimed at increasing revenues are thus not allowed for with pure low-cost model because these factors increase costs. In recent years, after economic crises, some low-cost airlines have changed their business model and started adding elements of model traditional airlines.

Many traditional airlines cut their services and decrease costs to address more price-sensitive passengers, i.e. people that travel for vocation. At the same time, in search of higher revenue, low-cost airlines started addressing passengers that were willing and able to pay, i.e. corporate consumers. Those passengers require high quality services, higher on-time performance, better flight connections and centrally located airports. The hybrid model was created.

A hybrid model on the market of air-traffic can be defined as model that combine low operational costs with various fare services, codeshare agreements, connect flights and enhanced distribution processes that, in most cases, allow bookings via GDS. The idea of offering different bundled services is very important element of hybrid model. Unlike the LCA basic model, the aircraft of such airlines offer more leg space; the seats are covered in leather; the cabin light has more quality, two passenger classes are offered at extra charge, entertainment offer is larger, use FF program, food and beverages are available at extra charge or part of ticket price [10]. In addition to all this, many hybrid airlines as Southwest, jetBlue, Norwegian, Vueling, Pegasusus and Germanwings offer connecting flights.

Using GDS as distribution channel and entering into interline and codeshare partnerships with other airlines are two important factors for hybrid airlines to gain additional sales and revenues. About 61% of all low-cost and hybrid airlines distribute their tickets using at least one GDS.

The trend towards codesharing low-cost and hybrid airlines has increased significantly: While only six low-cost and hybrid airlines had codeshare agreements with other airlines in September 2003 (Flybe, SkyEurope, Virgin Blue, Virgin Express, Volareand Zip Air), exactly ten years later, the number has increased by more than fourfold to up to 26. Despite the fact that the number of low-cost and hybrid airlines on the market has approximately doubled over the last decade, we can still observe a relative increase of codesharing low-cost and hybrid airlines by about 16% from 13% (2003) to almost 29% (2013).

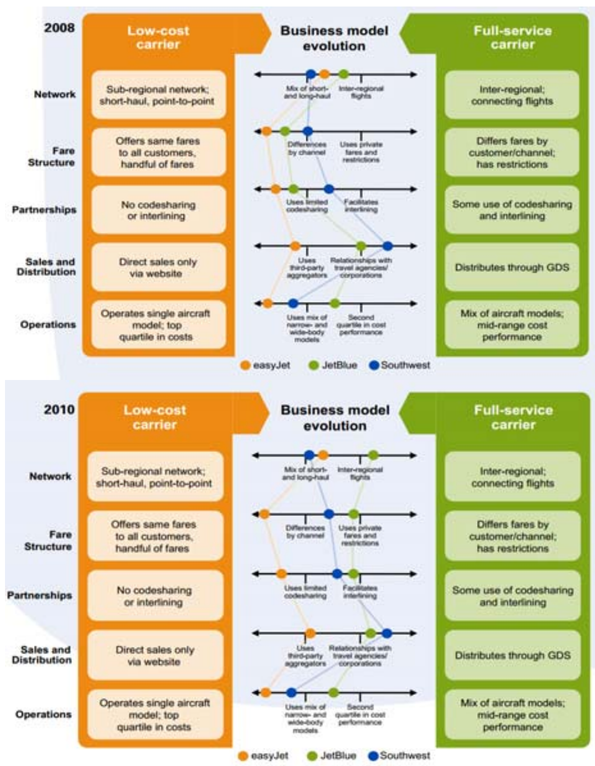

Fig. 2 Features of the Hybrid model in the period 2008-2010

Figure 2 shows the evolution of a hybrid model on the example of three airlines (EasyJet, Jetblue and Southwest) in the period from 2008 to 2010. In the observed period, the greatest change in the business model was related to the introduction of price discrimination. Apart from the application of price discrimination based on the channel sale, the observed airlines started using discriminatory prices based on certain limitations as well. The greatest element changes of the business model were noted with the low-cost airline Jetblue and they related to the network, price formation, partnership and choice of channel sale. Changes in partnership and choice of channel sale were noted within the business model of EasyJet.

Southwest was one of the first airlines to apply this kind of a business model. It is the oldest and most successful airline in the world. Like traditional airlines, it also offers free meals and drinks on its all flights, does not use the system ‘point to point’, uses services of global distributive systems, and employees’ income is similar to the income of those working at traditional airlines in the USA. It provides transport services on short-haul as well as long-haul flights which is characteristic of traditional airlines. In the period from 2008 to 2010, the most important changes in its business model related to the criteria of discriminatory price application, i.e. apart from applying discriminatory prices based on channel sale, it started applying discriminatory prices based on the quality of service and limitations as well.

CONCLUSION

The development of low-cost airlines is the result of air traffic deregulation and liberalisation, globalisation as well as the development and application of modern techniques and technologies. In terms of possible further development of air traffic, the application of contemporary techniques and technologies in this branch of transport system will foster its already important position in the transport of both tourists and business people.

Two recessions, oil price increase and competition growth yielded the transformation of low-cost airline business models, i.e. the formation of a hybrid model. The hybrid model represents a combination of low-cost airline elements which contribute to the decrease of expenses and traditional airline elements which relate to services, flexibility and line structure. At present, this business model may be one of the most present ones on the air traffic market. It is characterised by high quality standards and additional service charges. Travelers who travel for business reasons use airlines which have implemented the stated model. As representative examples of this model, JetBlue and Southwest from the USA as well as EasyJet from Europe stand out.

REFERENCES

[1] F. Alamdari, and S. Fagan, “Impact of the adherence to the original low-cost model on the profitability of low-cost airlines”, in Transport Reviews, Volume 25, Issue 3, 2005, pp. 377–392.

[2] D. Barret, “The Sustainability of the Ryanair model”, in International Journal of Transport Management, Volume 2, Issue 2, 2004, pp 89-98.

[3] B. Biederman, J. Lai, J. Laitamaki, H. Messerli, P. Nyheim and S. Plog, Travel and tourism: an industry primer, New Jersey: Pearson education Ltd, 2008.

[4] J. Button, and H. Vega, “The Effects of Air Transportation on the Movement of Labor”, in GeoJournal, Volume 71, Issue 1, 2008, pp 67-81.

[5] Y. Darmaputra, An Application of Heuristic Route Search Techniques for a Scalable Flight Search System, European master thesis, Vienna: University of Technology, 2008.

[6] F. Dobruszkes, “An analysis of European low-cost airlines and their networks” in Journal of Transport Geography, Volume 14, Issue 4, 2006, pp 249-264.

[7] R. Doganis, The Airline Business, London: Routledge, 2006.

[8] G. Francis, I. Humphreys, S. Ison, and M. Aicken, „Where next for low-cost airlines: A spatial and temporal comparative study”, in Journal of Transport Geography, Volume 14, Issue 2, 2006, pp 83-94.

[9] M. Franke, “Competition between network carriers and low-cost carriers retreat battle or breakthrough to a new level of efficiency?”, in Journal of Air Transport Management , Volume 10, Issue 1, 2004, pp. 15–21.

[10] W. Kurt, “A review of regional growth and sustainability in the LCC market”, in Proceedings of the 22nd annual Geneva International aviation forum, Aircraft Finance & Commercial Aviation, MBA Workshop, 2008.

[11] F. O'Connell, and G. Williams, “Passengers' perception of low cost airlines and full service carriers: A case study involving Ryanair, Aer Lingus, Air Asia and Malaysia Airlines”, in Air Transport Management 11, 2005, pp. 259-272.

[12] J. Petrović, Ključni faktori uspešnog poslovanja low-cost avio-kompanija, Industrija Vol 39, No 3, 2011, str. 109-125.

[13] J. Van der Zwan, Low-cost carriers – Europa, Thesis at Utrecht University, Human Geography and Planning, 2006.

[14] D. Zdravković, and J. Petrović, Diskriminacija cenama na tržištu avio-saobraćaja, Niš: Prirodno-matematički fakultet, 2013 (monografija nacionalnog značaja).

[15] http:// centreforaviation.com

[16] http://www.elfaa.com/Statistics_December2013.pdf

[17] http://www.sabreairlinesolutions.com

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THE MODERN TECHNOLOGY PACKAGING AND OPPORTUNITIES FOR ACTIVE PROMOTION OF PRODUCTS

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Abstract

Aluminum is a metal that is increasingly used in the packaging industry and packaging but also a good opportunity for effective advertising and product promotion. Processing technologies for aluminum plastic deformation provide superior packages that meet the most rigorous demands in the food, pharmaceutical, chemical, etc.. industries. This is about mass production and very little material pending charges that offers the possibility of multiple recycling. On the other hand, today's products for the general consumer can not be imagined without the aggressive advertising that has a major impact on the customer. Modern graphics techniques for printing of images and different surfaces offer great opportunities that manufacturers widely used in the promotion and sale of their products.

Key words: *Can, Deep drawing, Packaging, Graphical design and printing*

1. INTRODUCTION

Large investments in research and primary aluminum processing and especially in the production of finished aluminum products has become an industry on which to identify the most powerful of the world economy today. Increasingly can hear the data, aluminum consumption per capita, the share of aluminum per car, the amount of aluminum in the construction industry, or in everyday use, and so on. Of course that all this contribute to the benefits of aluminum to get the finest products now meet the most stringent demands of the market, i.e. the customer [1].

Industrial packaging of food products, fast food delivery to the customer with an unchanged performance today is impracticable without the use of various types of foil, cans, wrappers, and curlers and all on the basis of aluminum semi-finished products. Today, most current industry packaging based on aluminum saves energy as in the production and transportation of products. Weight of the beverage packaging in cans, for example. 0.331 is only 5% by weight of the beverage while in the case of glass packaging that is almost identical. Cans are promoted as packing material impervious to light, the fastest cools, simply open, best-kept flavor of drinks, but also as the only packaging that is 100% recyclable which significantly contributes to the preservation of the environment [2].

Fig.1 Modern packaging and design

2 TECHNOLOGY PRODUCTION OF CANS

Infinite continuous-rolled strip aluminum sheet is introduced in a combined tool for blanking workpiece of an agent that is immediately subjected to deep drawing. This process of refining metal requires very tight tolerances of thickness material with a special coating layer to the coefficient of friction to a minimum $\mu = 0.08$.
The tin plate strip is unwound, its surface coated with a thin film of lubricant and the strip continuously conveyed to the deep-drawing press. The full technological capacity is obtained almost unbelievable productivity of 1,700 pieces per minute, or 650 million per year. At first a blank is cut out (D = 164mm, s=0.25mm) at each individual tool of the press; the drawing ram then presses this blank through the draw ring to form a cup with diameter 100mm and height 41mm (fig.2). The tool is made up of 9 to 10 individual tools which are arranged next to each other and behind each other.

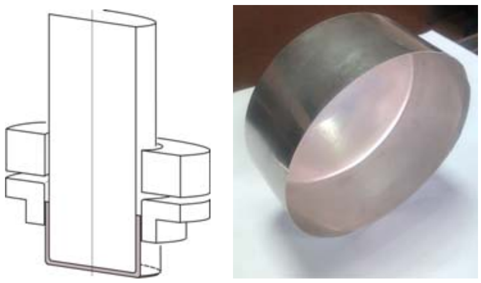

Fig. 2 Finished part after deep drawing process

The critical stress $\sigma_{\rho 1max}$ is a normal stress which occurs in the radial direction, where the workpiece material of an elongation suffers [3]. The maximum stress in the first operation of drawing occurs at the moment of full coverage rounded edges of tools upon which plastic deformation takes place only through the radius of the matrix.

$$\sigma_{\rho i \max} = \left(1{,}1 K_{sr}\, \ell n \frac{R_s}{R} + \frac{\mu F_d}{\pi R_s s} + K_{sr} \frac{s}{2r_M + s} \right)(1 + 1{,}6\,\mu)$$

where is:

K_{sr} – mean true stress of material workpiece [N/mm^2],
R_s – radius of workpiece at the moment maximal force,
R – radius of deep drawing element,
μ - coefficient of friction,
F_d – force at blank holder,
r_M – radius on die matrix

The cup is held by a pressure of blank holder to prevent puckers with which the flow of the manufacturing process it is not possible.

$$p_d = 0{,}25\left[\left(\frac{D_0}{d_i} - 1 \right)^2 + \frac{d_i}{200s} \right] \sigma_m$$

The cup is conveyed to the wall-ironing tool from the top (fig.2). The ram first pushes it through the redraw ring to reduce its diameter 65mm to the punch diameter whilst retaining the sheet thickness constant at 0.25mm.

There is a gap between the punch and the wall-ironing rings 1 to 4 immediately after the redraw ring where the wall thickness of the can is reduced by "ironing" the tin plate (s=0.15mm) and consequently lengthening the can to 170mm.

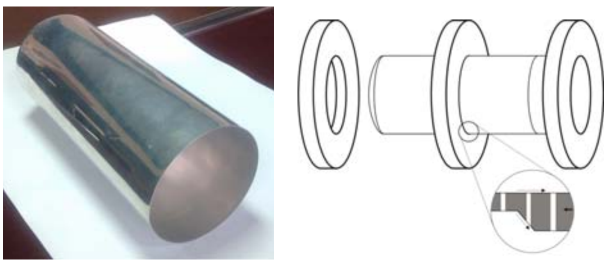

Fig. 3 Ironing the can wall

For a typical stress ironing sets the stress balance in the axial direction. Especially considering the conical part of the tool where there is a change in the thickness of the cylindrical wall and the output section with reduced wall thickness cans:

$$(\sigma_z + d\sigma_z)\left((x+dx)^2 - r_2^2\right)\pi - \sigma_z\left(x^2 - r_2^2\right)\pi -$$
$$-2\pi r_2 \tau_\beta \frac{dx}{tg\alpha} + \tau_\alpha \cdot \cos\alpha \frac{dx}{\sin\alpha} 2\pi x = 0$$

at the entrance of the conical part of the focus of deformation normal tensile σ_z stress has a value of 0 to make his exit receive the maximum value σ_p:

$$\sigma_p = 1.155 K_{sr} \frac{b}{b-1}\left[1 - \left(\frac{A_i}{A_{i-1}} \right)^{b-1} \right]$$

where is: b - coefficient which depend matrix angle and coefficent of friction μ.

A_{i-1}, A_i - ring area of cross section at wall of can before and after reduction of thickness.

How to can have the necessary strength during transport, process filling and sealing, it is necessary that the bottom of the can get a much higher stiffness of the wall. This is achieved by forming the bottom where it gets a characteristic profile (fig. 4) deep drawing technology in future operations.

Fig. 4 Increased stiffnes on bottom of the can

At the end of this stroke, the punch with the can comes into contact with the base panelling tool and the can base is formed. When the ram is withdrawn, the can is removed from the punch by a stripper and conveyed out of the machine via an unloader belt. All lubricants from a metal forming process must be removed by the process of washing. The wall-ironing lubricant used in the can forming process is removed prior to coating the can internally and externally. The cans are transported to the washer on a wide belt and conveyed through several washing chambers upside down.

In this way the outside of the can is rinsed with tap water supplied through the jets located at the top and the inside of the can by the jets located at the bottom. Immediately downstream of the washing unit, the can is dried with dry air at a temperature of approx. 200° in the drying oven.

3 GRAPHICAL DESIGN AND PRINTING OUTSIDE OF CAN

From the above to do a superior product like a can is not easy because this is a high quality, high productivity, very cheap and reliable products. By metal forming technology we meet the basic requirements of a customer who for many years considered conventional and commonplace. It remains the most sensitive part, so as fast as possible to reach the customer and his confidence. Of course that the main role is played by the contents of the can, its quality and price [4]. But a single element, all of which are known to be crucial, and it is a visual effect (fig.5). Market conditions, fierce competition, the modern way of life all the elements and how these affect the finished product. The cans are coated on the outside as protection against corrosion and in order to apply a decorative design. White, gold or transparent coating as well as aluminium-coloured coating can be used according to customer specifications. Nowdays the coatings are water-based.

Fig.5 Sample of modern graphic design

The cans are spaced by an intake wheel and drawn on to the coating mandrel of the mandrel wheel by means of a vacuum. They are then set in rotation around their own axis by the rotation belt. The coating film on the coater cylinder is then transferred to the cans positioned on the rotating coating mandrels (fig. 6). The coated cans are then blown off the coating mandrels and transported to the drying oven on a magnetic conveyor belt. The coating is pumped from a coating container to the engraved cylinder which transfers the appropriate quantity to the rubber-coated coating cylinder from where it is transferred to the cans (fig. 6).

Fig. 6 Generaly principal painting of can and technical solution

Options for printing the outer surface of the cans today are very large. It is a very accurate and precise technology that pays a lot of attention. Modern systems work with a variety of colors which are successively applied to the different cylinders [5]. He shows the accuracy and precision guidance the can through a system of rectilinear and rotary conveyer.

The externally coated cans are spaced by the intake wheel, as in the coating machine, and drawn on to the mandrel wheel mandrels by means of a vacuum. The mandrels are set in rotation around their own axis by a rotation belt.

The can positioned on the mandrel rolls synchronously over the blanket and absorbs the complete decorative design with all the ink colors from it. The individual colors are transferred by the inking units to the blankets via ink boxes, various rollers and the cliche cylinder with mounted printing plate. The high pressure printing cliches only absorb ink in the parts in which they are raised. Therefore each inking unit presses one color ink onto the rubber blanket. Prior to the can coming into contact with the blanket, all the ink colors are on the rubber blanket entering the inking section; here the printed image is mirror-inverted. The inks are transferred to the can by rolling the can over the rubber blanket and the printed image becomes positive. The printed cans are then blown off the mandrels and conveyed to the drying oven by a magnetic conveyer belt.

4 MANAGING THE PROCESS

The technology with the parameters of the process aims to illustrate the capabilities of a modern and complex technology that is now widely applied. Almost unbelievable data only indicates the kind of level is brought this process that not provides the opportunity for error. Design process and development afford to a main team with extensive experience of its proven results and achievements distributed to the lowest level of implementation [6].

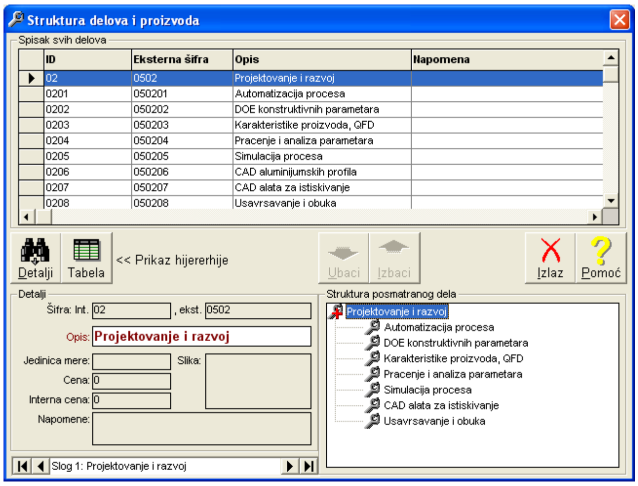

Fig. 7 Programing manag the process of design and development

A very small number of employees and teamwork come to the fore in an modern automated system. In the implementation phase of production just follow the given parameters via control charts where they can see their current trend and deviation indicates timely intervention, correction or the possible replacement of the critical elements [7].

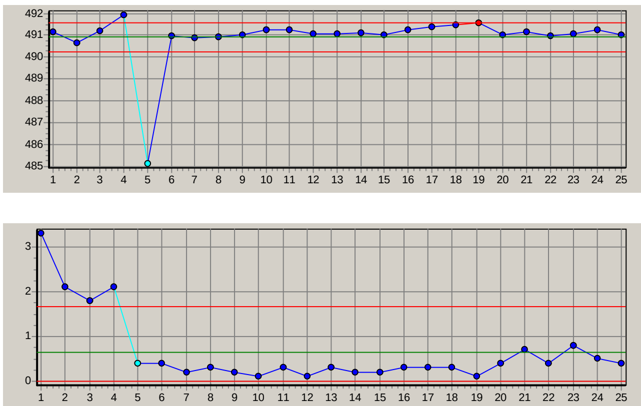

Fig.8 SPC control chart for production parameters

The generated problems, daily reports and data production is carefully analyzed in order to keep the system in the specified control limits. It goes as far as to the corrections, replacing the necessary tools and interventions to individual element operate at a central workplace to be corrected and returned tool and assemble, but with one goal, to the lower losses and empty work strokes.

5. CONCLUSION

This projected production system shows great robustness and resilience to disturbances that are always present. Its flexibility on the one hand and the speed of response to disturbance are designed exclusively for mass production. Each team only knows his job, which is a very narrow scope of knowledge and skills that are acquired and grow in a very long time. The fact that for Europe only in one place performs repair and correction tools, or teams of well laborer trained only specialize in quick change and assemble tools and much more telling. Design process and development is centralized and located in the United States. With above mentioned productivity losses delay in time must be minimal. Orientation to the market is through the follow of the latest trends and design effects that can be detected on the cover of the can. Customer of this product begins to appropriate, and treated as an integral part of his daily food basket. Viewed from the perspective of business success that was the goal, to create a product that in the long time generate large profits in the global market.

REFERENCES

[1] Majstorović, V, Quality Management (on Serbian), Mechanical Engineering Faculty, Beograd, 2001

[2] Eikelenberg N., Kok I., Tempelman E., The role of product design in closing material loops, Proceedings of the 3th international Symposium on Environmentally Conscious Design and Inverse Manufacturing, Tokyo, Japan, December 8-11, 2003, pp. 605-610.

[3] Luis Fernando Folle, Sergio Eglan Silveira Netto, Lirio Schaeffer, Analysis of the manufacturing process of beverage cans using aluminum alloy, Journal of material processing technology, No. 205, 2008, pp. 347-352

[4] Ranđelović S, The new product development for mass customization on the base integrated process model" Proceedings, 3rd International Conference on MCP - CE, pp. 149-153, Palic – Novi Sad, Serbia, June 3 - 6, 2008.

[5] Stoiljković V, Mlosavljević P, Ranđelović S, Industrijski menadžment Praktikum, Mašinski fakultet u Nišu, Niš 2010.

[6] Ranđelović S, Denić B, Mladenović S, Đorđević G, Aluminium industry, chance for mass customization and advancement of small enterprises, Proceedings, 4th International Conference MCP – CE, pp. 130 - 134, September 22-24, Novi Sad, Serbia. 2010.

[7] Ross Ph J., Taguchi Techniques for Quality Engineering, McGraw-Hill, 1996.

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OPTIMIZATION OF THE POWERTRAIN MANIPULATOR MECHANISMS WITH HYDROSTATIC DRIVE

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Abstract

This paper defines a criteria for optimal synthesis of powertrains bar linkages of manipulators that are used in materials handling equipment. The powertrain mechanisms for the actuators have two-way hydraulic cylinders powered by hydraulic pump with regulation of flow by criteria of constant hydraulic power. Hydraulic pump signal regulation is the pressure change in the actuators of the powertrain mechanisms, which occurs by change of the mechanism load. The objective function of optimal synthesis of powertrains mechanism is the minimum duration of the cycle of operation of manipulators.

Key words: hydrostatic systems, regulation

1. INTRODUCTION

The manipulators of a mobile machinery and vehicles are are derived as a multimember lever kinematic chains, plane or spatial configuration (Fig. 1). The members of chain are connected to rotary or translatory fifth class joints. The last member in the chain of the manipulator can be different tools with which can be perform a variety of cyclically functions of intermittent transport, with a certain number of operations. Manipulators reinforce the drive mechanisms that build the kinematic pairs of chain linked with hydrostatic actuators - double acting hydraulic cylinders.

For the synthesis of drive mechanism of manipulator of mobile machinery and vehicles it is developed multicriteria optimization method [1]. In this paper, the optimization criterion is defined as referring to the duration of the manipulative task.

Transformation parameters of the general model of the manipulators drive mechanism are size parameters of the hydrocilinders deteremined by set of sizes:

$$C_{ti} = \{ d_{i1}, d_{i2}, n_{ci} \} \tag{1}$$

where is: d_{i1},d_{i2} - piston and rod diameter of the hydrocilinder, n_{ci} - number of hydrocilinders of drive mechanism.

Transmission parameters of the general model of the drive mechanism of manipulators are determind by set of sizes:

$$C_{pi} = \{ \vec{a}_i, \vec{b}_i, c_{ip}, c_{ik} \} \tag{2}$$

where is: $\vec{a}_i, \vec{b}_i$ - position vector of the center of the joints where hydrocilinders linked to members of the kinematic pairs of the drive mechanism, c_{ip} - minimum length of hydrocilinder when rod is fully recessed; c_{ik} - maximum length of hydrocilinder when rod is fully drawn.

The parameters of a hydrostatic power N_h of hydropump are: flow Q and pressure p as input parameters, hydrocilinder of manipulator drive mechanism, with its transformational functions of flow i_{ti}^Q and pressure i_{ti}^p turns into output mechanical parameters of power: translational speed v_{ci} and force F_{ci} of the hydrocilinder, wherein:

$$i_{ti}^p = \frac{1}{i_{ti}^Q} = \begin{cases} n_{ci} \dfrac{d_{1i}^2 \pi}{4} & \forall \quad v_{ci} \geq 0 \\ n_{ci} \dfrac{\left(d_{1i}^2 - d_{2i}^2\right)\pi}{4} & \forall \quad v_{ci} \leq 0 \end{cases} \tag{3}$$

The mechanical parameters of hydrocilinder power, the speed v_{ci} and force F_{ci}, the drive mechanism further with own kinematic $i_{ri}^{\dot{\theta}}$ and mechanical i_{ri}^M transfer function, converts to the output values: the angular velocity $\dot{\theta}_i$ and the torque M_{ci} in the joint of manipulators kinematic chain, where is:

$$i_{ti}^M = \frac{1}{i_{ti}^{\dot{\theta}}} = \frac{a_i b_i}{c_i} \sin \gamma_i \tag{4}$$

$$\gamma_1 = \arccos \frac{a_i^2 + b_i^2 - c_i^2}{2 a_i b_i} \tag{5}$$

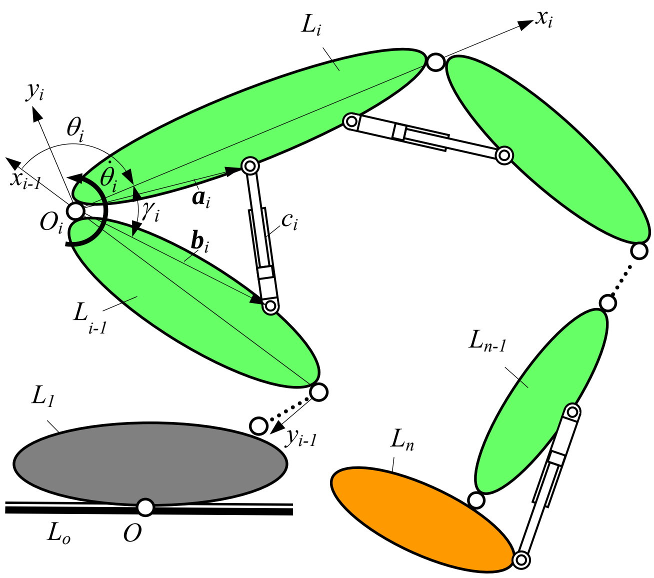

Fig. 1 General model of the manipulator kinematic chain

Where is: c_i - the current length of drive mechanism hydrocilinder.

2. ANALYSIS

The duration of manipulative task is one of the basic parameters of performance. This is indicated by the equation that defines the technical performance of machines or vehicles:

$$U_t = \frac{V}{t_c} \tag{6}$$

where is: U_t - performance of machine, V - volume or capacity of manipulator tools, t_c - duration of manipulative task.

According to the above equation, for the same tool, the manipulator will achieve maximum performance for minimum duration of the cycle. To be perceived time criterion set as criterion of powertrains optimization, first it was analyzed the influence of the mechanisms parameters on the duration of manipulative task.

The duration of the manipulative task is equal to the sum of the duration of individual operation cycle:

$$t_c = \sum_{j=1}^{n_o} t_j \tag{7}$$

wherein the duration of the operation determined by equation:

$$t_j = \int_{\theta_{ij1}}^{\theta_{ij4}} \frac{d\theta_i}{\dot{\theta}_{ij}} = \int_{\theta_{ij1}}^{\theta_{ij4}} \frac{d\theta_i}{Q\; i_{ti}^{Q}\; i_{ri}^{\dot{\theta}}} \tag{8}$$

where is : n_o - number of the operations of manipulative task; θ_{ij1}, θ_{ij4} - the initial and final generalized coordinates of the member L_i of kinematic chain of the machine that holds the operation j of cycle, $\dot{\theta}_{ij}$ - angular velocity of the member in carrying out the operation j; $i_{ti}^{Q}, i_{ri}^{\dot{\theta}}$ - transformation function of the flow and kinematic transfer function of the drive mechanism of a member who is the holder of operation j, Q – flow of the drive mechanism actuator during operation j.

The transformation function of flow and the kinematic transfer function of the drive mechanism are known for a particular position θ_i of executive member of the mechanism that performs the operation. However, according to equation 8, to determine the time of operation, it is necessary to define and change the flow of the mechanism actuator during the operation.

The flow is one of the parameters of hydrostatic power of hydropump, which, among other things, depends on the chosen conceptual design of the hydrostatic power transmission of machines or vehicles.

The hydrostatic drive systems of mobile machines and vehicles have evolved, and continue to develop in the direction of optimal energy use of the engine under different operating conditions, with the possibility of simultaneously performance, at least, two operations cycle. The above requirements are achieved with hydropump of hydrostatic system with collective regulation of power and with regulator of ideal hyperbolic characteristics.

These hydropump 3 (Fig. 2) in the case have two same hydropumps that through integrated power splitter 3.12, in the form of meshed gears and flexible couplings 2 drive by diesel engines 1. The regulation of hydropumps is volumetric. A signal of regulation is change of the sum of the pressures (p1+p2) in the pressure port of hydropump. It is caused by the same or different workloads of kinematic chain members of manipulators that drive by hydrocilindres [2] [3] [4].

The scope of hydropump regulation, determined by pressures of start regulation $(p_1+p_2)_p$ and pressure of end regulation $(p_1+p_2)_k$, the flow Q of hydropump is the same and with hyperbolic dependency it is changed by the sum of the pressures (p_1+p_2) at constant hydraulic power (Fig. 2a):

$$N_h = \frac{(p_1+p_2)_p Q_p}{60 \cdot \eta_{pu}} = \frac{(p_1+p_2)Q}{60 \cdot \eta_{pu}} = \frac{(p_1+p_2)_k Q_k}{60 \cdot \eta_{pu}} = const \tag{9}$$

Changing the force of the spring 3.5 regulator changes the start pressure $p_p=(p_1+p_2)_p$ of regulation (points P_1,P_2), and thus changes and hydraulic power (N_{h1}, N_{h2}) covered by the regulation. In doing so, the pressure $p_k=(p_1+p_2)_k$ at the end of regulation (points K_1,K_2) remains the same.

Further analysis of the influence of parameters on the drive mechanisms during manipulative task is performed under the following conditions: (a) hydrostatic power of drive systems N_h is known, (b) Hidropump of hydrostatic power transmission systems with an sumary power regulation and with regulator of ideal hyperbolic characteristics.

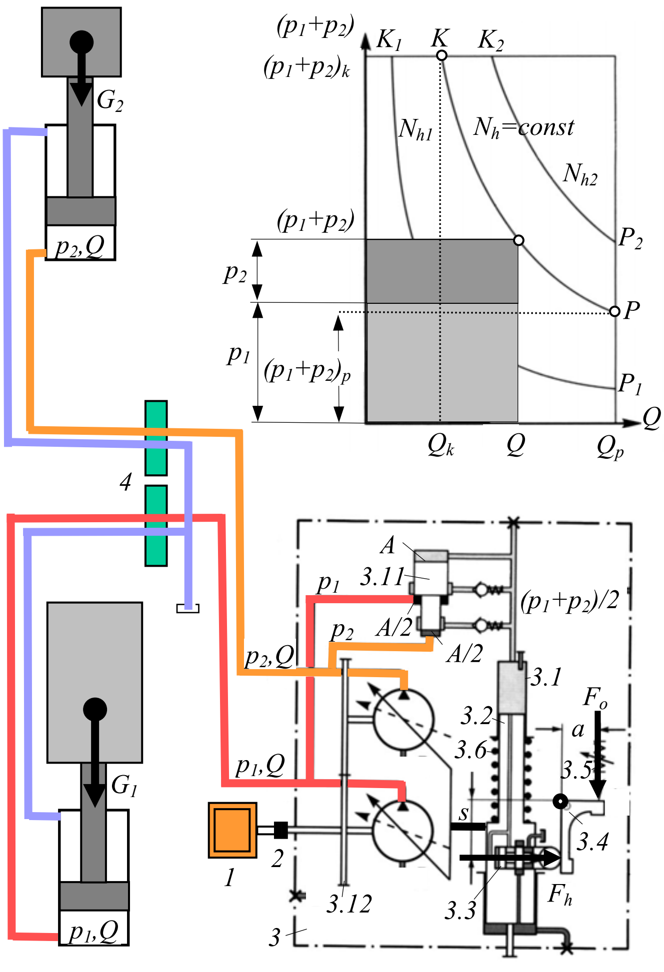

Fig.2 Hydropump with summary power regulation and with regulator of ideal hyperbolic characteristics [5]

For the chosen regulation of hydrostatic power parameters dependence of flow Q of pressure (Fig. 2a) is determined by the equation:

$$Q = \begin{cases} \dfrac{N_h}{(p_1 + p_2)_k} & \forall \ (p_1 + p_2) = (p_1 + p_2)_k \\ \dfrac{N_h}{p_1 + p_2} & \forall \ (p_1 + p_2)_p \le (p_1 + p_2) \le (p_1 + p_2)_k \\ \dfrac{N_h}{(p_1 + p_2)_p} & \forall \ 0 \le (p_1 + p_2) \le (p_1 + p_2)_p \end{cases} \quad (10)$$

where is: p_1,p_2 - pressures in the hydrocilinders of drive mechanisms with which is simultaneously perform the operation of manipulative task.

By substituting equation 10 into equation 8, the duration of the operation is obtained, that depends on the pressures that prevailing in hydrocilinders, apropos, on movement resistance of the kinematic chain members of manipulator and transformation and transmission paramaters manipulator drive mechanism.

Influence of the driving mechanisms parameters on the pressure in the hydrocylinders is shown by results of the obtained analysis. The model of hydraulic excavators with the same kinematic chain manipulators bucket (volume 0.6 m3), with two variants, A and B, drivetrains with the same transformation and different transmission parameters was used. It is simulated the same manipulative task. Results of the analysis is given in the form of a diagram (Fig.3a, b, c) they shows that the change of pressure in the actuators, at same movement resistance of the operation cycle, dependent on the parameters of the drive mechanism.

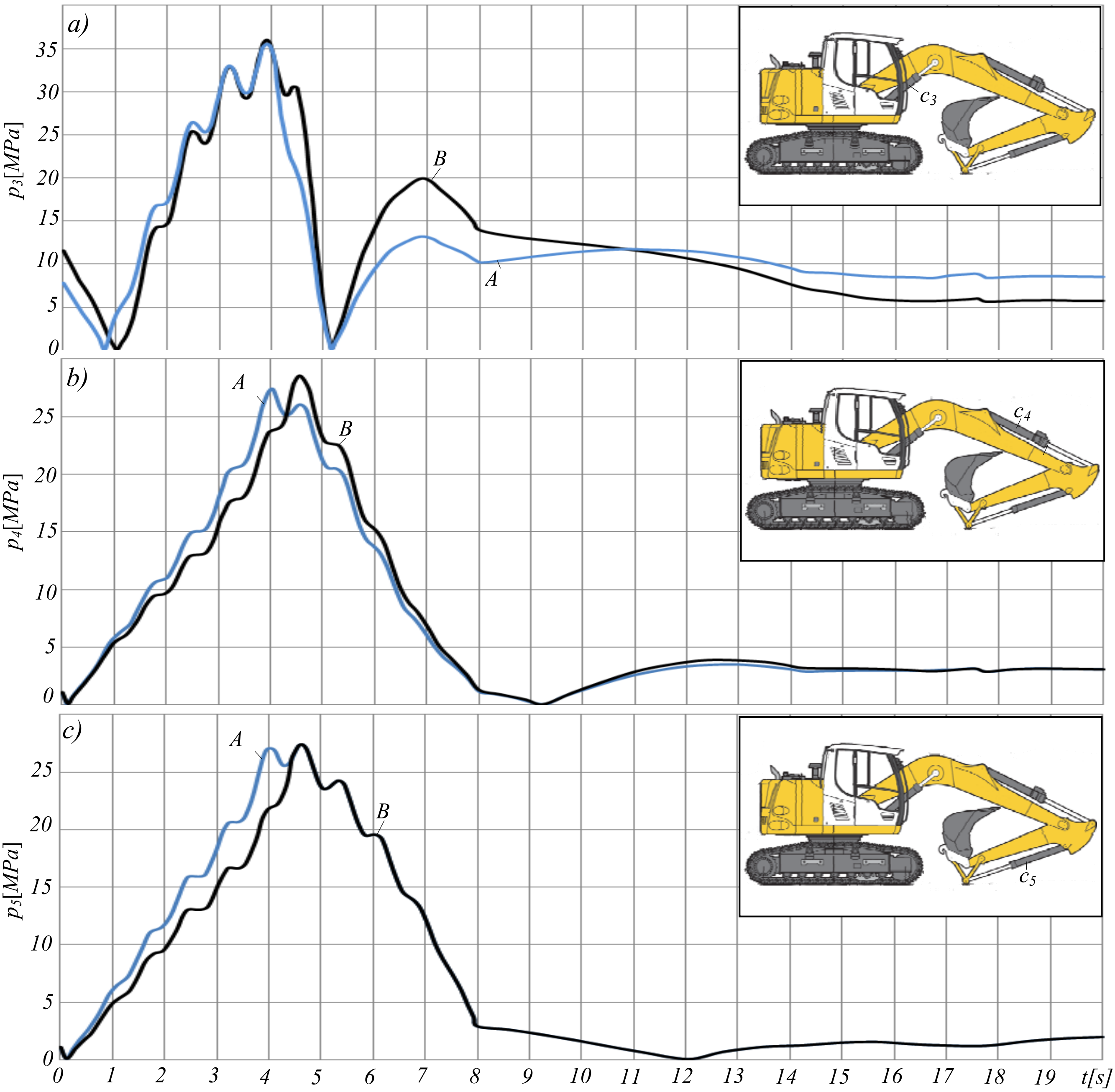

Fig.3 Change of pressure in the actuators backhoe manipulator of the hydraulic excavator: a) boom hydrocilinders c_3, b) arm hydrocilnders c_4, c) bucket hydrocilnders c_5 [1]

3. OPTIMIZATION CRITERIA

Based on the analysis above, it defines a criterion for the optimal synthesis of the drive mechanism in order to duration time of the manipulative task is minimum:

$$K_t = min(t_c) \tag{11}$$

Relative indicator of the set objective function is determined by the relation:

$$k_{rt} = n_c \frac{t_{cm}}{\sum_{c=1}^{n_c}\sum_{j=1}^{n_o} t_{cj}} \tag{12}$$

where is: t_{jc} - duration time of operation of manipulative task, t_{cm} - reference time of manipulative task, n_o - the number of operations, n_c - selected number of different manipulative tasks throughout the workspace of manipulators

To determine the parameters and indicators of the timing criteria optimization of the drive mechanism of backhoe manipulators of hydraulic excavator, it is developed the program. The inputs of program are : the file of alternative solutions of manipulator drive mechanism; the desired number of depth levels with the desired number of horizontal reach for each depth level; the plane of unloading and coordinates of unloading of a material; the hydraulic power of drive system of excavator and character of regulation of its parameters ; number of positions in the range of kinematic chain members movement for each operation of manipulative task; reference - parallel duration time of the cycle .

The program first determines the range of motion of each member of the kinematic chain of the machine for each operation of manipulative task. Then, according to resistance of the movement determined pressures in the actuators by which the flow rate is determined by their supply. With the iterative procedure, the choice of step range of active member motion of kinematic chain, the duration of the operation of each manipulative task is determined.

On the output of program, for possible alternative solutions of drive mechanism of manipulator, the next values are obtained: the medium duration time of individual operations; the medium duration time for a selected number of manipulative tasks as well as a relative indicator of the optimization criteria.

As an example, using the developed program for possible alternative solutions of drive mechanisms A, B, C and D of hydraulic modules of excavator with bachhoe bucket manipulator with volume 0.6 m^3, the parameters and data timing optimization criteria are determined.

At the input of the program next values are given: 16 manipulative tasks (four levels of digging depth, from the level of reliance to a maximum depth of excavation, with four different horizontal reach at each level of excavation); hydraulic power is *55 kW*; the pressure of the start regulating is *28 MPa*; the pressure of end regulation is 70 *MPa*. The part of obtained results is given in Table T1, the table is containing: the mark of alternative solutions of excavators; diametars of hydrocilinder pistons of boom d_{31}, arm d_{41} and bucket d_{51}; medium values of the duration time of the operation: digging t_1 , transport t_2, and unloading t_3 of material and the relative value of the time optimization criteria k_{rt}.

Table T1: Indicators of the time optimization criteria

Variants of excavators	d_{31} *mm*	d_{41} *mm*	d_{51} *mm*	t_1 *s*	t_2 *s*	t_3 *s*	k_{rt} -
A	*115*	*140*	*115*	*4,743*	*6,848*	*2,222*	*0,869*
B	*115*	*140*	*115*	*4,999*	*7,761*	*2,063*	*0,809*
C	*140*	*160*	*140*	*4,934*	*6,857*	*2,565*	*0,835*
D	*140*	*160*	*140*	*4,923*	*7,613*	*2,565*	*0,794*

The obtained results show that the at synthesis of manipulator drive mechanism, the indicators of the objective function at a time optimization criteria, in principle, does not depend on the transformation but from transmission parameters, and transfer functions of drive mechanisms.

4. CONCLUSION

Time optimization criteria of manipulator drive mechanism of mobile machinery and vehicles, which is determined in this study, was defined in order to achieve maximum performance and minimum cycle time of manipulative task. As a constraint of optimization it takes the regulation characteristic of hydrostatic parameters of hydropump that powers hydrocilinders of drive train of manipulator. Time criterion belongs to a set of defined criteria on which is based the selection of optimum solutions of drive manipulator mechanism of mobile machinery and vehicles.

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REFERENCES

[1] D. Janošević, *Optimalna sinteza pogonskih mehanizama hidrauličkih bagera*, Ph. D. thesis, Faculty of Mechanical Engineering University of Niš, 1997.

[2] *Programe Information Axial Piston Units*, Mannesmann Rxroth, Brueninghaus Hydramatik, Elchingen,1999.

[3] *Mobile 2000*, International Mobile Hydrauliks Conference, Ulm, Brueninghaus Hydromatik GmbH, Elchingen, 2000.

[4] *Mobile 2003*, International Mobile Hydrauliks Conference, Ulm, Bosch Rexroth AG, Mobile hydraulics, Elchingen, 2003.

[5] D. Janošević, *Projektovanje mobilnih mašina*, Faculty of Mechanical Engineering University of Niš, 2006.

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DYNAMICAL RESPONSE OF STRUCTURES TO MALICIOUS AND RANDOM ACTIONS

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Abstract

Irregular behaviour of cranes isespecially interesting in the practical world in order to protect them fromtheir collapse.The investigation was first performed experimentally and afterwards numerically.Vertical motions of the bridge cranecaused by swinging are mathematically modeled and demonstrated through numerical simulation.In this paper, some random and malicious actions on bridge cranes are shown that cause the extreme dynamical appearances and breakdowns. The theoretical-mechanical models were developed using the methods of modal dynamic structural analysis. These analyses provide answers for the actual risk frequencies of excitations that can cause serious damages to cranes.

Keywords*: Crane, vibration, misuse.*

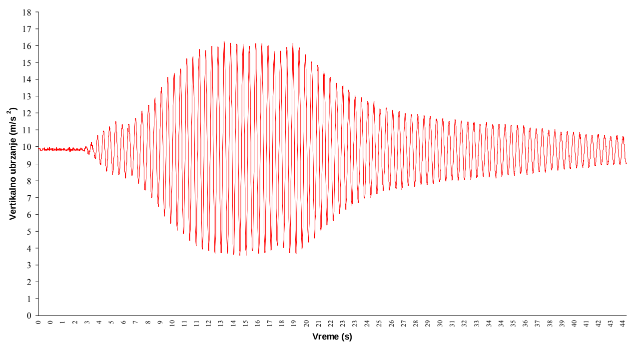
1. INTRODUCTION

Random and malicious appearances are load sway,sudden discharge of load, load bumping into obstacle and blockade of load (jam) in manipulation.
The investigations of vibrations experimentally conducted on bridge cranes [1,3] at various work regimes, provided interesting results in terms of strain and the remaining carrying capacity of the structure. Irregular actions were particularly researched for the assessment of risk class. An understanding of risk provides an opportunity for electronic protection against adverse events.
On the basis of these experiments, the numerical models were developed in which the modal and other analyses had been performed.

The eigenfrequencies and mode shapes of the support structure were determined using modal analysis.The obtained eigenfrequency values were used subsequently in the dynamic FEM analysis of the structure at excitation of a malicious crane swinging.The analyses of risk class actions on cranes are a scientific topic of interest. They arebeing studied through research of meteorological and seismic phenomena as well as through malicious human actions [4].

2. EXPERIMENTAL RESEARCH

The testing results of a bridge crane with relatively low carrying capacity, a longer bridge span and middle structure elasticity in bending (Q=5t, L=30 m, H/L=0.03) [5] are presented in the frame of this paper. This crane structure of the mass of 17.2 t is characterized by elastic supports of medium stiffness (L/f=3000cm/7.07cm=424>250). The first excitation was accomplished with synchronous hopping of five people (the total mass of 350 kg) on the carrier. Thereby, the noticeable amplitudes of vibrations were caused only at the medium hopping effort of people. The acceleration of 16.2 $m/s^2$and the lowest (minimal) longitudinal stress of -3.65 kN/cm^2 in the middle of bridge span (on the upper box lamella) caused only by abovementioned action were measured. The longitudinalstress of 16kN/cm^2 is the allowable (limited) stress for crane structures in the first load case. Fig.1a,b shows the records of these experiments.



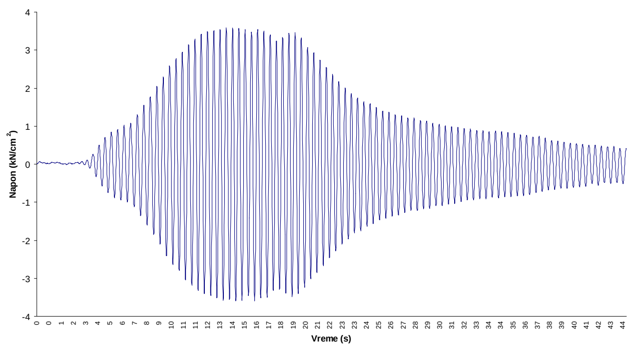


Fig. 1a,b. Acceleration diagram (a) and longitudinalstress diagram (b) for the carrier box of bridge crane MIN D800 (1977) at an intentional swinging

In the second experiment, vibrations caused by a rough hoisting of load of 4t off the ground were measured. It was done in order to compare the previously described effect of swinging with an action of regular exploitation, Fig. 2a,b.

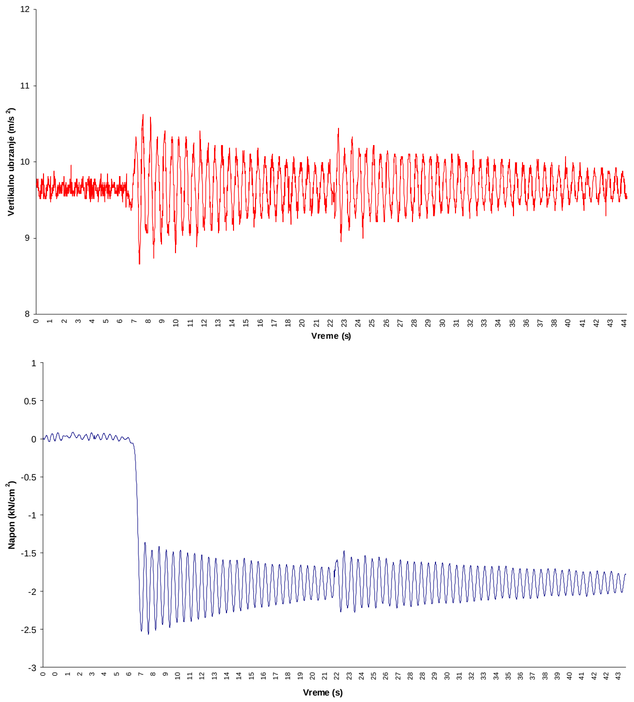


Fig. 2 a, b. Load of 4t hoisting – experimental records of accelerations (a) and longitudinal normal stresses (b) on the bridge

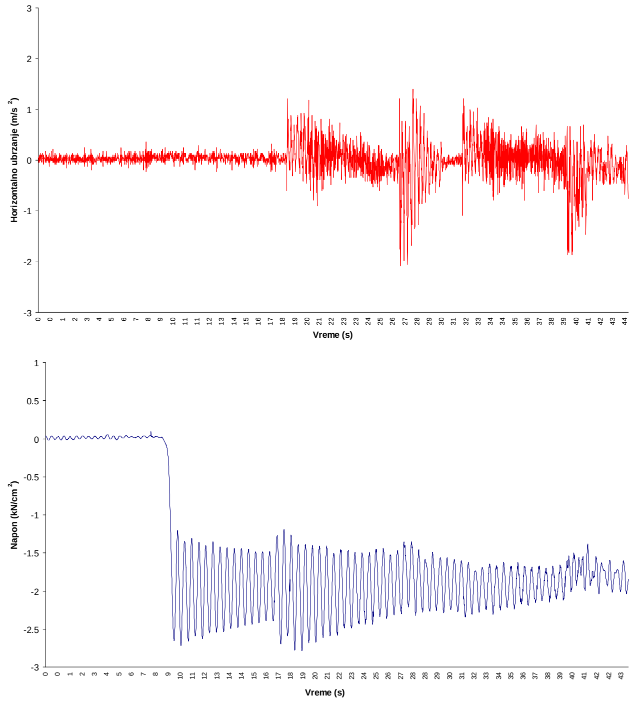


Fig. 3 a, b. Horizontal crane moving – experimental record of accelerations (a) and longitudinal normal stresses (b) on the bridge

In the second experiment, the accelerations of 10.6 m/s^2 in the middle on the bridge span and the largest stress rise of -2.65kN/cm^2 were obtained. The medium longitudinal stress was -2.0kN/cm^2 around which vibrations had occurred. The swinging period of bridge carrier was 0.525 s at 4 t of load.

The third experiment was performed by driving crane along track at velocity of 32 m/min together with the load mass of 4 t, Fig. 3a,b.During the experiment, the maximal horizontal acceleration of 2 m/s^2 was measured due to uneven resistances of movement. Thereby, the highest increase of stress of 2.8 kN/cm^2 was caused. A higher increase of the stress of driving in relation to the stress of hoisting was an unexpected increase as a result of a bad track on which the crane had been driven. The track was made at 8 m height, out of open steel girders and masts with 10 m range.

By analysing these three tests, it is easy to see that the bridge carrier swinging showed the greatest dynamic amplitude in the first test, both in terms of acceleration and stress increase.The increase of stress obtained by this random irregular action amounted 25% of the total allowable complex (comparative) stress.Increase in value of this stress would definitely damage the structure.For example, by an action of a few stronger heavy people.Wherein, these people must not be on the bridge carrier but on the ground. Such intention can be characterized as a misuse which was registered in the investigations of incidents with cranes in the world [4].Safety measures against similar actions are taken in the domain of security services.Nowadays, electronic equipment is very helpful for triggering of alarm against adverse actions.

3. NUMERICAL SIMULATION

The vibration properties check of selected structure was conducted by searching eigenfrequencies and mode shapes. These shown simulations were numerically performed using the program MSC NASTRAN 2005. The model of crane MIN D800 with 15902 elements and 89034 algebraic equations (DOF) was developed. Verification of the model was performed on the basis of comparison to stresses and deflections at operation with the load of 4 t as shown by the testing no.2, Fig. 2. A high convergence of results was obtained, for example: the longitudinal static stress numerically calculated only from load of 4 t took the value of 1.945kN/cm^2, while experimentally obtained medium stress took the value of 2.00kN/cm^2. Also, total deflection numerically calculated amounted 0.0704 m (D800.7) and the deflection only from load 0.0201 m. The deflection of 0.019 m was experimentally obtained from load of 4 t (D800.4).Such experimentally verified model served further for modelling of dynamic simulations. The dynamic simulation is related only to the modal frequency analysis in this paper.

The frequency polynomial solvingwas done using the Lanczos method for the first 50 frequencies. The frequencies at which were performed the forced malicious vibratory movements had been separated by using the mode shapes.These frequencies are the base for transient analysis in which the velocities of active damping are required.Certain limited frequencies of vibrating motion took values between 0.658 Hz and 4.148 Hz.Figures 4 and 5 show the eigenvalues (mode shapes) of vibrations for two selected frequencies. The extraction of the abovementioned frequencies was performed by observing the appearance of the first mode shape at the maximal amplitude (eigenvalue) in the middle of girder span. Table 1 provides an insight into the dynamic parameters from the numericalsimulation.

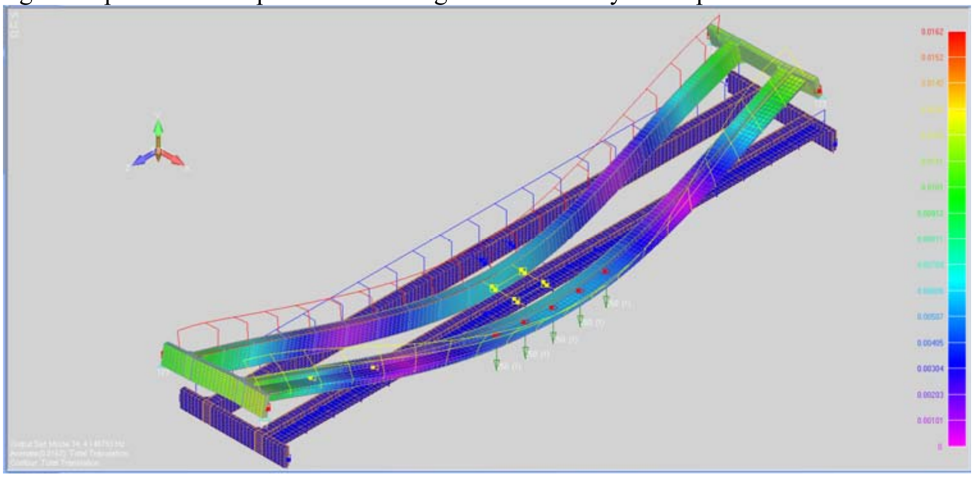


Fig.4. Mode-34 (4.148 Hz),crane D 800-9,vibration with hook load of 4 t, rigid pathway support

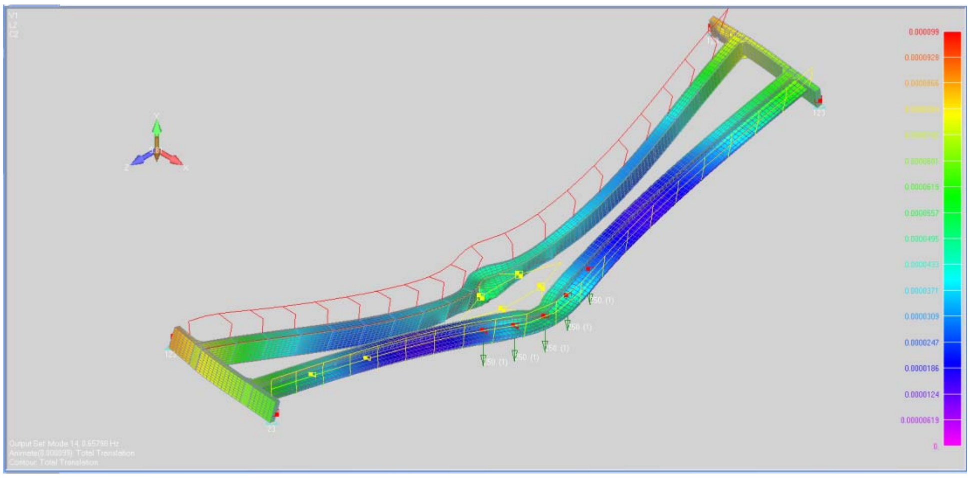


Fig.5. Mode-14 (0.658 Hz),crane D 800-9,vibration with hook load of 4 t, rigid pathway support

Table 1

	Eigenfrequencies of the crane structure D800.9 (Hz)				
Category of frequency	The lowest determined eigenfrequency f_1	The measured eigenfrequency f_{11}	The first significant eigenfrequency f_{14}	The second significant eigenfrequency f_{34}	The highest determined eigenfrequency f_{50}
Value (Hz)	3.051 E-6	0.460	0.658	4.148	10.874

CONCLUSION

1. A malicious action, according to the conducted analysis, can causehigher stress states than the regular actions. This fact raises the question of protection of all significant structures.
2. In terms of protection, technologies for remote control of cranes without access of man on the crane should be developed.
3. It should be expected that the development of system to detect high stresses in structures becomes justified and supported by development of universal electronic safety controllers.
4. The use of electronic safety controllers would protect expensive facilities against the working exceeding of limit states.
5. The limit parameters for adjustment of each structure with built-in protection can be identified by transient and modal analysis.
6. The controller could serve for determining the state of fatigue or amortization by registering all significant events in the exploitation of structure.
7. The proposed controller can be a commercial device, independent of the type of structure which is controlled. For proper installation of the controller, it is necessary to perform numerical analysis (simulation) for characteristic (dangerous) situations.
8. This controller is a type of black box and the data source for the judiciary in case of malicious events. By its presence on the structure, in the same time, the

controller is a mean of asset and people protection against adverse effects. Therefore, this device must be an autonomous and protected from the adverse effects.

9. By this analysis (simulation) based on the FEM technology, the procedure of basic conceptual model for protection of one type of structure (crane) is shown.

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REFERENCES

[1] J. Jovanović, M. Jovanović, R. Bulatović, S. Šekularac, “Infuence of bridge crane vibrations on dynamic behaviour of operator’s spinal column“, ASME the First International Conference on Recent Advances in Mechanical Engineering, Patras, Grecce, 2001.

[2] J. Jovanović, M. Jovanović, “Analysis of dynamic behavior of bridge crane operator’s spinal column“, YUINFO, National Conference – Information technology, Žabljak, 2002, pp. 17-20.

[3] M. Jovanović, J. Jovanović, “Frequency response of Crane operator’s spinal Column to random Vibrations“, FACTA UNIVERSITATIS, University of Niš, 2003, Vol.1, No 10, 2003 pp. 1299 – 1310.

[4] R.Isherwood, “Tower crane incident worldwide”, research report, Health and Safety Executive, *www.hse.gov.uk/research/rrpdf/rr820.pdf*, 2014.

[5] M. Jovanović, D.Mijajlović, Lj.Petković, J. Jovanović, “Experimental investigation of MIN D800 Crane supporting structure to random Exitations“, Mechanical Faculty University of Niš, Report, 2000.

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SIMPLIFIED LIFE CYCLE ASSESSMENT OF BELT CONVEYOR DRIVE PULLEY

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Abstract

This simplified Life Cycle Assessment (LCA) of belt conveyor drive pulley is part of complete LCA study of belt conveyor and it will be used for establishment of methodology for conducting LCA studies of Bucket Wheel Excavator (BWE) or similar types of belt conveyors. Drive pulley as all other belt conveyor pulleys is considered as part of belt conveyor system that doesn't need electricity to fulfill its function. The only component of belt conveyor system that actually consume electricity is electric motor (EM). Drive pulley is analyzed with Ecodesign Assistant (EA) and Ecodesign PILOT (EP) software tools. Analysis had shown that drive pulley manifest the biggest impact on the environment in raw materials stage of its life cycle. Accompanying EP strategies suggested possible product improvements.

Keywords*: Life Cycle Assessment, Bucket Wheel Excavator, Belt Conveyor Drive Pulley.*

1. INTRODUCTION

Purpose of this paper is to provide basis for conducting simplified Life Cycle Assessment (LCA) of variety of different pulleys as well as basis for their mutual comparison. Simplified LCA is conducted with Ecodesign Assistant (EA) and Ecodesign PILOT (EP) software tools. These software tools and terms such as life cycle, LCA and product types are explained in [1, 2].

2. DESCRIPTION OF THE PRODUCT

Bucket wheel excavator (BWE) 1201 belt conveyor drive pulley main components are drum, bearings and shaft, see fig. 1.

Fig. 1 BWE 1201 belt conveyor drive pulley

Drive pulley flange is not considered in this study. If it is necessary flange can be modeled as steel part and be aded to steel parts.

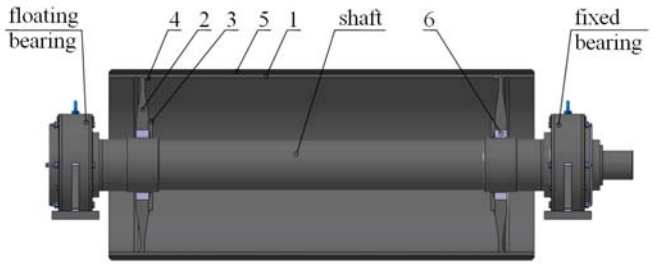

Fig. 2 Drum cross section

Drum assembly, shown in fig. 2 is consisted of 6 parts which are listed in table 1. Position numbers of the parts in table 1 are in correlation with fig. 2.

Table 1 Drum assembly parts list

Pos.	Part name	Mass [kg]	Material	Quantity
1	Rim	550.9	Steel (S335J2G3)	1
2	End disc	102.0	Steel (S335J2G3)	2
3	Ring	24.0	Steel (S335J2G3)	2
4	Positioning plate	0.3	Steel (S335J2G3)	6
5	Rubber lagging	156.8	Rubber	1
6	Flexible locking device	12.2	Steel	2

From aspect of ecodesign there is a small difference between fixed and floating bearing. Differences are in construction of bearing housing external covers, rotary seals and extra bushing in case of fixed bearing.

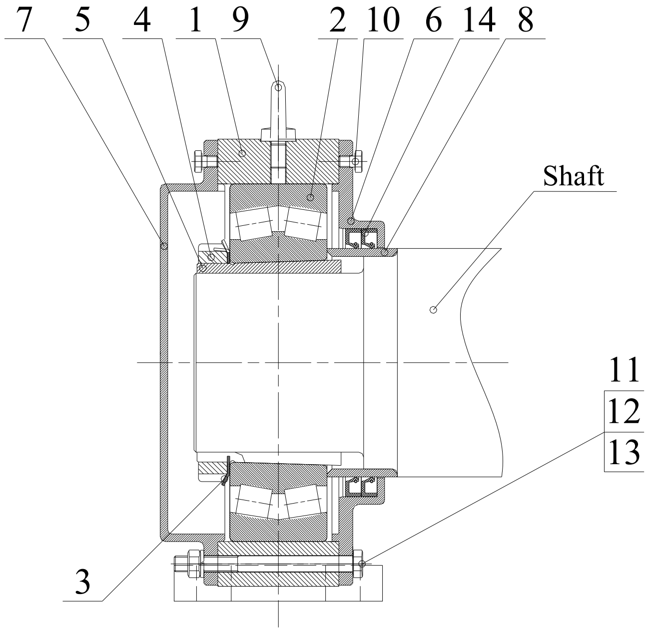

Fig. 3 Floating bearing

Floating bearing shown in fig. is consisted of 14 parts listed in table 2. Lubricating nipple is neglected due to different lubrication method retrieved from [2].

Table 2 Floating bearing parts list

Pos.	Part name	Mass [kg]	Material	Quantity
1	Welded housing	131.8	Steel (S335J2G3)	1
2	Roller bearing SKF 22240 CCK/W33	42.5	Steel	1
3	Locking washer MB 40	0.293	Steel	1
4	Locknut KM 40	3.7	Steel	1
5	Adapter sleeve H3140	12.1	Steel	1
6	Housing cover – internal	14.1	Steel (S335J2G3)	1
7	Housing cover – external	15.6	Steel (S335J2G3)	1
8	Bushing	3.07	Steel (CK45)	1
9	Lifting eye bolt	0.3	Steel Zn (C15E)	1
10	Screw M12x16	0.03	Steel Zn	6
11	Bolt M16x180	0.32	Steel Zn	6
12	Nut M16	0.04	Steel Zn	6
13	Washer A16	0.01	Steel Zn	6
14	Rotary seal BA Simrit 230x270x16	0.1	Rubber	2

Fixed bearing shown in fig. 4 is consisted of same parts as floating bearing except diffrent constuction of external cover of bearing housing, aditional rotary seals BA simrit 180x210x15 and aditional bushing. Contituent parts of fixed bearing are listed in table 3.

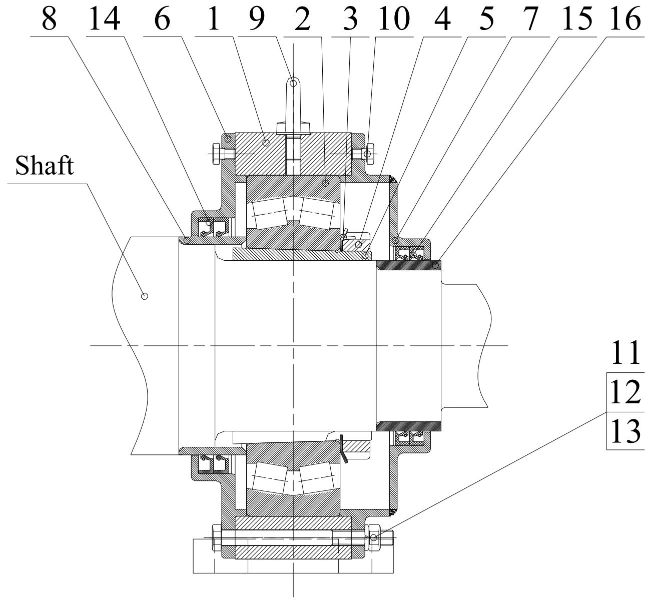

Fig. 4 Fixed bearing

Shaft is single material part made of steel 42CrMo4 and its mass is 751.30 kg. It is produced by forging. Steel 42CrMo4 is recognised as High Alloyed Steel in EA material class table.

Table 3 Fixed bearing parts list

Pos.	Part name	Mass [kg]	Material	Quantity
1	Welded housing	131.8	Steel (S335J2G3)	1
2	Roller bearing SKF 22240 CCK/W33	42.5	Steel	1
3	Locking washer MB 40	0.293	Steel	1
4	Locknut KM 40	3.7	Steel	1
5	Adapter sleeve H3140	12.1	Steel	1
6	Housing cover – internal	14.1	Steel (S335J2G3)	1
7	Housing cover – external	15.6	Steel (S335J2G3)	1
8	Bushing	3.07	Steel (CK45)	1
9	Lifting eye bolt	0.3	Steel Zn (C15E)	1
10	Screw M12x16	0.03	Steel Zn	6
11	Bolt M16x180	0.32	Steel Zn	6
12	Nut M16	0.04	Steel Zn	6
13	Washer A16	0.01	Steel Zn	6
14	Rotary seal BA Simrit 230x270x16	0.1	Rubber	2
15	Rotary seal BA Simrit 180x210x15	0.074	Rubber	2
16	Bushing	1.21	Steel (CK45)	1

Product life time is estimated to be 5 years, according to [2] and functional unit is defined as "transferring rotation of the shaft to translation of the belt at 3,9 m/s speed and load bearing".

3. ANALYSIS IN ECODESIGN ASSISTENT

Prior to conducting analysis in EA and EP simplifications similar to those made in [2] had to be done. All drive pulley parts are grouped according to table 4.

Table 4 Simplified parts list

Product Part	Mass [kg]	Material	Class
Steel parts	1252	Steel	III
Steel Zn parts	5.5	Steel Zn	IV
High Alloyed Steel parts	751.3	Steel High Alloyed	VI
Rubber parts	157.35	Rubber	IV

Parts made of same or similar material are treated as one part. Process energy needed for manufacturing each of the parts is taken into account. Material class for grouped parts is determined based on predominant material relative to classification of different materials provided by EA.
Roller bearing SKF 22240 CCK/W33, marked with number 2 in fig. 3 and fig. 4 is treated as a single part predominantly made of steel. Becides roller bearings steel parts obtain parts marked with numbers 1, 3, 4, 5, 6, 7, 8 and 16 in fig. 3 and fig. 4 and parts marked with numbers 1, 2, 3, 4, and 6 in fig. 2.
Steel Zn parts are consisted of parts marked with numbers 9, 10, 11, 12, 13 in fig. 3 and fig 4.
High Alloyed Steel parts are consisted of single part – shaft.
Rubber parts are consisted of parts marked with number 5 in fig. 2 and with numbers 14 and 15 in fig. 3 and fig. 4.
Main manufacturing methods of material processeing for this product are machining, forging, welding and injection moulding. Specific energy consumption (SEC) for these processes is obtained from [3, 4, 5]. Calculated energy for all of those processes was 9196 MJ. Waste genarated in production phase is estimated to be 10% of part mass. According to this assumption there is generated 113.6 kg of steel scrap and 15.7 kg of rubber scrap. Energy for heating and lighting is estimated as moderate. Percentage of external parts was 30-60%. Since all external parts are obtained from manufacturers situated in vicinity of the production facility, their hauling distance per unit is determined as "rather short".
Production facility is situated approximately 20 km from location of product's utilization. Chosen means of transportation is truck.
Use frequency of BWE 1201 belt conveyor drive pulley is defined as number of working days per year. According to data obtained from product user there are 325 working days per year. Electric energy input is not needed for drive pulley service. The only component of conveyor that consume electric energy is electric motor. Analysis of electric motor is not covered with this study. As in [2] FOR LPD 2 lubricating grease is treated as auxiliary material in product use stage. Amount of lubricant per use is calcualted and scaled according to [2]. It's calculated input per use was $8.4 \cdot 10^{-3}$ kg. Lubricant is consisted of Li-soap and mineral base oil. It is recognized as environmentally hazardous material and classified as material class V.
Drive pulley is being partially recycled at the end of it's life. Steel parts and High Alloyed Steel parts are being reused. Other parts are being disposed off or returned to the manufacturer.
Analysis carried out in EA identified idler roller as basic type A product, that is raw material intensive product. Following improvement strategies were recommended.
Main recommended strategies were:

- "reducing material inputs" and

Recommended strategies with lower priority which are to be realized later were:

- "selecting the right materials",
- "optimizing product use",
- "optimizing product functionality",
- "increasing product durability",
- "improving maintenance",
- "improving reparability",
- "improving disassembly" and
- "reuse of product parts".

One additional recommended strategy was "ecological procurement of external components".

4. ANALYSIS IN ECODESIGN PILOT

Improvement strategies provided by EA are further considered within EP. They are not presented in this paper particularly. Instead, they are discussed as tasks, measures and recommendations which are to be conducted in order to improve product's functionality and energy efficiency, as well as environmental performance.
As FOR LPD 2 lubricant is considered environmentally hazardous improvement of its environmental performances was considered and explained in [2]. There was recommended use of lubricants with renewable base oils and new concept of ionic liquid based lubricants. There was recommended use of energy-saving bearings and use of remanufacturing service for bearings also.
EP suggested possible utilisation of recycled steel for manufacturing steel parts of drive pulley. Having in mind that SEC for virgin steel production is much greater than SEC for recycled steel production, significant energy saving could be achieved by using recycled steel for steel parts manufacturing.
As steel parts are being refurbished or reused recycling rate could be maximised even more by recycling rubber parts.
Surface of the drum in contact with belt is exposed to soiling. To prevent formation of material buildup on the drum surface there can be utilised belt cleaners.
Since drive pulley components are locally available, transportation and its influence is reduced to minimum.

5. CONCLUSION

It has been shown that particular issues considered within this paper were already considered in [2]. Among these issues were environmentally friendly lubricants, energy saving bearings, material buildup and wear reduction, transportation of external parts and end of life options. Analysis in EP has shown that energy and consequently cost savings as well as environmental improvements could be accomplished by conducting provided recommendations. Conducting this type of LCA for different types of pulleys can provide significant base for analyzing environmental performances of the BWE conveyor pulleys in general. With more conducted LCAs there could be made pattern for analyzing pulleys in general and there can be recognized main issues which could occur during conveyor pulley utilization. Thus there can be suggested adequate solutions for these issues and achieved more energy efficient and more environmentally friendly utilization of conveyor pulleys.

ACKNOWLEDGMENT

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REFERENCES

[1] W. Wimmer, R. Züst, "Ecodesign PILOT – Product Investigation, Learning and Optimization Tool for Sustainable Product Development", Kluwer Academic Publishers, Dordrecht, The Netherlands, 2003.

[2] M. Đorđević, N. Zrnić and M. Pantelić, "Simplified life cycle assessment of a return belt conveyor idler" in Proceedings of 11th International conference on accomplishments in Electrical and Mechanical Engineering and Information Technology - DEMI 2013, pp. 201-206, University of Banja Luka, Faculty of Mechanical Engineering, 30th May – 1st June, 2013.

[3] S. Kalpakjian, R.S. Schmid, "Manufacturing Processes for Engineering Materials", 5th Edition, Pearson Prentice Hall, New Jersey, 2007.

[4] N. Zrnić, M. Đorđević, "Dizajn i Ekologija: Održivi Razvoj Proizvoda", Faculty of Mechanical Engineering, Belgrade, 2012.

[5] A. Thiriez, T. Gutowski, "An environmental analysis of injection molding", in Proceedings of the 2006 IEEE – International Symposium on Electronics and the Environment, pp. 1-7, 2006.

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DEVICE FOR TRANSPORTING OUT OF DIMENSION SHEET METAL WITH TRUCK

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Abstract

Some times Small and Medium sized transport companies are in demand for transport of special kind of goods that usually cannot be performed with the transport equipment they posses. In this paper is considered such case for transport the sheet metal in dimensions that exceed the usual dimensions of the tuck. The equipment (supporting structure positioned on the truck) is required to have the lowest possible weight and the highest possible durability. In such case the transport can achieve its maximum effect.
In this paper the analysis and verification of such structure is considered. In order to find optimal design in manner of lowest possible weight, the Finite Element Analysis was performed.
The results of the analysis and the verification of the structure is presented in this paper.

Key words*: sheet metal transport, out of dimension transport, device, design verification, FEA.*

1. INTRODUCTION

During the transport of sheet metal with dimensions that exceed the overall dimensions of the truck and in the case when the width of the sheet metal is wider then the width of the trunk of the vehicle-trailer, the problem is how to load the sheet metal and transport it safely.
For that purpose it has been constructed a supporter of the sheet metal where the sheet metal is positioned during the loading in the diagonal position. Such supporters are set in the loading trunk of the truck (in this case and usually there are four supporters) on which the sheet metal is fixed during the transport. The position of the supports is presented on the Figure 1.
The manner of fixing the supporters is not a subject of consideration in this paper.
The appearance of the loaded sheet metal on the truck is presented on the Figure 2.

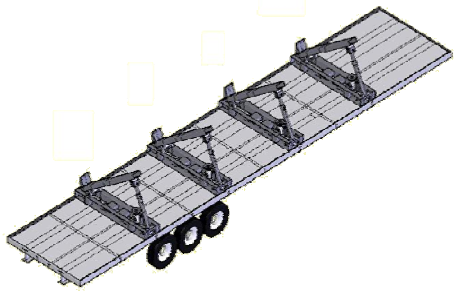


Fig. 1: Position of the supporters on the truck

Fig. 2: Loaded sheet metal on the supporters during the transport

Initially, the sheet metal is set in horizontal position and then with a hydraulic system they are lifted in the necessary position that satisfies the overall dimensions of the system adequate for the transport. In that new slanting position of the sheet metal, a support is established with vertical poles of variable length. At the same time also the hydraulic cylinders are active for achieving the required position. During the transport the hydraulic lifting system is not active and the supporting tube (Figure 6) maintains the support.
The hydraulic system for lifting is not subject of research in this paper.

2. DESCRIPTION OF THE SYSTEM

The construction of the support is formed by horizontal element (Figure 4), slanting element (Figure 5) and tube for supporting and maintaining the security(Figure 6). The horizontal supporter and the slanting supporter are joint connected and can take different positions (different angle of slanting). The appearance of the whole structure is presented on Figure 3.

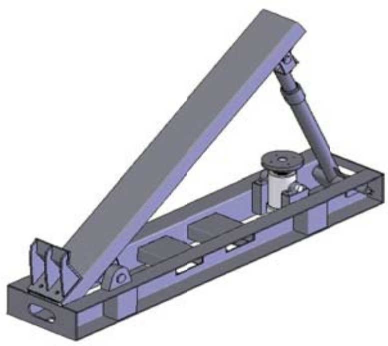


Fig.3: The appearance (construction) of the supporter

The supporters are made from steel type Č.0361 and the supporting tubes are made from steel type Č.1204. The overall dimensions of the horizontal supporter as well as the dimensions of different consisting elements are presented on Fig. 4.

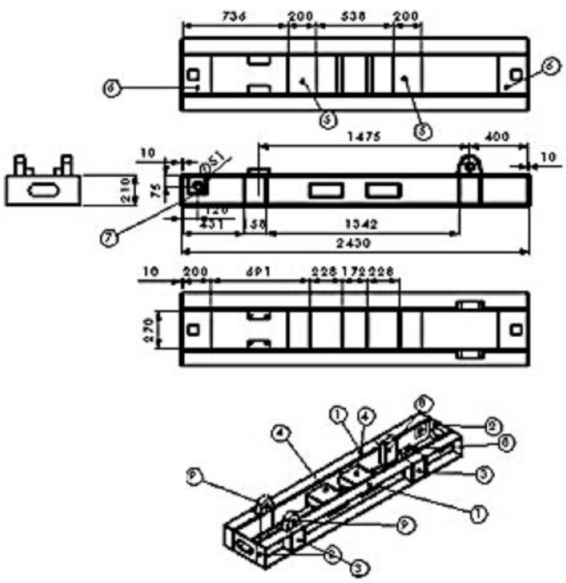


Fig. 4: Horizontal supporter

The overall dimensions of the slanting supporter and the dimensions of the different consisting elements are presented on Figure 5.

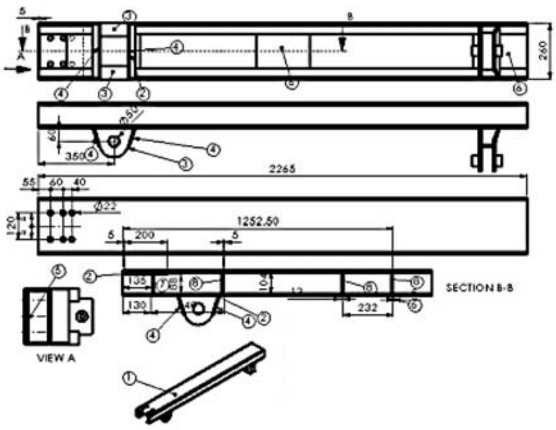


Fig. 5: The slanting supporter

The construction and the dimensions of the supporting element (tube) are presented on Figure 6.

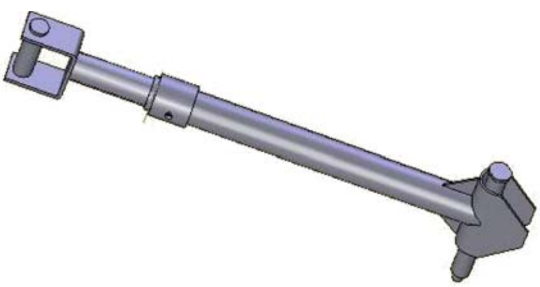


Fig. 6: Supporting element – the tube

3. DESIGN VERIFICATION OF THE SYSTEM

The verification of the support system design was performed with Finite Element Analysis (for the horizontal and the slanting supporters), and the classical calculation method (for the supporting tube).
The Theory background is presented in References [1], [2], [3], [4] and [5]
The presumed loading of the system is 9000 kg.

3.1. Finite Element Modelling of the supporters

The supporters, the horizontal one and the slanting are modelled with combination of plate and brick elements.
The Plate elements have 5 degrees of freedom per node and the 3D Bricks have 3 degree of freedom per node. The properties of the built in material are:

Jung module: E= 210000 N/mm2
Volume density: γ= 7,85 kg/dm3
Poison coefficient: μ= 0,3

These are typical properties of the steel required for linear FEA.

3.1.1. Model of the Horizontal Supporter

The Finite Element Model (FEM) is presented on the Figure 7.

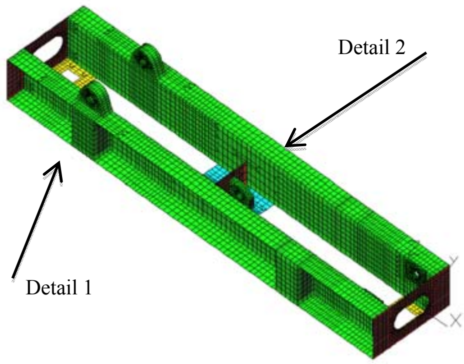
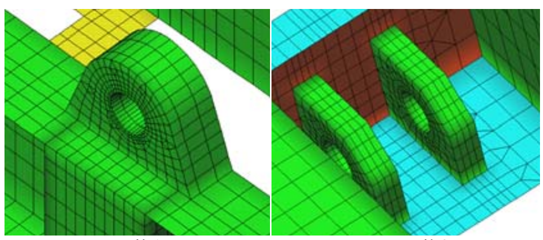


Fig. 7: FEM of the horizontal supporter

On the Fig. 7 with the different colours represent the different thickness of sheet metal: green-8mm, red-4mm, yellow-10mm, and blue-15mm.
The details of the FEM in characteristic locations are presented on Figure 8.



Detail 1 Detail 2

Fig.8: FEM in characteristic locations due to Fig. 7

The loads of the system and the boundary conditions are presented on Figure 9.
The supporter on its bottom part is positioned on the loaded truck, and at the ends it is firmly tightened to the trunk. The boundary conditions are presented with red colour. The forces are presented with yellow colour. The forces actually

are the reactions from the upper element.

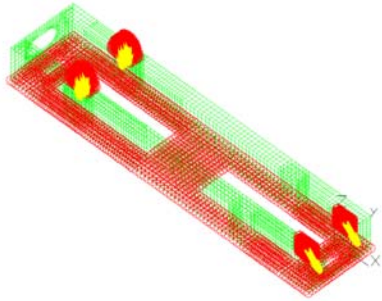


Fig. 9: Loads and boundary conditions of the horizontal supporter

3.1.2. <u>Model of the Slanting Supporter</u>

The FEM of the slanting supporter is presented on the Figure 10. On the Fig. 10 with different colours are presented the different thickness of the sheet metal: green-8mm, red-10mm, yellow-20mm and blue-8mm.

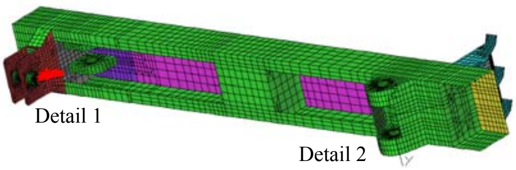
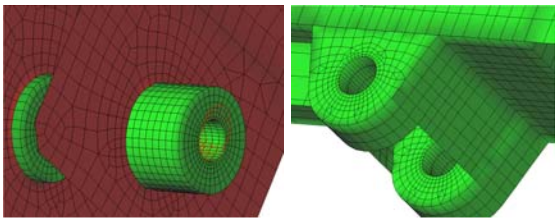


Fig. 10: FEM of the slanting supporter

The details of the FEM in characteristic locations are presented on Figure 11.



Detail 1 Detail 2

Fig. 11: FEM incharacteristic locations due to Fig. 10

The loads of the system and the boundary conditions are presented on Figure 12. The load is in fact the weight of the sheet metal (presented with brown colour).
The boundary conditions are presented with red colour.

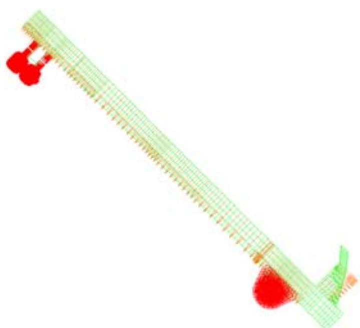


Fig. 12: Loads and boundary conditions of the slanting supporter

3.2. Finite Element Analysis of the supporters – The stress analysis

3.2.1. <u>Analysis of the horizontal supporter during the lifting of the load</u>

The stress distribution of the horizontal supporter during the lifting of the load is presented on Figure 13.

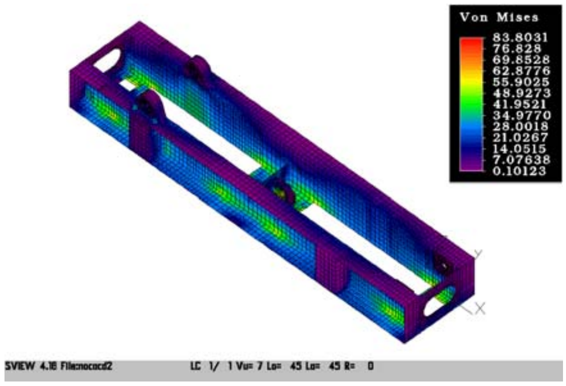


Fig. 13: Stress distribution of the horizontal supporter during the lifting of the load (Von Mizes)

The maximum Von Misses stress in the critical sections is about 85 N/mm^{2}and it is far below the allowed stress of the used material (σ_{doz}=165 N/mm^2). The distribution of the stress in the critical locations is presented on the Figures 14 and 15.

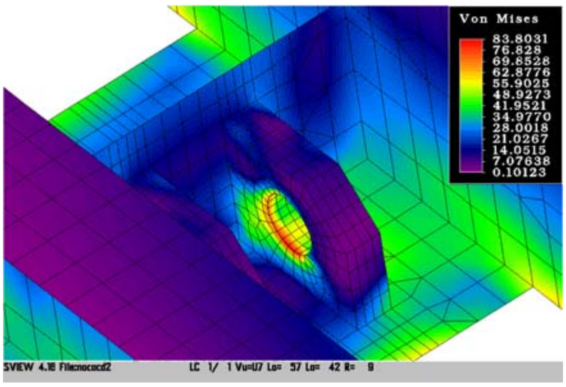


Fig. 14 Stress distribution at the location of the supporting tube (about 83 N/mm^2)

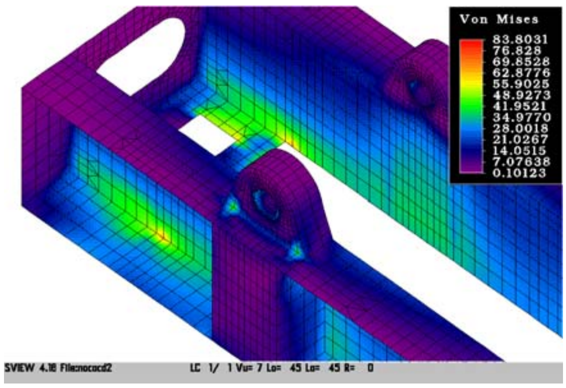


Fig. 15: Stress distribution at the location of the contact with the slanting supporter (about 50 N/mm^2)

3.2.2. <u>Analysis of the horizontal supporter during the transport</u>

The stress distribution of the horizontal supporter during the transport of the load is presented on Figure 16.

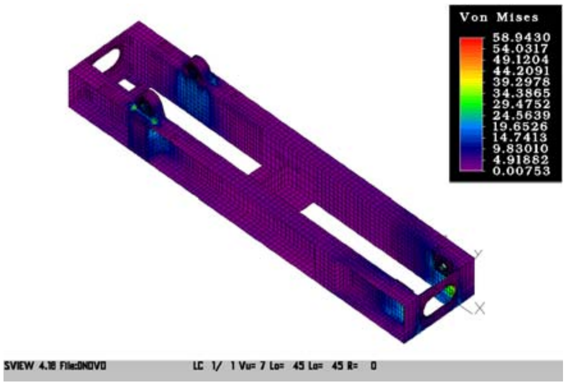


Fig. 16: *Stress distribution of the horizontal supporter during the transport (Von Mizes)*

The maximum Von Misses stress in the critical sections is about 59 N/mm^2 and it is far below the allowed stress of the used material (σ_{doz}=165 N/mm^2). The distribution of the stress in the critical locations is presented on the Figures 17 and 18.

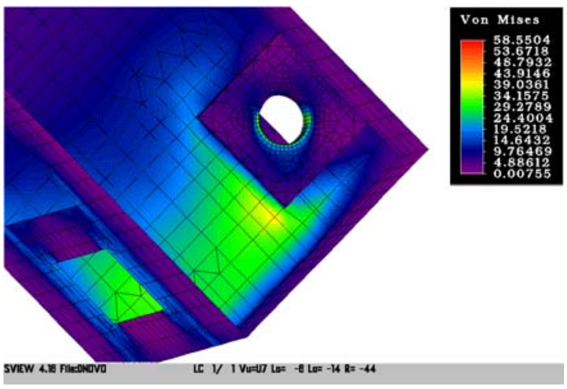


Fig. 17: Stress distribution at the location of the contact with the horizontal supporter (about 40 N/mm2)

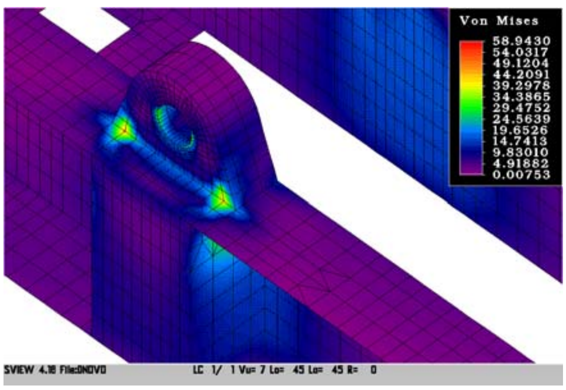


Fig. 18: Stress distribution at the location of the contact with the slanting supporter (about 25 N/mm^2)

3.2.3. <u>Analysis of the slanting supporter during the lifting of the load</u>

The stress distribution of the slanting supporter during the lifting of the load is presented on Figures 19 and 20.

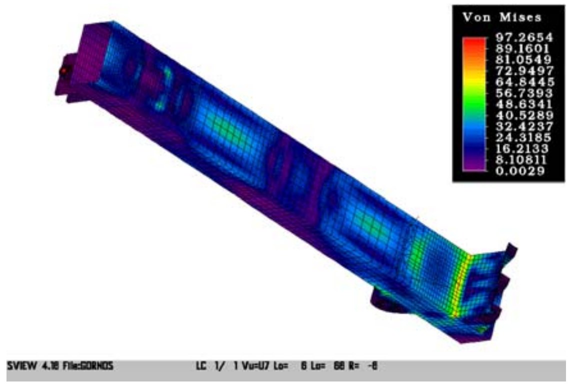


Fig. 19: Stress distribution of the slanting supporter during the lifting of the load – upper view

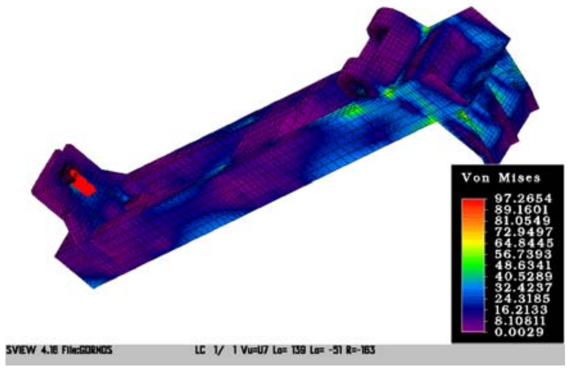


Fig. 20: Stress distribution of the slanting supporter during the lifting of the load – bottom view

Locations with maximum stress are presented on Figure 21.

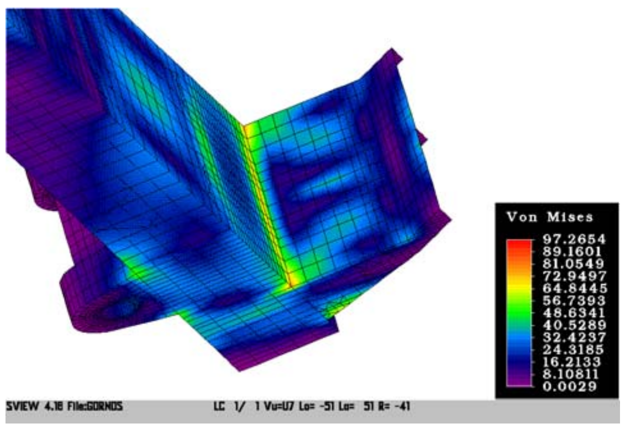


Fig. 21: Maximum stress during the lifting of the load – upper side (about 90 N/mm^2)

3.2.4. Analysis of the slanting supporter during the transport

The stress distribution of the slanting supporter during the lifting of the load is given on the Figure 22.

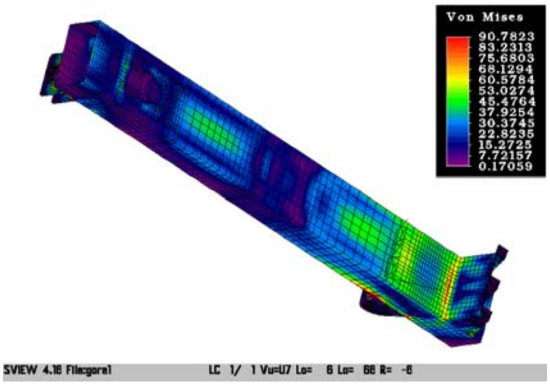


Fig. 22: Stress distribution of the slanting supporter during the transport – upper view

Stress distribution in the locations of maximum stress is presented on Figure 23 and 24.

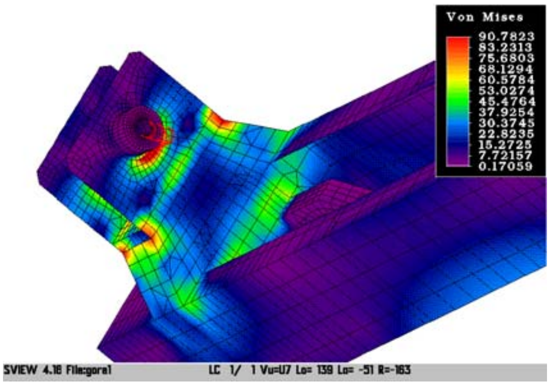


Fig. 23: Stress distribution of the slanting supporter during the transport – bottom view

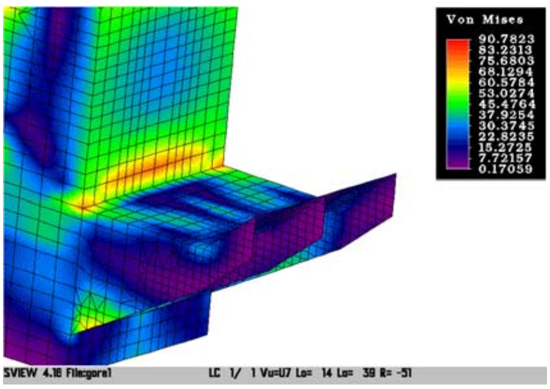


Fig. 24: Stress distribution of the slanting supporter during the transport – upper view

3.3. Analysis of stability of the supporting tube

After the setting of the sheet metal in the transport position with the hydraulic system, the slanting supporter is put into the desired position.

In such slanting position the hydraulic cylinder is released and the support is established with the supporting tube. Then, the system is fully capable for transport. The supporting tube then is fully loaded.

The dimensions of the tube and its cross section are presented on Figure 25.

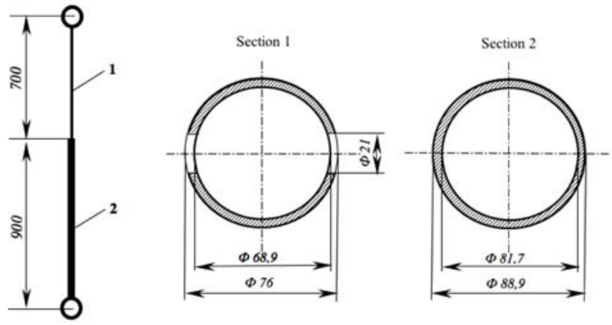


Fig. 25. The dimension and cross section of supporting tube

The cross section properties are presenter in Table 1.

Table 1: Cross section properties

Section	Geometrical Properties		
	Area (mm^2)	Moments of inertia	
		J_x (mm^4)	J_y(mm^4)
1	667,24	532007,0	339262,0 (J_0)
2	964,23	878541,2	878541,2 (J_1)

$J_0 = 339262mm^4$ - The least moment of inertia

$J_0 = 878541{,}2mm^4$ – The greatest moment of inertia

$$\frac{J_0}{J_1} = 0{,}386 \rightarrow \beta = 1{,}22$$

$$i_{min} = \sqrt{\frac{878541{,}2}{667{,}24}} = 36{,}28mm$$

$$l_k = \beta \cdot 1600 = 1952mm$$

$$\lambda = \frac{1952}{36{,}28} = 53{,}8 \rightarrow \omega = 1{,}21$$

2.) *Forces at the support*

The calculation scheme for the reactive forces is presented on Figure 26.

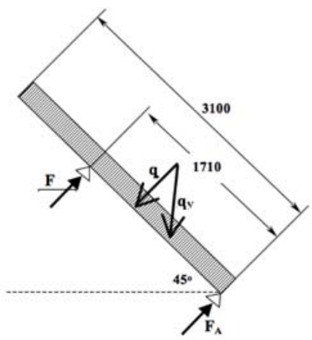


Fig. 26

$$q_v = \frac{6500}{3,1} = 20967,74 \frac{N}{m}$$

$$q = q_v \cdot cos45^O = 14826 \frac{N}{m}$$

$$\sum M_A = 0 \Rightarrow q \cdot 3,1 \cdot \frac{3,1}{2} - F_B \cdot 1,71 = 0$$

$$F_B = \frac{14826 \cdot 3,1^2}{2 \cdot 1,71} = 41660N$$

$$\sum M_B = 0 \Rightarrow F_A \cdot 1,71 - q \cdot 1,71 \frac{1,71}{2} + q(3,1 - 1,71) \frac{3,1 - 1,71}{2} = 0$$

$$F_A = \frac{1}{1,71}(1,46205q - 0,96605q)$$

$F_A = 4300\ N$

$s = 1,33$ - Factor of irregularity

$F_{Bv} = 1,33 \cdot 41660 = 55408\ N$

3.3.1. Control of the stress and stability

A. Static Loading

Stress:

$$\sigma = \frac{F_{Bv}}{A_{min}} = \frac{55408}{667,24} = 83,04 < \sigma_{doz} = 165 \frac{N}{mm^2}$$

Stability

$$\sigma = \frac{F_{Bv} \cdot \omega}{A_{min}} = \frac{55408 \cdot 1,21}{667,24} = 100,48 < \sigma_{doz} = 165 \frac{N}{mm^2}$$

B. Dynamic Loading

$$\sigma_{Ddoz} = \frac{\sigma_{doz}}{K_d} = \frac{165}{1,5} = 110 \frac{N}{mm^2}$$

stress

$$\sigma = \frac{F_{Bv}}{A_{min}} = \frac{55408}{667,24} = 83,04 < \sigma_{Ddoz} = 110 \frac{N}{mm^2}$$

stability

$$\sigma = \frac{F_{Bv} \cdot \omega}{A_{min}} = \frac{55408 \cdot 1,21}{667,24} = 100,48 < \sigma_{Ddoz} = 110 \frac{N}{mm^2}$$

4. CONCLUSIONS

Considering the facts presented in this paper it can be concluded:

- The maximal values of the stress in different sections of the horizontal and the slanting supporter satisfy the design safety
- The stress and the stability of the supporting tube support satisfy the design safety.
- The constructed device can be used for transport of the sheet metal that exceeds the overall truck width.

The constructed device has been put in operation by Transport Company and successfully operates for several years in the international transport. Thus, the most important verification of the construction has been done by successfully exploiting it in practice.

REFERENCES

[1] CHEN W.F., LUI E.M, *Handbook of Structural Engineering*, 2nd Edition, CRC Press, 2005

[2] SPYRAKOS K., *Finite Element Modelling in Engineering Practice*, Algor Publishing Division, Pittsburgh, 1996

[3] SPYRAKOS K., RAFTOYIANNIS J., *Finite element Analysis in Engineering Practice*, Algor Publishing Division, Pittsburgh, 1997

[4] BEERMAN H.J., Analysis of Commercial Vehicle Structures, Verlag TUV Rheinland, Koln, 1986

[5] VINSON J.R., *The behaviour of Thin Walled Structures Beams, Plates, and Shells*, Kluwer Academic Publishers, Dordrecht, 1989

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THE FIFTH INTERNATIONAL CONFERENCE
TRANSPORT AND LOGISTICS

til 2014

INVESTIGATION OF OPERATING TEMPERATURE OF SPUR GEARS USING CVFEM

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Abstract

Friction that occurs during operation of the spur gears, on the meshing flanks of its teeth, causes heating of the teeth, which could lead to the formation of different surface defects. Proper choice of gear geometry may reduce the friction and operating temperature of the gear, preventing surface defects in order to increase its reliability. Therefore, this paper deals with a sensitivity analysis of operating temperature to changes of spur gear geometry over a range of applied load and rotational speed. The final reduction of the main gearbox of helicopter's rotor head, consisted of a bull gear with two spur gear inputs, is an example of spur gears used in an air transporter. The control volume finite element model – CVFEM, using three-noded triangular elements, has been employed to investigate spur gear frictional heating over a range of gear dimensions. The results obtained by this investigation involve distributions of contact pressure, sliding velocity, coefficient of friction, frictional heat flux and temperature along meshing flank of the tooth, as well as, temperature distribution of the tooth body.

Keywords: *spur gear, operating temperature, gear geometry, CVFEM*

1.INTRODUCTION

The teeth profile and the dimensions of the spur gears affect the distribution of load and contact pressure, as well as sliding velocity along pressure line of the meshed teeth. Relative sliding of meshed teeth under high rotational speed of gears causes the appearance of intense friction that causes heat generation, which leads to a significant heating of the surface of teeth. Heat generated by friction is conducted in gear teeth and simultaneously taken away over the teeth flanks by the cooling oil. This process leads to heating of gear teeth and the formation of uneven temperature field with maximum temperatures at the meshing teeth flank which results in uneven thermal stress filed and may lead to formation of surface defects, such as hot scoring, wear and surface pitting. Therefore, proper choice of the teeth profile and the dimensions is very important in order to prevent surface defects caused by frictional heating of the spur gears. An example of spur gears used in an air transporter is the final reduction of the main gearbox of helicopter's rotor head as shown in figure 1.

Fig.1. Main gearbox of helicopter's rotor head

The main gearbox of helicopter's rotor head has as its final reduction a bull gear with two spur gear inputs as shown in figure 2.

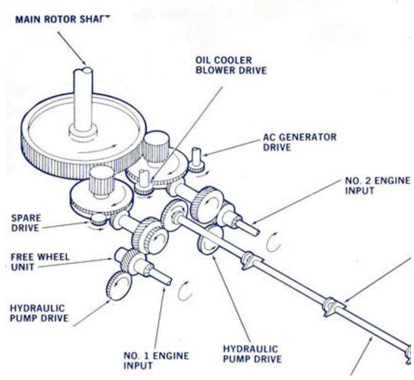

Fig.2. Scheme of main gearbox of rotor head of Sikorsky S-76 helicopter

Previous studies of the frictional heating of the gears are mainly in the field of numerical modeling and experimental measurements [1-6]. Developed numerical models were used to investigate the influence of gear geometry and other influental parameters on the distribution of operating temperature along the pressure line of meshed gears. The influence of face width, outside diameter and pitch diameter [2,3], as well as, face width and module [4] on the distribution of operating tamperature of the gear were investigated by these models. The result of these investigations are insufficient for complete understanding of the gear geometry influence to distribution of its operational temperature. Therefore, this paper deals with a sensitivity analysis of operating temperature to changes of medium speed spur gear geometry over a range of applied load and rotational speed in order to achieve deeper insight into influence of gear geometry to distribution of its operating temperature. Control volume finite element model [5], using three-noded triangular elements, has been employed to investigate spur gear frictional heating over a range of gear dimensions.

2.METHODS

2.1.Heat equations and boundary conditions

The governing equation of two-dimensional transient heat conduction is described by the following equation:

$$\frac{\partial T}{\partial t} = \alpha \cdot \nabla^2 T \tag{1}$$

where $\nabla^2 = \partial^2/\partial x^2 + \partial^2/\partial y^2$, α is thermal diffusivity and $T=T(x,y)$ is temperature changing with time t and position (x,y).

Fricition that occurs during the meashing of gears on the contact surface of the teeth causes them to heat, which, in conditions of constant load, after a certain time, i.e., number of revolutions, ends by reaching an equilibrium state. Change of the temperature field of the teeth during an equilibrium state are negligible because the heat generated by friction is mainly taken away by cooling lubricant. Since each gear tooth during operation passes through the same cycle that is consisted of frictional heat, then convective cooling and conduction, transient heat conduction of the gear can be analysed by a single-tooth model shown in figure 3.

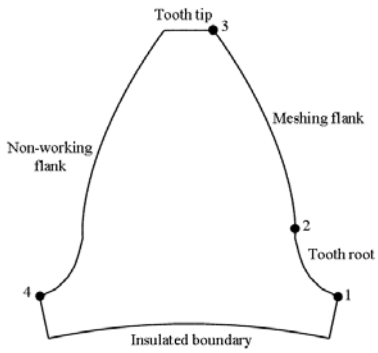

Fig.3. Single tooth model of the gear

Convective boundary conditions for different boundaries are specified as follows:

$$-\left.\frac{\partial T}{\partial n}\right|_{1-2} = -\left.\frac{\partial T}{\partial n}\right|_{3-4} = h \cdot \left(T - T_{oil}\right)$$

$$-\left.\frac{\partial T}{\partial n}\right|_{2-3} = h \cdot \left(T - T_{oil}\right) + q_F \tag{2}$$

$$\left.\frac{\partial T}{\partial n}\right|_{4-1} = 0$$

where h is heat transfer coefficient, q_F is frictional heat flux, T_{oil} is lubricant temperature.

2.2.Frictional heat

Teeth flanks of the meshed gears slide one by another, due to that, the friction occurs at the meshing point that causes frictional heating of the gears. The intensity of the friction that occurs at the contact of teeth of the meshed gears is determined by the coefficient of friction which depends upon many parameters, such as geometry, load, velocities and surface roughness of the meshed gears and lubricant viscosity. Model for determining the friction coefficient of contact surfaces proposed by Winter and Michaelis [7], which is used for this research, is given by the following expression:

$$\mu = 0.002 \cdot \left(\frac{2 \cdot F_N}{b \cdot \cos\varphi \cdot \left(v_{t1} + v_{t2}\right) \cdot R}\right)^{0.2} \cdot \eta^{-0.05} \cdot X_R \tag{3}$$

where where F_N is normal force at meshing point, b is gear width, φ is pressure angle, R is equivalent radius of curvature at meshing point, v_{t1} and v_{t2} are velocities in the direction of the tangent at meshing point of the pinion and gear, η is dynamic viscosity, and X_R is roughness factor. Determination of F_N, R, v_{t1} and v_{t2}, η, and X_R is fully explained in [5].

The heat flux generated by friction of the teeth of the pinion and gear in an arbitrary meshing point, according to Long et al. [4] can be determined by the following equations:

$$\begin{aligned} q_1 &= \beta \cdot \gamma \cdot \mu \cdot p \cdot \left(v_{t1} - v_{t2}\right) \\ q_2 &= \left(1 - \beta\right) \cdot \gamma \cdot \mu \cdot p \cdot \left(v_{t1} - v_{t2}\right) \end{aligned} \tag{4}$$

Contact pressure p at meshing point is determined by Hertzian contact theory as the average compressive pressure for a meshing point as explained in [5]. The heat conversion factor γ is defined to be 0.95 and the partition constant of the heat between the contact areas of the meshing teeth β is 0.5 [4]. During each revolution every tooth of the pinion and gear is only once at the contact when receives heat input which is equal to the average frictional heat flux, which can be expressed as:

$$q_{F1} = \frac{a \cdot n_1}{60 \cdot v_{t1}} \cdot q_1 \text{ and } q_{F2} = \frac{a \cdot n_2}{60 \cdot v_{t2}} \cdot q_2 \tag{5}$$

where n_1 and n_2 are rotational speeds of the pinion and gear, and a is width of the teeth contact area.

2.3.Heat transfer coefficient

Lubrication and cooling of the pinion and gear is realized by jet lubrication. DeWinter and Blok [8] have developed a model to estimate the heat transfer coefficient on the flank of the gear tooth for this lubricating and cooling method:

$$h = \sqrt{\frac{n}{2 \cdot \pi} \cdot k \cdot \rho \cdot c \cdot \left(\frac{v_o \cdot H}{\alpha \cdot r}\right)^{0.25}} \cdot q_n \tag{6}$$

where n is rotational speed, k is lubricant conductivity, ρ is lubricant density, c is lubricant specific heat, ν_o is lubricant kinematic viscosity, α is lubricant thermal diffusivity, H is height of meshing point, r is radius of meshing point, and q_n is normalized cooling capacity.

2.4.Control volume finite element method

The governing equation of transient heat conduction (1) could be alternatively expressed in the integral form:

$$\frac{d}{dt}\int_A T \cdot dA = \oint_S \alpha \cdot \nabla T \cdot n \cdot dS, \qquad x \in \Omega \tag{7}$$

where Ω is arbitrary two dimensional domain. In this research domain Ω is gear tooth geometry shown in figure 4.

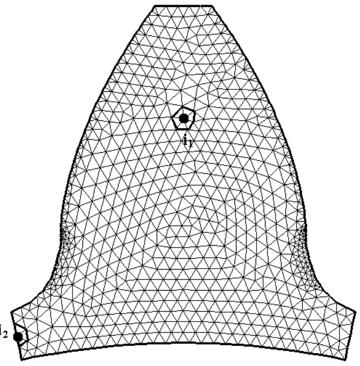

Fig.4. Gear tooth geometry with mesh of triangular elements

The key objective of CVFEM is to reduce the integral form of equation (7) to set of discrete algebraic equations in the unknown nodal values of temperature. First step of this procedure is meshing two dimensional domain into mesh of linear triangular elements shown in figure 4. The continuous unknown field of temperature over triangular elements, can be expressed as the linear combination of the temperature values at nodes placed at the vertices of triangular elements:

$$T(x,y) = \sum_{j=1}^{3} N_j(x,y) \cdot T_j \tag{8}$$

where $N_j(x,y)$ are shape functions and T_j are nodal temperature values. For each node i in the mesh the region of support, shown in figure 2, is identified by counting and listing all the neighboring nodes j that share a common element side with node i. Using numerical integration and shape function aproximations of temperature (8) in each element of i^{th} support, equation (7) is expanded in terms of nodal values of temperature in the region of support. On gethering terms, the resulting equation for node i can be written in the discrete form:

$$a_i \cdot T_i = \sum_{j=1}^{Ns_i} a_{i,j} \cdot T_{i,j} + b_i \tag{9}$$

where a_i is coefficient associated with the unknown nodal values of T_i and $a_{i,j}$ are coefficients associated with the unknown nodal values of $T_{i,j}$ at neighboring nodes in the i^{th} support, and the additional coefficient b_i accounts for the contribution from sources, transients and boundaries. Equation (9) provides an algebraic relationship between the value of temperature at node i and the neighboring nodes j in its region of support.

A fully implicit scheme has been used to solve CVFEM equations (10) and to determine the nodal field values of temperature T_i:

$$\begin{aligned}&(V_i + B_{Ci}) \cdot T_i^{t+\Delta t} = V_i \cdot T_i^t + \\ &\Delta t \cdot \left(\sum_{j=1}^{Ns_i} a_{i,j} \cdot T_{i,j}^{t+\Delta t} - a_i \cdot T_i^{t+\Delta t} \right) + B_{Bi}\end{aligned} \tag{10}$$

where V_i is control volume of node i, B_{Bi} and B_{Ci} are coefficients of CVFEM boundary conditions, Δt is time step. Determination of coefficients a_i, $a_{i,j}$, b_i, B_{Bi} i B_{Ci} is fully explained in [9]. Gauss-Seidel iterative solver has been used to find solution of CVFEM equations.

3.RESULTS AND DISCUSSION

CVFEM model of spur gear frictional heating was tested and verified in the paper [5]. This verification was performed by the comparison of the results obtained by the CVFEM model with results of experimental measurements of spur gear tooth temperatures conducted by Long et al. [4]. These measurements are realized for rotational speeds of 2000, 4000 and 6000 r/min and the load cases A, B, C, D, E, F and G given respectivelly by values of torque 17.4 Nm, 26.0 Nm, 35.0 Nm, 43.0 Nm, 52.0 Nm, 61.0 Nm and 73.0 Nm.

Geometric properties of investigated spur gear set are as follows: number of teeth z_1=15 and z_2=16, module m=5.33 mm, pressure angle φ=26°, width b=4.775 mm, and coefficient of profile shift x_1=x_2=0. The material of the pinion and gear is 665M17 (EN-34) steel with the following mechanical and thermal properties: Young's modulus E=185.42 GPa, Poisson's ratio ν=0.3, thermal conductivity k=41.8 $Wm^{-1}K^{-1}$ and thermal diffusivity α=$1.077 \cdot 10^{-5}$ m^2s^{-1}. Gear set is case-hardened and ground to a surface finish of 0.6 μm Ra. The lubricant oil, applied via spray system, is Mobile Jet II with the following properties: density ρ=998 kgm^{-3}, kinematic viscosity ν_o=$27.6 \cdot 10^{-6}$ m^2s (40 °C), ν_o=$5.1 \cdot 10^{-6}$ m^2s (100 °C), thermal conductivity k=0.1337 $Wm^{-1}K^{-1}$ (37.8 °C), k=0.1278 $Wm^{-1}K^{-1}$ (93.3 °C), specific heat c=2000 $Jkg^{-1}K^{-1}$ (90 °C) and oil temperature T_{Oil}=90 °C.

In order to investigate an influence of gear geometry on the distribution of its operating temeperature a serie of gear models is generated with variation of coefficient of profile shift regarding to gear set used for model verification [5]. Dimension range of interest for this research is x_1=(-0.4÷0.2). Geometries of the pinion tooth with different values of coefficient of profile shift and corresponding triangular finite element meshes are generated. Finite element mesh of each model involved not more than 1000 nodes. The positions of all nodes on each tooth boundaries are identified. Then heat flux and heat transfer coefficient in all nodes along meshing flank of the pinion tooth for different combinations of rotational speeds and load cases are determined. Afterwards, transient heat analysis of the frictional heating of the pinion was carried out. As an example, obtained distributions of tooth temperature for T=73 Nm and n=10000 rpm are shown in figure 5.

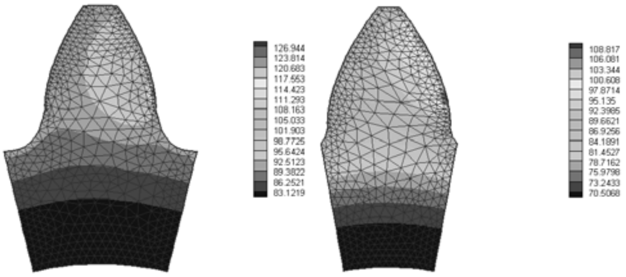

Fig.5. Distribution of tooth temperature of the pinion a) x1=-0.4 and b) x1=0.2

Obtained temperature distributions show that gear temperature increases with increase of rotational speed and even more intense with increase of load. Temperature distributions also show that the maximum temperature occurs on the meshing flank of the pinion tooth in the zone below the pitch circle, which was expected according to obtained distribution of heat flux. Temperature distributions are smoother for lower rotational speeds and loads and more uneven for higher rotational speeds and loads with very strong temperature peaks on mashing flank of the pinion tooth located below the pitch circle at the position of maximum temperature and above the pitch circle at the position of another local maxumum of temperature. This is shown in figure 6.

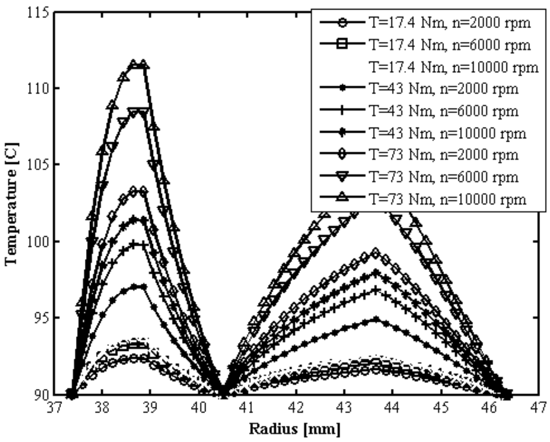

Fig.6. Temperature distribution along the tooth meshing flank of the pinion with x1=0.2

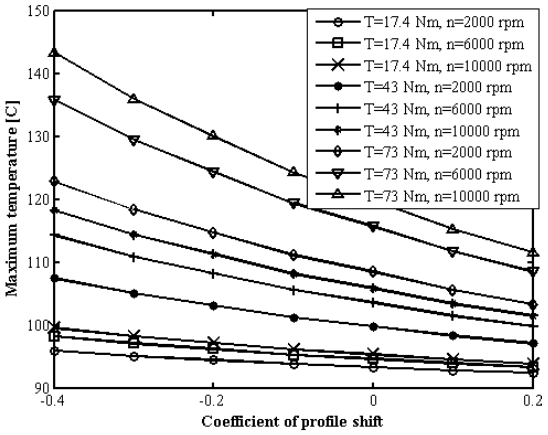

Fig.7. Coefficient of profile shift versus gear maximum temperature

Increase of coefficient of profile shift significantly influences on decrease of gear maximum temperature as shown in figure 7. Curves in figure 7 confirm this conclusion especially for high load gears. For example, increase of coefficient of profile shift from -0.4 to 0.2 causes temperature reduction up to 23%.

4.CONCLUSION

The CVFEM models with different combinations of operating conditions and gear geometries are established for evaluating the influences of operating conditions and gear geometry on tooth temperature variations. According this models the zone of highest operational temperature of gear is its meshing flank. There are two temperature peaks along meshing flank one below and another above the pitch circle. The maximum gear temperature for each investigated case is at the peak below the pitch circle. Regarding operating conditions, load is more influencing on the gear maximum temperature than rotational speed. High loads also cause more uneven distribution of gear tooth temperature with two very distinct temperature peaks along its meshing flank. Regarding gear dimensions, distribution of the gear tooth temperature is quite sensitive to changes of its coefficient of profile shift. Sensitivity of distribution of tooth temperature of the gear to changes of its geometry increases with increase of load magnitude.

REFERENCES

[1] Terrauchi, Y., Mori, H. (1974), Comparison of theories and experimental results for surface temperature of spur gear teeth, Journal of engineering for industry, 96

[2] Wang, K.L, Cheng, H.S. (1981), A numerical solution to the dynamic load, film thickness and surface temperatures in spur gears, Part I:Analysis, Journal of mechanical design,103

[3] Wang, K.L, Cheng, H.S. (1981), A numerical solution to the dynamic load, film thickness and surface temperatures in spur gears, Part II:Results, Journal of mechanical design,103

[4] Long, H., Lord, A.A., Gethlin, D.T., Roylance, B.J. (2003), Operating temperatures of oil-lubricated medium-speed gears: Numerical models and experimental results, Proceedings of institution of mechanical engineers, Part G: Journal of aerospace engineering, 217

[5] Jovanović J.D., Tombarević E.M., Vušanović I.Ć. (2013), Control volume finite element method for modeling of spur gear frictional heat, TTEM, Vol.8, No.2

[6] Koshigoe, S., Murdock, J.W., Akin, L.S., Townsend, D.P. (1996), A computer program for the computation of running gear temperatures using Green's function, NASA technical report ARL-TR-1117, USA

[7] Winter, H, Michaelis, K. (1983), Scored load capacity of gears lubricated with EP-oils, AGMA technical meeting, Montreal, Canada

[8] DeWinter, A., Block, H. (1974), Fling-off cooling of gear teeth, Journal of engineering for industry, 96

[9] Voller, V.R. (2009), Basic control volume finite element method in fluids and solids, World scientific publishing Ltd., Singapore.

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SIMULATIONS OF ELEVATOR CABINS LIFTING AND DYNAMIC MODELS

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Abstract

Consideration of passengers travelling problems in an elevator car represents the study of complex processes and procedures. Nowadays, high ride quality of elevators is demanded. Besides modern elevator cars, we must provide the low vibration and noise levels.
The dynamic characteristics of the elevator car system play a very important role in elevator engineering.
The paper shows the process of forming adequate dynamic models for elevators grouped according to their features, and with this an analysis can be performed of the influence of certain parameters on their behaviour in operation.
Based on the formed elevator models, simulations have been performed, and the obtained results are graphically shown through diagrams, with the conclusions on their influence on elevator behaviour.

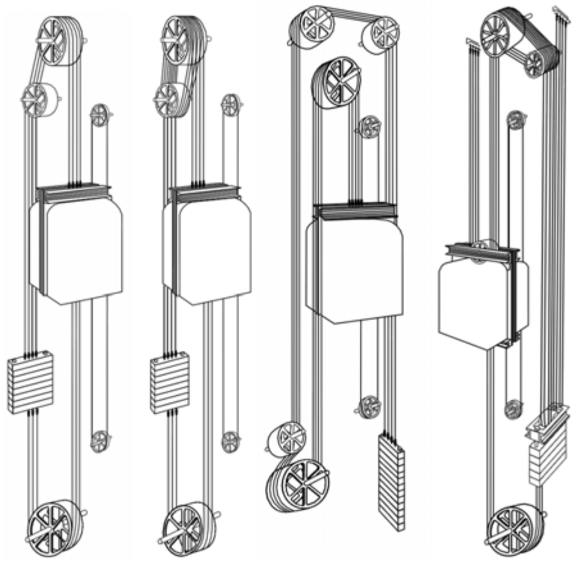
Keywords*: simulations of elevator operating, dynamic models*

1. INTRODUCTION

The problem of force transfer and driving by friction (driving pulley – supporting rope) and dynamic behaviour of certain elements of elevator device in exploitation is the subject of research in many studies and is still not satisfactorily solved as a whole.
At great lifting heights and great lifting velocities, a dynamic model is applied which considers the influence of changing the free rope length in relation to its dynamic behaviour [2], [7] and [8] where different solutions are applied for solving the partial differential equations of movement for the cabin side and the counterweight side. Besides, in [2] there is an analysis of a connection problem between longitudinal and transversal oscillations of the steel rope in exploitation facilities in mining ("Köppe" system).
At low velocities and great heights we observe longitudinal oscillations of the dynamic model with an infinite number of degrees of freedom (oscillations of the steel rope as an elastic stick of constant length) [6].
Driving torque (force) in the transient regime of operation is defined approximately as a time function, depending on the characteristic of a driving motor (soft, medium, and rigid regime). Final solutions for lifting by a driving pulley are obtained based on the equilibrium of torques of both sides.
Ref. [5] shows the problem of longitudinal oscillations and stability of movement of an elastic string with concentrated masses.
With the purpose of solving the stated problems, this paper shows different dynamic models of a drive module and supporting elements which are suitable for elevator analysis depending on their drive characteristics (height, lifting velocities, mechanical characteristics of the rope...). It also shows the simulations of elevator dynamic behaviour for mechanical models of a driving mechanism whose movement is defined through the law of changing the acceleration on a driving pulley (application of classical motors with one and two velocities).

2. DYNAMIC MODELS IN THE LIFTING SYSTEM BY A DRIVING PULLEY

Elevators represent a specific group of transport machines for vertical lifting. Needs of contemporary society have influenced developments of different elevator constructions. Fig. 1 shows some kinematic solutions. Dynamic analysis is a specific problem and it is related to every single case. In real life, most often applied elevators are those whose kinematic scheme is shown in Fig. 1a.



a) b) c) d)
Figure 1. Kinematic solutions for hanging the cabin and counterweight

Since the parameters of a dynamic model depend on masses, mechanical features of the elements' materials, forces which affect the system, rope sliding conditions on a driving pulley..., the dynamic analysis of elevators is a very complicated problem. However, the problem can be greatly simplified [1], based on detailed research of drive lifting, especially the influence of element stiffness on its dynamic behaviour.

Rope modelling is most often done by combining a Hook's model (an ideal elastic body) and a Newton's one (an ideal viscose body), as shown in Fig. 2. For the drive systems with vertical lift, it is justified to observe the rope as a Calvin's or standard model (Fig. 2b and 2c), where the rope is considered as a spring of great stiffness (c) combined with damping (b). Those parameters depend on the construction and load of the rope and they are defined by an experimental method.

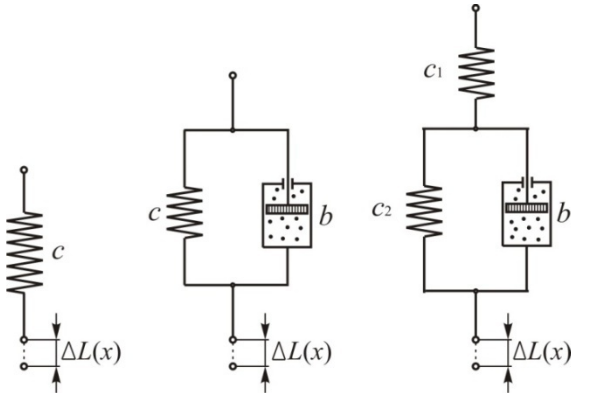


Figure 2. Rheological models of material (a - Hook's ideal elastic body, b - Calvin's model, c - Standard model)

The elevator cabin and counterweight are modelled in most of cases as concentrated masses (rigid elements). However, because of elasticity of the cabin frame, there is a possibility of forming different models, Fig. 3. One can also consider the elasticity of the upper and lower supporters in the cabin frame (m_4) with the stiffness of c_3. That model can be expanded, so one can also consider the elasticity of side supporters (m_5) with c_4 stiffness, as well as elastic leaning on the cabin's guide rails (c_5).

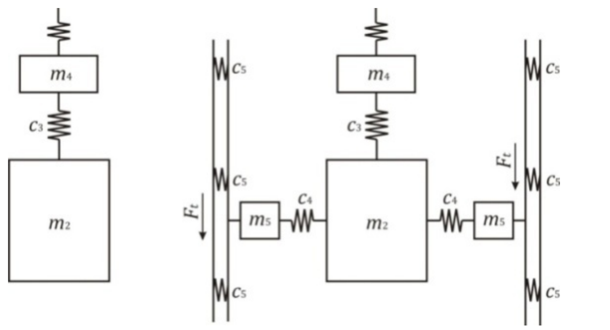


Figure 3. Cabin dynamic models

Besides modelling of the elevator supporting elements and elevator cabin, modelling drive characteristics is also very important. As mentioned before, because of the significant difference between the rope stiffness and the stiffness of driving mechanism elements, when modelling elevators they are observed as absolutely rigid, with the reduction of masses and inertia moments on the shaft of a driving pulley.

Modelling of a driving moment, i.e. driving force, is complicated because it depends on the features of the driving motor, i.e. electromagnetic flux, balance masses, (especially of the first shaft, and the way of control (direct motor supply, motors with one or two velocities, control via frequency regulator...). These influences are defined in electronics through a system of six differential equations which describe the interdependence of mechanical and electric parameters.

It is most common to approximately define the amount of driving force in the transferring operating regime [6], depending on the way of releasing the driving motor, based on these relations:

$$P(t) = P_0 = \text{const., Fig. 4a, (p. 1)}$$

$$P(t) = P_0 \cdot \left(1 - \frac{t}{t_1}\right) \text{ – soft drive regime, Fig. 4a, (p. 2)}$$

$$P(t) = P_0 \cdot \left(1 - \frac{t^2}{t_1^2}\right) \text{ – medium drive regime, Fig. 4a, (p. 3)}$$

$$P(t) = P_0 \cdot \left(1 - \frac{t^4}{t_1^4}\right) \text{ – rigid drive regime, Fig. 4a, (p. 4)}$$

with:

t_1 – acceleration time, s

P_0 – pulled force (moment), N

More precisely, but analytically more difficult, the driving moment can be defined by a so-called "static characteristic of an electrical motor" in the velocity function, or number of revolutions – P=f(v). The moment characteristic of an asynchrone machine in Fig. 4b, has this form according to [4]:

$$M = \frac{q}{2 \cdot \pi \cdot f} \cdot U^2 \cdot p \cdot \frac{\frac{R'_r}{s}}{\left(R_s + \frac{R'_r}{s}\right)^2 + \left(X_{\gamma s} + X'_{\gamma rk}\right)^2} \tag{1}$$

with:

q – number of phases

$f = 50$ – network frequency, Hz

U – change of voltage, V

p – number of pole pairs

s – slip

R_s – stator resistance, Ω

R'_r – narrowed down rotor resistance, Ω

$X_{\gamma s}$ – reactance of overflowing of stator, Ω

$X'_{\gamma rk}$ – narrowed down reactance of rotor overflowing, Ω.

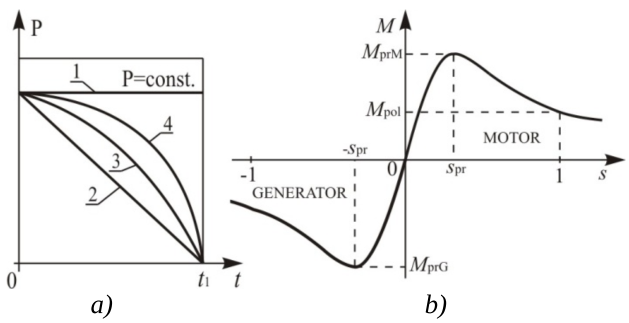


Figure 4. Different drive regimes (a) and static moment characteristic of an asynchronous machine as a function of slip (b), [4]

Apart from the before mentioned, this paper is considering only the dynamic behaviour of the upcoming rope to a pulley for the analysis, which can be expanded to the other cases by analogue procedures. Elevator models depend in the first line on the lifting height and velocity. As real combinations of the two parameters there occur:

- Passenger and freight elevators with small heights and low velocities of lifting, the so-called elevators with small lifting velocities.
- Passenger and freight elevators with great heights and medium velocities of lifting, the so-called elevators with high lifting velocities.
- Passenger elevators and exploitation facilities in mining with great heights and lifting velocities, the so-called express elevators.

The fourth combination (small height and great velocity) is not applied in practice.

3. NUMERAL PROCESS AND ELEVATOR OPERATING SIMULATIONS

Based on the analysis it can be deduced that it is possible to apply with satisfying accuracy the elevator models with reduced cabin masses, counterweight and elements of driving mechanism with the rope models shown in Fig. 5, where we have m_1 – reduced mass of the driving part, m_2 – load and cabin mass, and P – driving force. It is interesting to stress that the rope model, in the shape of an inelastic flexible element, defines the so-called rigid-kinetic elevator model, Fig. 5a, which is used for defining the optimal relation between the cabin weight and counterweight, and it is also very useful for defining the average values of dynamic parameters. Fig. 5b, 5c, 5d show dynamic models with two degrees of freedom, which are often used when analysing elevators. Those cases are analysed in great details in general literature and they are not going to be especially dealt with.

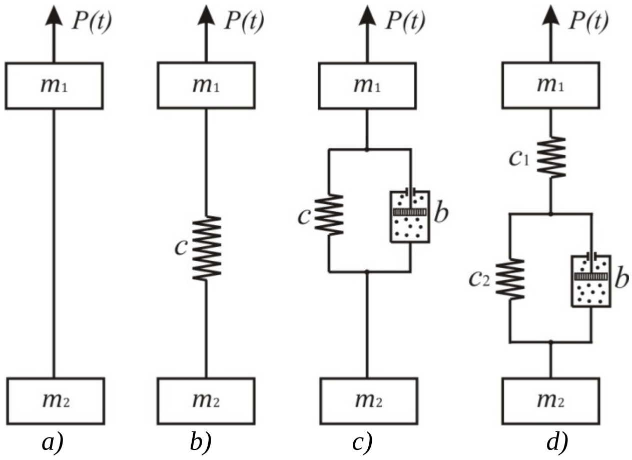


Figure 5. Dynamic model of a supporting element, inelastic element (a), Hook's model (b), Calvin's model (c) and a standard model (d).

At the express elevators, a rope can be seen as a visco-elastic body with varying stiffness. The rope stiffness changes in the function of change of the free rope length, and the basic oscillation form is an approximatelly straight line. However, sliding between the ropes and a driving pulley in the coming point is neglected.

Modelling of movement can be done in various ways through models of driving mechanisms. These are the ways:

- Defining the function for changing the number of revolutions of electrical motor (through the velocity of a driving pulley),
- Defining acceleration on a driving pulley,
- Assigning driving force depending on the way of releasing a driving motor, Fig. 4a,
- Modelling of a driving moment on the rotor of an electrical motor through a "static characteristic", Fig. 4b etc.

This paper represents the case of asigning movement defining acceleration on a driving pulley. In such cases a simulation of dynamic behaviour of elevator elements is performed for different operating regimes (acceleration, stationary movement and breaking).

3.1. Defining the change in number of revolutions and the change of acceleration on a driving pulley

Basic kinematic values which occur in elevators are velocity and acceleration. Due to the comfort in passenger elevators, there are specific acceleration values and velocity shifts, the so-called hitch. By various examinations, boundary values of acceleration and velocity of its shift (hitch) have been determined, and they are: $a_{\max} = 1,4\,\mathrm{m/s}^2$ and $\dot{a}_{\max} = 1\mathrm{m/s}^3$. Kinematic diagrams characteristic for special elevators are given in Fig. 6 and Fig. 7. Such movement diagrams are available when there is a regulated moment of revolution of a driving motor, which is applied on elevators with high lifting velocities and express elevators.

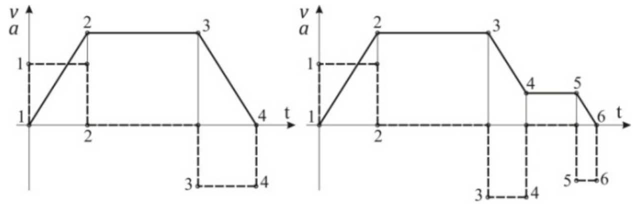


Figure 6. Ideal diagrams of elevator movement for one (a) and two (b) velocities of motor

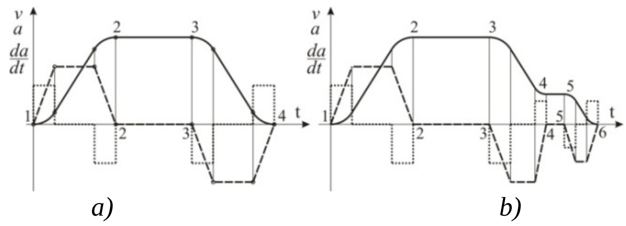


Figure 7. Ideal diagrams of elevator movement for one (a) and two (b) velocities of motor

Setting the movement at elevators is a problem which is not easily and simply solved. Most software does not contain tools for representing the supporting rope - driving pulley system. In such cases one has to use a combination of existing tools in order to get satisfying results. After various attempts of movement, several suitable solutions emerged. Setting a function for chanaging the number of revolutions of an electrical motor can be seen as setting a function for changing the position of a certain marker on the rope in the direction of lifting the cabin. That enables setting a translatory movement on a translatory or cilindric joint, which can simply model the connection of a rope to a driving pulley.

Description of a movement in time can be assigned in many ways, although a combination of commands *If* and *Step* is the most often applyed The *If* command has the following inscription:

IF (expression1: expression2, expression3, expression 4).

Expression1 is actually a variable in a movement function, which is time in this case. If *expression1* is less than a zero, the function equals *expression2*. If it equals zero, the function is equal to *expression3* and when it is bigger than zero, it equals *expression4*.

Step command defines the *Step* function, which is approximately like Heaviside function with a cube polynome. Such function is given in Fig. 8, which is approximatelly suitable to the velocity change in Fig. 7.

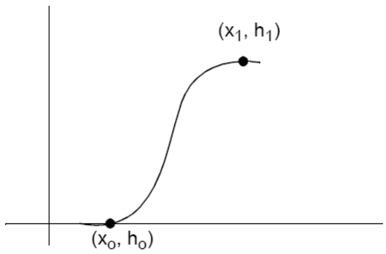


Figure 8. Step function

This equation defines *Step*:

$$Step = \begin{cases} h_0 & : x \le x_0 \\ h_0 + \left(h_1 - h_0\right) \cdot \left[\dfrac{x - x_0}{x_1 - x_0}\right]^2 \cdot \left\{3 - 2 \cdot \left[\dfrac{x - x_0}{x_1 - x_0}\right]\right\} & : x_0 < x < x_1 \\ h_1 & : x \ge x_1 \end{cases}$$

Step command format goes like this:

STEP (x, x_0, h_0, x_1, h_1)

with:

x – independent variable,

x_0 – real variable which defines h value where the *step* function begins,

x_1 – real variable that defines h value where the *step* function ends,

h_0 – the *step* function value at the beginning,

h_1 – the final value of the *step* function.

It should be noted that the movements can be given by displacement, by velocity or acceleration, depending on what is easier to define at a specific moment. In this paper, movements are defined by the If command through acceleration on the driving pulley.

3.2. Movement simulation results defined through acceleration of a driving pulley

The following figures contain diagrams of certain parametres, where instead of the velocity at the driving pulley, acceleration was defined, and it was for cases with and without damping, with the constant and variable rope stiffness.

When defining the movement through rope acceleration on a driving pulley, we discussed the lifting situation where the lifting capacity was 1000 kg, lifiting height 100 m, acceleration 2 m/s^2, and damping 4 Ns/mm.

The function of the change of acceleration is set like this (Fig. 9):

IF(time-5:2000,0,IF(time-9:0,-2000,IF(time-14:-2000,0,0)))

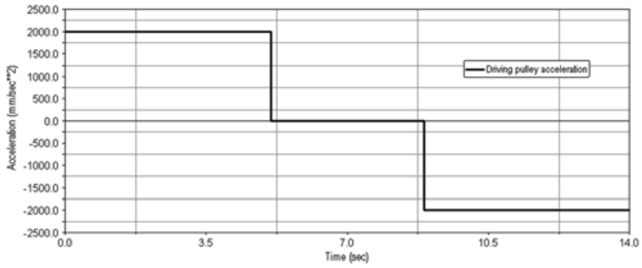


Figure 9. Change of rope acceleration at the point of meeting the driving pulley

The function shows that within the time span 0 to 5 s, the acceleration is constant and equals 2 m/s^2. After that, the cabin moves at a constant velocity (acceleration equals zero) for the next 4 s. Then the breaking begins. In the mentioned expression it is represented with the last *IF* function, according to which the slowing down is constant, amounts to -2 m/s^2, and lasts for the next 5s.

Fig. 10 represents the change in the cabin position and velocity, and the change in the cabin acceleration at the constant rope stiffness during the simulation, with and without inner friction within them. As in the previous example, there is a difference whether the movement was defined through a change in the number of revolutions (velocity at a pulley). Nevertheless, the cause of the difference is a *step* function which makes a "slight" transfer from accelerated to constant velocity movement, which is closer to the real drive operating.

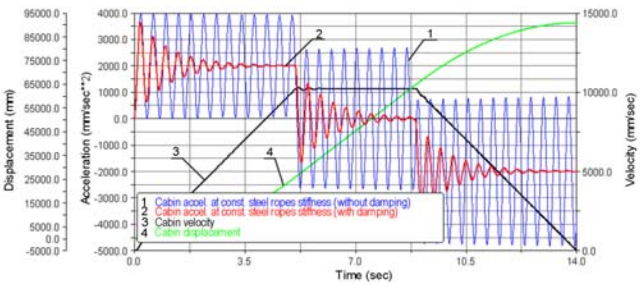


Figure 10. Diagram of the change in position, velocity and acceleration of the cabin with constant rope stiffness, with and without damping

Fig. 11 shows a change in cabin acceleration during the simulation considering the change of stiffness and the quotient of inner friction of supporting ropes. Also, the figure represents time dependence of rope elongation, as well as a change in stiffness. Fig. 12 represents, in the same diagrams, the changes of cabin positions and rope stiffness, as well as the changes in stiffness and rope elongations.

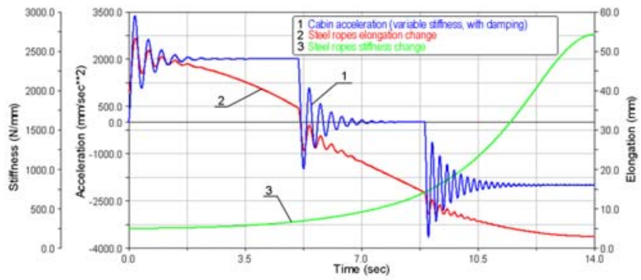


Figure 11. Diagram of the change in cabin acceleration with variable rope stiffness, and rope elongation and stiffness

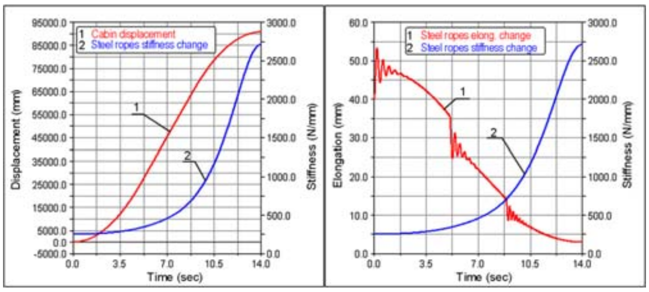


Figure 12. Diagram of the change in cabin position, elongation and stiffness of driving pulleys

CONCLUSION

The paper represents the procedures and methods of elevator modelling, depending on their features, with the application of numerical methods and contemporary software packages. The represented dynamic elevator models enable to grasp the most influential parametres which occur during their exploitation.

The dynamic models provided in the paper enable simulations of elevator behaviour with a defined pulley movement. Based on the previous analysis, we came to the conclusion that:

- It is possible to analyse the influence of weight of the cabin, cabin load, lifting height, rheological rope features (E,A, b, c,...) influences of various movement diagrams (the defined movement through a control system).
- The influence of the change in stiffness can be neglected at small lifiting heights, especially in the cases when there is bigger inner friction within supporting ropes,
- At greater lifting heights, one must take into consideration the influence of the change in stiffness, because it strongly influences the size of dynamic load, especially at high movement velocities and low inner friction, i.e. damping,
- Simulation results can be used for determining control parameters (determining an optimal moment of change from accelerated to stationary movement and breaking), aiming at decreasing the dynamic load,

With the aim of verification and comparing the results obtained from the simulations of dynamic models for different parameters, represented in this paper, the paper predicts experimental research.

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REFERENCES

[1] R. Đokić, “Development of analitic-numerical procedures for determining of elevator's dynamic behaviour”, Master thesis, Faculty of Technical Sciences, Novi Sad, 2010. (org. in Serbian)

[2] S. Kaczmarczyk, W. Ostachowicz, “Transient vibrat. phenomena in deep mine hoisting cables”, Journal of Sound and Vibration 262 (2003), pp. 219-244

[3] H. Kimura, H. Ito, T. Nakagawa, “Vibration analysis of elevator rope (Forced vibration of rope with time-varying length)”, Journal of Environment and Engineering, Vol. 2, No. 1, 2007., pp. 87-96.

[4] E. Levi, V. Vučković, V. Strezoski, “Fundamentals of electrical engineering (Power converters)”, Faculty of Technical Sciences Novi Sad, 1996. (org. in Serbian)

[5] M. Pakdemirli, A.G. Ulsoy, “Stability analysis of an axially accelerating string”, Journal of Sound and Vibration, 203, 5 (1997), pp. 815-832.

[6] В. Ф. Столярчук, “Dynamic of Vertikal Lifting”, University of L'viv, 1965. (org. in Russian)

[7] J. Vladić, P. Malešev, R. Šostakov, N. Brkljač, “Dynamic analysis of the load lifting mechanisms”, Strojniški vestnik, 54, 10 (2008), pp. 655-661.

[8] J. Vladić, R. Đokić, M. Kljajin, M. Karakašić, “Modelling and simulations of elevator dynamic behaviour”, Tehnički vjesnik/Technical Gazette, Vol. 18, No. 3, Slavonski Brod, July - September 2011., pp. 423-434.

[9] J. Vladić, R. Đokić, “Dynamic simulations and type of electrical elevators models“, Machine Design, Vol. 4, No. 4 (2012), ISSN 1821-1259, pp. 219-224.

[10] B. Vujanović, “Theory of oscilations”, University of Novi Sad, 1995. (org. in Serbian)

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APPLICATION OF COPRAS METHOD FOR SUPPLIER SELECTION

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Abstract

Evaluation of alternative suppliers and selection of the most appropriate has always been viewed as the most important responsibility of logistics management. Although a large number of mathematical approaches are proposed to evaluate and select the alternative suppliers, this paper explores the applicability and capability of recently developed method i.e. complex proportional assessment (COPRAS) for supplier selection. The methodology of COPRAS method for the supplier performance evaluation for a firm that manufactures agricultural and construction equipment was given and the results were compared with those derived by the past researchers.

Keywords: *supplier selection, COPRAS, decision making.*

1. INTRODUCTION

In today's highly competitive and interrelated manufacturing environment, the effective selection of suppliers is very important to the success of a manufacturing firm. Many manufacturing firms have given increased attention to strategic supplier selection in an effort to reduce the number of suppliers to support JIT manufacturing [1]. Supplier selection decisions are an important component of production and logistics management for many companies [2].

Supplier selection is a multi-criteria decision making problem involving a set of different and opposite criteria. Information and communication technology, financial position, flexibility in meeting customer needs, reputation and position in industry, attitude, flexibility, packaging ability, management and organization, geographical location, production facilities and capacity, personnel capability, warranties and claim policies, repair service, payment options, parity, cost can be considered as main criteria that influence the supplier selection of a given product in a supply chain management.

Various multi-criteria decision-making (MCDM) methods and different optimization techniques have been proposed to aid the supplier selection process. Decision analysis is concerned with those situations where a decision maker has to choose the best alternative among several candidates while considering a set of conflicting criteria [3]. In order to evaluate the overall effectiveness of the candidate alternatives, rank and select the most appropriate (the best) supplier, the primary objective of an MCDM method is to identify the relevant supplier selection problem criteria, assess the alternatives information relating to those criteria and develop methodologies for evaluating the significance of criteria.

Bayazit [4] explored the use of ANP methodology as a method for supplier selection. Šimunović et al. [5] applied AHP method for the purpose of systematic evaluation and selection o of suppliers. Liu et al [1] proposed and demonstrated the use of data envelopment analysis (DEA) in evaluating the overall performances of suppliers in a manufacturing firm. Kwang [6] proposed a combined scoring method with fuzzy expert systems approach to perform the supplier assessment. Feng et al. [7] presented a stochastic integer programming approach for simultaneous selection of tolerances and suppliers based on the quality loss function and process capability indices. Linear programming as one of the techniques of operational research, integrated with other methods, is applied in the papers [8, 9]. Shyur and Shih [10] proposed a hybrid MCDM model using ANP and TOPSIS methods for strategic supplier selection. Wadhwa and Ravindran [11] presented multi-objective optimization methods including weighted objective, goal programming and compromise programming. Venkata Rao [12] presented a logical procedure for solving the vendor selection problem in a supply chain environment with multiple objectives which is based on a combined AHP and genetic algorithm method. Kumar and Roy [13] proposed hybrid modeling approach by using AHP and artificial neural network to assess supplier performance. An extensive review of MCDM methids for supplier evaluation and selection is given by Ho et al. [14].

As seen from literature, many MCDM methods have been proposed for solving supplier selection problem. However, there is need for a systematic and simple mathematical approach for efficient and effective evaluation of competitive suppliers. In this paper, an attempt is made to explore the applicability and capability of recently developed MCDM method, i.e. complex proportional assessment (COPRAS) method for selection of the most appropriate supplier. Till date, COPRAS method has very limited application in the logistics domain.

2. COPRAS METHOD

The preference ranking method of complex proportional assessment (COPRAS) method was developed by Zavadskas et al. [15]. In this method, the influence of maximizing and minimizing criteria on the evaluation result is considered separately. The selection of the best alternative is based considering both the ideal and the anti-ideal solutions. The main procedure of COPRAS method includes several steps [3].

Step 1: Set the initial decision matrix, X.

$$X = \left[x_{ij}\right]_{m \times n} = \begin{bmatrix} x_{11} \; x_{12} \dots x_{1n} \\ x_{21} \; x_{22} \dots x_{2n} \\ \dots \; \dots \; \dots \; \dots \\ x_{m1} \; x_{m2} \dots x_{mn} \end{bmatrix} \tag{1}$$

where x_{ij} is the assessment value of i-th alternative in respect to j-th criterion, m is the number of alternatives and n is the number of criteria.

Step 2: Normalization of the decision matrix by using the following equation:

$$R = \left[r_{ij}\right]_{m \times n} = x_{ij} / \sum_{i=1}^{m} x_{ij} \tag{2}$$

Step 3: Determination of the weighted normalized decision matrix, D, by using the following equation:

$$D = \left[y_{ij}\right]_{m \times n} = r_{ij} \cdot w_j, \, i = 1,...,m, \; j = 1,...,n \tag{3}$$

where r_{ij} is the normalized performance value of i-th alternative on j-th criterion and w_j is the weight of j-th criterion.

The sum of weighted normalized values of each criterion is always equal to the weight for that criterion:

$$\sum_{i=1}^{m} y_{ij} = w_j \tag{4}$$

Step 4: In this step the sums of weighted normalized values are calculated for both the beneficial and non-beneficial criteria by using the following equations:

$$S_{+i} = \sum_{j=1}^{n} y_{+ij}, \, S_{-i} = \sum_{j=1}^{n} y_{-ij} \tag{5}$$

where y_{+ij} and y_{-ij} are the weighted normalized values for the beneficial and non-beneficial criteria, respectively.

Step 5: Determination the relative significances of the alternatives, Q_i, by using the following equation:

$$Q_i = S_{+i} + \frac{S_{-min} \cdot \sum_{i=1}^{m} S_{-i}}{S_{-i} \cdot \sum_{i=1}^{m} \left(S_{-min} / S_{-i}\right)}, \, i = 1,...,m \tag{6}$$

where S_{-min} is the minimum value of S_{-i}.

Step 6: Calculation of the quantitative utility, U_i, for i-th alternative by using the following equation:

$$U_i = \frac{Q_i}{Q_{max}} \cdot 100\% \tag{7}$$

where Q_{max} is the maximum relative significance value.

As a consequence of Eq. 6, utility values of the candidate alternatives range from 0% to 100%.The greater the value of U_i, the higher is the priority of the alternative. Based on alternative's utility values a complete ranking of the competitive alternatives can be obtained.

3. SUPPLIER SELECTION AND DISCUSSION OF THE RESULTS

In this paper a case study presented by Liu et al. [1] was considered. The authors demonstrated the supplier performance evaluation using DEA method for a firm that manufactures agricultural and construction equipment. The multi-criteria decision making problem with the goal (the supplier selection), criteria and alternatives is shown in Figure 1.

As could be seen from Figure 1, five criteria for the best supplier selection were proposed i.e. price, quality, delivery performance, distance and supply variety. Also, multi-criteria decision making problem involves assessment and ranking of 18 alternatives (suppliers). Price and distance to the category of "non-beneficial" criteria, and smaller assessment values are preferred. On the other hand quality, delivery performance and supply variety are "beneficial" criteria and higher values are preferred. The data for the assessment of alternatives are given in Table 1.

The application of COPRAS method for ranking of alternative suppliers begins with normalization of decision matrix. Firstly by using Eq. 2 the normalized decision matrix is obtained (Table 2).

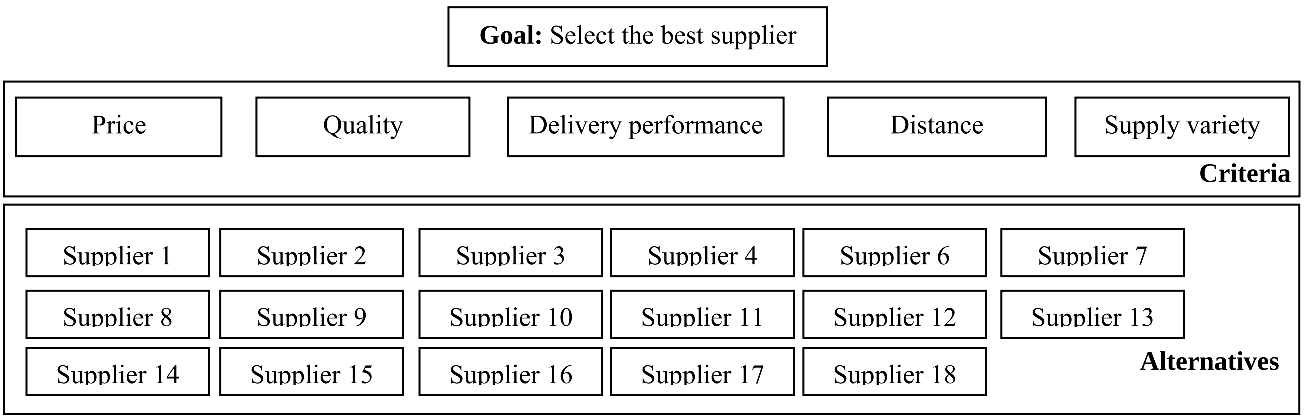

Fig. 1 Structure of MCDM problem for the supplier selection

Table 1. Decision matrix for supplier selection problem

	Price ($)	Quality (%)	Delivery performance (%)	Distance (miles)	Supply variety
Goal	Min	Max	Max	Min	Max
Supplier 1	100	100	90	249	2
Supplier 2	100	99.79	80	643	13
Supplier 3	100	100	90	714	3
Supplier 4	100	100	90	1809	3
Supplier 5	100	99.83	90	238	24
Supplier 6	100	96.59	90	241	28
Supplier 7	100	100	85	1404	1
Supplier 8	100	100	97	984	24
Supplier 9	100	99.91	90	641	11
Supplier 10	100	97.54	100	588	53
Supplier 11	100	99.95	95	241	10
Supplier 12	100	99.85	98	567	7
Supplier 13	100	99.97	90	567	19
Supplier 14	100	91.89	90	967	12
Supplier 15	80	99.99	95	635	33
Supplier 16	100	100	95	795	2
Supplier 17	80	99.99	95	689	34
Supplier 18	100	99.36	85	913	9

Table 2. Normalized decision matrix for supplier selection problem

	Price ($)	Quality (%)	Delivery performance (%)	Distance (miles)	Supply variety
Goal	Min	Max	Max	Min	Max
Supplier 1	0.0568	0.0560	0.0547	0.0193	0.0069
Supplier 2	0.0568	0.0559	0.0486	0.0499	0.0451
Supplier 3	0.0568	0.0560	0.0547	0.0554	0.0104
Supplier 4	0.0568	0.0560	0.0547	0.1404	0.0104
Supplier 5	0.0568	0.0559	0.0547	0.0185	0.0833
Supplier 6	0.0568	0.0541	0.0547	0.0187	0.0972
Supplier 7	0.0568	0.0560	0.0517	0.1090	0.0035
Supplier 8	0.0568	0.0560	0.0590	0.0764	0.0833
Supplier 9	0.0568	0.0560	0.0547	0.0497	0.0382
Supplier 10	0.0568	0.0547	0.0608	0.0456	0.1840
Supplier 11	0.0568	0.0560	0.0578	0.0187	0.0347
Supplier 12	0.0568	0.0559	0.0596	0.0440	0.0243
Supplier 13	0.0568	0.0560	0.0547	0.0440	0.0660
Supplier 14	0.0568	0.0515	0.0547	0.0750	0.0417
Supplier 15	0.0455	0.0560	0.0578	0.0493	0.1146
Supplier 16	0.0568	0.0560	0.0578	0.0617	0.0069
Supplier 17	0.0455	0.0560	0.0578	0.0535	0.1181
Supplier 18	0.0568	0.0557	0.0517	0.0709	0.0313

The decision maker express or define the ranking i.e. significance (relative importance) of criteria by assigning weighting coefficients. It may be added here that relative importance of criteria may be expressed either with ordinal (qualitative) or cardinal (quantitative) level data, or a mix of both. Using the AHP method, Venkata Rao [2] determined the significance of each criterion, i.e. criteria weighting coefficients as: w_{price}=0.1361, $w_{quality}$=0.4829, $w_{delivery\ performance}$ =0.2591, $w_{distance}$=0.0438 and $w_{supply\ variety}$=0.0782. For the comparison purpose the same weighting coefficients are considered.

By using Eq. 3 the weighted normalized decision matrix is obtained (Table 3). As mentioned earlier, the purpose of normalization is to obtain dimensionless values of different supplier selection criteria so that all these criteria can be compared.

By applying Eq. 5 sums of weighted normalized values are calculated for all criteria. Subsequently, relative significance (priority) of each alternative was obtained by using Eq. 6 (Table 4).

Finally, by using Eq. 7, quantitative utility for each alternative was calculated upon which the final ranking was obtained (Table 5).

From Table 5, the ranking of the alternative suppliers is observed as 10-17-15-8-6-5-13-11-12-9-2-18-16-14-3-4-1-7. Hence the best choice is supplier 10. Supplier 17 is the second choice and the third choice is supplier 15 and these results match with those of Liu et al. [1]. The last ranked alternative is supplier 7. Venkata Rao [2] obtained a ranking of the alternative suppliers as 10-17-15-6-5-8-13-11-12-9-2-1-16-14-3-18-4-7 while solving the problem using the TOPSIS method. Figure 2 compares the ranking performance of COPRAS method with respect to TOPSIS method by Venkata Rao [2]. The results do not show much difference between COPRAS and TOPSIS method except in the rankings of the middle rated alternatives. It can be observed that supplier 10 received the highest attention by all methods, hence may be regarded as the most appropriate.

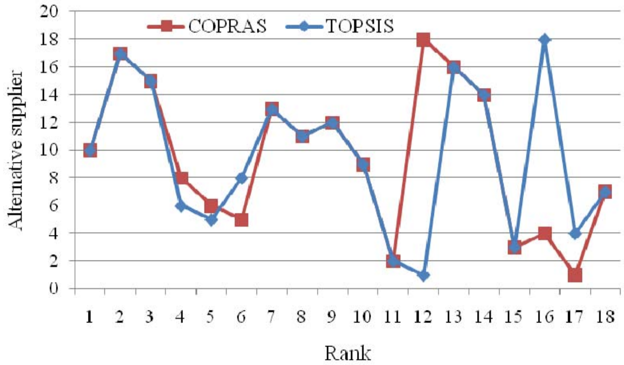

Fig. 2 Comparative rankings of CORPAS and TOPSIS

In some cases it may be advantageous to develop and maintain high quality relationships with several suppliers in order to maximize profitability, minimize risk and achieve competitive advantage. As noted by Liu et al. [1], with a smaller number of suppliers, the company will be able to develop better partnerships with suppliers which in turn can result in reduced order processing costs. Considering present case study it seems that it would beneficial to develop long term relationships with suppliers 10, 17 and 15. Liu et al. [1] had suggested that five vendors, i.e., 1, 10, 12, 15, and 17 were efficient, the remaining vendors were inefficient, and vendors 2 and 14 were most inefficient.

Table 3. Weighted normalized decision matrix for supplier selection problem

	Price ($)	Quality (%)	Delivery performance (%)	Distance (miles)	Supply variety
Goal	Min	Max	Max	Min	Max
Supplier 1	0.0077	0.0271	0.0142	0.0008	0.0005
Supplier 2	0.0077	0.0270	0.0126	0.0022	0.0035
Supplier 3	0.0077	0.0271	0.0142	0.0024	0.0008
Supplier 4	0.0077	0.0271	0.0142	0.0061	0.0008
Supplier 5	0.0077	0.0270	0.0142	0.0008	0.0065
Supplier 6	0.0077	0.0261	0.0142	0.0008	0.0076
Supplier 7	0.0077	0.0271	0.0134	0.0048	0.0003
Supplier 8	0.0077	0.0271	0.0153	0.0033	0.0065
Supplier 9	0.0077	0.0270	0.0142	0.0022	0.0030
Supplier 10	0.0077	0.0264	0.0158	0.0020	0.0144
Supplier 11	0.0077	0.0270	0.0150	0.0008	0.0027
Supplier 12	0.0077	0.0270	0.0154	0.0019	0.0019
Supplier 13	0.0077	0.0271	0.0142	0.0019	0.0052
Supplier 14	0.0077	0.0249	0.0142	0.0033	0.0033
Supplier 15	0.0062	0.0271	0.0150	0.0022	0.0090
Supplier 16	0.0077	0.0271	0.0150	0.0027	0.0005
Supplier 17	0.0062	0.0271	0.0150	0.0023	0.0092
Supplier 18	0.0077	0.0269	0.0134	0.0031	0.0024

Table 4. Relative significance of alternatives

Q_i	0.0423	0.0436	0.0425	0.0424	0.0482	0.0484	0.0411	0.0493	0.0447
Supplier	1	2	3	4	5	6	7	8	9
Q_i	0.0570	0.0453	0.0448	0.0469	0.0427	0.0515	0.0430	0.0518	0.0431
Supplier	10	11	12	13	14	15	16	17	18

Table 5. Utility values and ranking of the candidate alternatives

U_i	74.22	76.47	74.55	74.34	84.62	84.99	72.07	86.42	78.34
Supplier	1	2	3	4	5	6	7	8	9
U_i	100.00	79.39	78.64	82.20	74.93	90.39	75.44	90.85	75.68
Supplier	10	11	12	13	14	15	16	17	18

An analysis and comparision with previous results suggest that COPRAS method can be successfully applied for dealing with complex supplier selection problems.

The COPRAS and TOPSIS methods are mathematically simple to moderately complex to understand. Although both methods can be relatevely easy applied using EXCEL worksheet, the implementation i.e. calculation/computation time of COPRAS method requires less time and effort. The ease of implementation of COPRAS method in EXCEL worksheet, enables efficient use of this method for solving complex supplier selection problems which involve assessment of a number of alternatives over a number of criteria, and also with different types of criteria.

4. CONCLUSION

Evaluation of alternative suppliers, ranking and selection of the most appropriate involves consideration of numeruos and conflicting criteria. Application of different multi-criteria decision making methods to the problem of supplier selection helps to make a more objective and reliable decisions. In the formulation and solving procedure of supplier selection problems multi-criteria decision making methods often involve active participation of decision makers. This is particularly related to formulation of criteria relative importance as well as to analysis, ranking and selection of the final solution, i.e. best alternative. Throught the use of specialized software packages many different multi-criteria decision making methods can be easily applied.

Although different multi-criteria decision making methods have already been proposed by the past researchers to address the problem of supplier evaluation and selection, it is still not clear which method is the best for a given problem. It seems that the ease of understanding an method is a primary concern in the choice of whether (or not) it is used.

This paper explores the applicability and capability of recently developed COPRAS method while solving complex supplier selection decision-making problem, involving cardinal criteria. The decision maker can easily apply COPRAS method for the formulation of a reduced performance criterion which is directly proportional to the relative effect of the compared criteria values.

Regarding the COPRAS methodology and and comparision with previous results, it is clear that this approach has good competitive potential for wider application. Further investigation will include comparisons of COPRAS method with other multi-criteria decision making methods for supplier selection.

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REFERENCES

[1] F. Liu, F.Y. Ding, and V. Lall, "Using data envelopment analysis to compare vendors for vendor selection and performance improvement", Supply Chain Management, An International Journal, vol. 5, pp. 143-150, 2000.

[2] R. Venkata Rao, Decision Making in the Manufacturing Environment: using graph theory and fuzzy multiple attribute decision making methods, Springer-Verlag London Limited, 2007.

[3] P. Chatterjee, V.M. Athawale, and S. Chakraborty, "Materials selection using complex proportional assessment and evaluation of mixed data methods", Materials and Design, vol. 32, pp. 851-860, 2011.

[4] O. Bayazit, "Use of analytic network process in vendor selection decisions", Benchmarking: An International Journal, vol. 13, pp. 566-579, 2006.

[5] K. Šimunović, T. Draganjac, and R. Lujić, "Supplier selection using a multiple criteria decision making method", Strojarstvo, vol. 53, pp. 293-300, 2011.

[6] K. Kwang, W.H. Ip, and J.W.K. Chan, "Combining scoring method and fuzzy expert systems approach to vendor assessment: a case study", Integrated Manufacturing Systems, vol. 13, pp. 512-519, 2002.

[7] C.X. Feng, J. Wang, and J.S. Wang, "An optimization model for concurrent selection of tolerances and vendors", Computers and Industrial Engineering, vol. 40, pp. 15-33, 2001.

[8] S.C. Ting, and D.I. Cho, "An integrated approach for supplier selection and purchasing decisions", Supply Chain Management: An International Journal, vol. 13, pp. 116-127, 2008.

[9] W.L. Ng, "An efficient and simple model for multiple criteria supplier selection problem", European Journal of Operational Research, vol. 186, pp. 1059-1067, 2008.

[10] H.J. Shyur, and H.S. Shih, "A hybrid MCDM model for strategic vendor selection", Mathematical and Computer Modelling, vol. 44, pp. 749-761, 2006.

[11] V. Wadhwa, and A.R. Ravindran, “Vendor selection in outsourcing”, Computers and Operations Research, vol. 34, pp. 3725-3737, 2006.

[12] R. Venkata Rao, “Vendor selection in a supply chain using analytic hierarchy process and genetic algorithm methods”, International Journal of Services and Operations Management, vol. 3, pp. 355-369, 2007.

[13] J. Kumar, and N. Roy, “Hybrid method for vendor selection using neural network”, International Journal of Computer Applications, vol. 11, pp 35-40, 2010.

[14] W. Ho, X. Xu, and P.K. Dey, “Multi-criteria decision making approaches for supplier evaluation and selection: a literature review”, European Journal of Operational Research, vol. 202, pp.16-24, 2010.

[15] E.K. Zavadskas, A. Kaklauskas, Z. Turskis, and J. Tamošaitien, “Selection of the effective dwelling house walls by applying attributes values determined at intervals”. Journal of Civil Engineering and Management, vol. 14, pp. 85-93, 2008.

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A MULTI-CRITERIA DECISION MAKING APPROACH FOR EVALUATING SUSTAINABLE CITY LOGISTICS MEASURES

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Abstract

In this paper is presented a multi-criteria decision making approach for evaluating sustainable city logistics initiatives or measures based on qualitative information, using fuzzy TOPSIS method. While the AHP method is used to analyze the structure of the sustainable city logistics measure problem and to determine weights of criteria, fuzzy TOPSIS method is used to obtain final ranking. Several stakeholders associated with urban freight transport are included in selection of evaluation criteria and allocation of linguistic ratings to alternatives. According to results of implementation of CIVITAS measures for urban freight logistics in European cities, four alternative/measures are evaluated as an illustrative example for selection of best city logistics measure.

Keywords:*city logistics, sustainable measures, multicriteria evaluation, AHP method, fuzzy TOPSIS method*

1. INTRODUCTION

In the last years urban freight transport system has become an important issue in sustainable urban development. With urban traffic increasing, and the raise of congestion, negative environmental impacts and energy consumption, public administrations in cities were confronted with the problem of urban freight distribution, that was managed traditionally only by the transportation carrier [3]. According the importance of sustainable development, city logistics initiatives are recognized as the best solutions for efficient urban freight distribution with high environmental objectives [9]. In order to meet the specific local conditions and cope with the problems caused by commercial transport, within the CIVITAS-Initiative, co-financed by the European Union, the cities got together searching for appropriate solutions and measures demonstrated in field *urban freight logistics* which is one of eight thematic categories of measures identified as the basic building blocks of an integrated strategy for sustainable mobility [3].
Based on literature and best practices review, this paper presents an approach for qualitative multicriteria evaluation of sustainable city logistics measures using AHP and fuzzy TOPSIS method, which allows inclusion of the main aspects of each sphere of sustainability, respectively economic, environmental and societal, and the stakeholders associated with urban freight transport decision making process [7].

In this paper we use only AHP method because the fuzzy AHP method is only practically usable if the number of criteria and alternatives is sufficiently low so that the number of pairwise comparisons performed by decision makers must remain below a reasonable threshold. The fuzzy TOPSIS is applied to achieve the final ranking of alternatives in order to avoid an unreasonably large number of pairwise comparisons [5].

2. METHODS

2.1. The AHP method

Analytic Hierarchy Process (AHP), developed by Saaty[6], is a quantitative technique used to determine the relative importance of a set of activities in a multi-criteria decision problem. The AHP method is based on three principles: structure of the model, comparative judgment of the alternatives and criteria and synthesis of the priorities. Following to that, the AHP method consists of three steps.
In the first step, a complex decision problem is structured as a hierarchy of criteria, sub-criteria (if exist) and alternatives. A hierarchy has at least three levels: overall goal of the problem at the top, multiple criteria that define alternatives in the middle and decision alternatives at the bottom [1]. The second step is the comparison of the alternatives and criteria. Procedure starts in order to determine the relative importance of the criteria within each level. In each level, the criteria are compared pairwise according to their levels of influence and based on the specific criteria in the higher level [1]. In AHP method, multiple pairwise comparisons are based on a standardized comparison scale of nine levels (Table 1).

Table 1. Scale of measurement forAHP

Definition	Intensity of importance
Equally emportant	1
Slightlymore important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediate values to reflect compromise	2,4,6,8
Used to reflect dominance of the second alternative as compared with the first	Reciprocals

Let $C = \{C_j \mid j = 1,2,...,n\}$be the set of criteria. The result of pairwise comparison on *n* criteria can be summarized in an (nxn) comparison matrix A (Eq.1) in which every element $a_{ij}\,(i, j = 1,2,..., n)$ is the quotient of weights of the criteria.

$$A=\begin{bmatrix}1 & a_{12} & \cdots & a_{1n}\\ a_{21} & 1 & \cdots & a_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ a_{n1} & a_{n2} & \cdots & 1\end{bmatrix}=\begin{bmatrix}1 & a_{12} & \cdots & a_{1n}\\ 1/a_{12} & 1 & \cdots & a_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ 1/a_{1n} & 1/a_{2n} & \cdots & 1\end{bmatrix} \quad (1)$$

where $a_{ii}=1,\ a_{ji}=1/a_{ij}\ ,\ a_{ij}\neq 0$

In the last step, the mathematical process commences to normalize and find the relative weights for each matrix. The relative weights are given by the principal eigenvector (*w*) corresponding to the largest eigenvalue ($\lambda_{\max}$):

$$Aw=\lambda_{\max}w \quad (2)$$

The quality of the output of the AHP is related to the consistency of pairwise comparison judgments. The Consistency Ratio (CR) for each of the matrix and overall inconsistency for the hierarchy are calculated in order to control the results of this method. The Consistency Ratio is used to estimate directly the consistency of pairwise comparisons. CR is computed by using Eq (3).

$$CR=CI/RI \quad (3)$$

$$CI=\frac{\lambda_{\max}-n}{n-1} \quad (4)$$

where CI is consistency index and RI is random index which is shown in Table 2 (*n* is matrix size). If the CR ≤ 0.10 the consistency of the matrix is considered as acceptable, otherwise the evaluation procedure has to be repeated to improve consistency.

Table 2. The Random Consistency Index (RI)

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41
n	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
RI	1.45	1.49	1.51	1.48	1.56	1.57	1.59	1.6

2.2. The fuzzy TOPSIS method

Definition 1.A triangular fuzzy number is represented as a triplet $\tilde{a}=(a_1,a_2,a_3)$. The membership function $\mu_{\tilde{a}}(x)$ of triangular fuzzy number $\tilde{a}$ is given by:

$$\mu_{\tilde{a}}(x)=\begin{Bmatrix}0, x\le a_1,\\ \dfrac{x-a_1}{a_2-a_1}, a_1\le x\le a_2,\\ \dfrac{a_3-x}{a_3-a_2}, a_2\le x\le a_3,\\ 0, x\ge a_3\end{Bmatrix} \quad (5)$$

Definition 2. In fuzzy set theory, conversion scales are applied to transform the linguistic terms into fuzzy numbers.

In this paper, we will use a scale of 1–9 to rate the alternatives. Table 3present the linguistic variables and fuzzy ratings used for evaluation of alternatives.

Table 3.Linguistic terms for alternatives ratings

Lingvistic term	Membership function
Very poor (VP)	(1, 1, 3)
Poor (P)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Good (G)	(5, 7, 9)
Very good (VG)	(7, 9, 9)

The fuzzy TOPSIS approach involves fuzzy assessments of alternatives in TOPSIS. The TOPSIS approach chooses alternative that is closest to the fuzzy positive ideal solution (FPIS) and farthest from the fuzzy negative ideal solution (FNIS). A positive ideal solution is composed of the best performance values for each criterion whereas the negative ideal solution consists of the worst performance values. If the objective is to maximize criteria then closeness to FPIS and far distance from FNIS is preferable. If the objective is to minimize criteria, then closeness to FNIS and distance from FPIS is preferable.

Suppose a multicriteria decision making problem has *m* alternatives/possible candidates ($A_1, A_2, ..., A_m$), and *n* decision criteria ($C_1, C_2, \ldots, C_n$). Each alternative is evaluated with respect to the *n* criteria. All the values assigned to the alternatives with respect to each criterion form a decision matrix denoted by X = $(x_{ij})_{mxn}$. Let W= ($w_1, w_2, \ldots, w_n$) be the relative weight vector about the criteria, satisfying $\sum_{j=1}^{n} w_j=1$.

Then the various steps of fuzzy TOPSIS method can be summarised as follows:

Step 1. Compute aggregate fuzzy ratings for the alternatives. If the fuzzy ratings of all decision makers are described as triangular fuzzy number $\tilde{R}_k=(a_k,b_k,c_k), k=1,2,...,K$ than the aggregated fuzzy rating is given by $\tilde{R}=(a,b,c),\ k=1,2,...,K$ where:

$$a=\min_k\{a_k\},\ b=\frac{1}{K}\sum_{k=1}^{K}b_k,\ c=\max_k\{c_k\} \quad (6)$$

Step 2. Normalize the fuzzy decision matrix X=$(x_{ij})_{mxn}$ by calculating r_{ij} which represents the normalized criteria value/rating.

$$\tilde{r}_{ij}=\left(\frac{\tilde{a}_{ij}}{c_j^*},\frac{\tilde{b}_{ij}}{c_j^*},\frac{\tilde{c}_{ij}}{c_j^*}\right),\quad j\in B;\ c_j^*=\max_i c_{ij} \quad (7)$$

where $i=1,2,...,m;\ j=1,2,...,n$

$$\tilde{r}_{ij}=\left(\frac{a_j^-}{c_{ij}},\frac{a_j^-}{b_{ij}},\frac{a_j^-}{a_{ij}}\right),\quad j\in C;\ a_j^-=\min_i a_{ij} \quad (8)$$

where $i = 1,2,...,m;\ j = 1,2,...,n$

Step 3. Calculate the weighted normalized decision matrix $\tilde{V} = [\tilde{v}_{ij}]_{m\times n}$ where:

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times \tilde{w}_j(C_j) \quad (9)$$

w_j is the relative weight of the jth criterion or attribute and $\sum_{j=1}^{n} w_j = 1$. Note that $\tilde{v}_{ij}$ is a fuzzy triangular number represented by $(\tilde{a}_{ij}, \tilde{b}_{ij}, \tilde{c}_{ij})$.

Step 4. Determine the fuzzy positive ideal solution (A^*) and fuzzy negative ideal solution (A^-):

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, ..., \tilde{v}_n^*),\ v_j^* = \max_i \{v_{ij}\} \quad (10)$$

where $i = 1,2,...,m;\ j = 1,2,...,n$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, ..., \tilde{v}_n^-),\ v_j^- = \min_i \{v_{ij}\} \quad (11)$$

where $i = 1,2,...,m;\ j = 1,2,...,n$

Step 5. Calculate the Euclidean distances of each alternative from fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS), respectively:

$$d_i^* = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^*),\quad i = 1,2,...,m, \quad (12)$$

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^-),\quad i = 1,2,...,m, \quad (13)$$

where $d_v(\tilde{a}, \tilde{b})$ is the distance measurement between two fuzzy numbers $\tilde{a}$ and $\tilde{b}$ and is equal to:

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\right]} \quad (14)$$

Step 6. Calculate the relative closeness of each alternative to the ideal solution. The relative closeness of the alternative A_i with respect to A^* is defined as CC_i:

$$CC_i = \frac{\tilde{d}_j^-}{\tilde{d}_j^* + \tilde{d}_j^-},\quad i = 1,2,...,m \quad (15)$$

Step 7. Rank the alternatives according to the relative closeness to the ideal solution. The bigger the CC_i, the better the alternative A_i .

3. SELECTION OF BEST CITY LOGISTICS MEASURE USING AHP AND FUZZY TOPSIS: AN ILLUSTRATIVE EXAMPLE

The proposed approach for selecting sustainable city logistics measure consists of next steps: selection of evaluation criteria, identification of prospective alternatives/measures and allocation of linguistic ratings to potential alternatives for the selected criteria. Schematic diagram of the proposed approach for selecting sustainable urban logistics measure is provided in Figure 1.

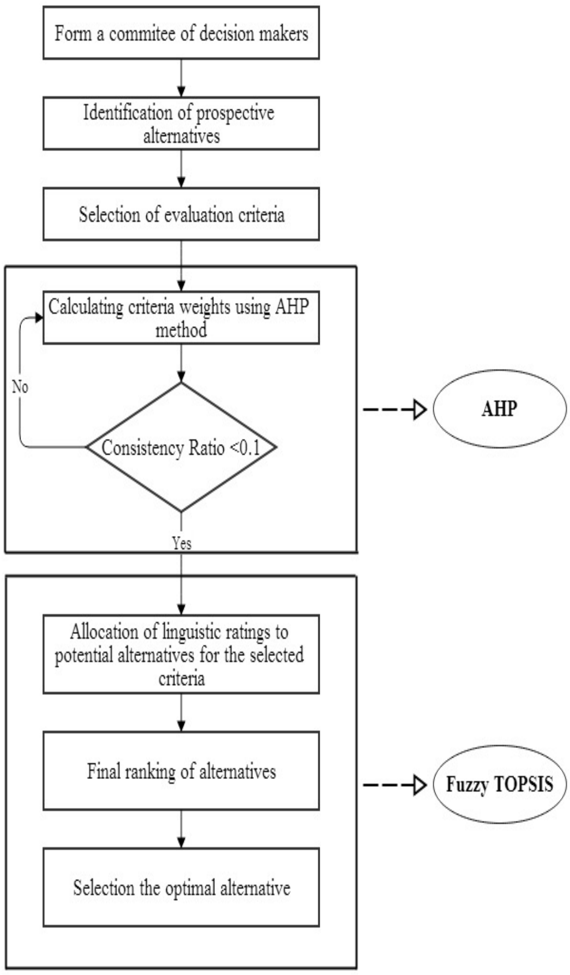

Figure 1. Schematic diagram of the proposed model

3.1. Selection of evaluation criteria

The first step involves selection of criteria for evaluating city logistics initiatives. A committee comprising of representativesof city logistics stakeholders (end users, shippers, receivers, transport operators, public administrators) is formed to generate criteria for evaluating city logistics measure. The final list of 16 criteria, which could be categorized into economic, environmental, social and techical respectively, is based on the literature review [2]. The criteria are Operational costs, Energy Consumption, Revenues, Air pollution, Noise, Land Use, Congestion, Accidents, Mobility, Accessibility, Freeing of public space, Logistical efficiency, Trip effectiveness, Loading factor of vehicles, Service quality, Customer coverage. Table 4 presents the detailed definitions of the 16 criteria.

Table 4.Criteria for evaluating city logistics initiatives

Category	Criteria	Definition	Category
Economic	Operational costs (C1)	Costs involved in delivery of goods to customers	C (↓)
	Energy consumption (C2)	Consumption of fossil fuel by transportation resources	C (↓)
	Revenues (C3)	Revenues generated from the delivery service	B (↑)
Environmental	Air pollution (C4)	Air pollution (CO2, NOx, particulates) generated from delivery activities	C (↓)
	Noise (C5)	Noise generated from urban goods vehicle movement	C (↓)
	Land use (C6)	Land use generated from delivery activities	C (↓)
	Congestion (C7)	Traffic congestion generated due to freight/goods delivery vehicles and material handling activities	C (↓)
Social	Accidents (C8)	Accidents caused due to the delivery service	C (↓)
	Mobility (C9)	Facilitation of passenger travel and goods movement conditions inside cities	B (↑)
	Accessibility (C10)	Ease of accessing delivery depots and customer locations	B (↑)
	Freeing of public space (C11)	Number of parking spaces freed from the delivery service	B (↑)
Tehnical	Logistical efficiency (C12)	Delivery targets successfully met by the logistical organizations	B (↑)
	Trip effectiveness (C13)	Measured by reduction in number of trips, distance between trips, trip travel time, reliability of trips, etc.	B (↑)
	Loading factor (C14)	Capacity utilization of delivery vehicles	B (↑)
	Service quality (C15)	Measured in terms of customer satisfaction with the delivery service performed	B (↑)
	Customer coverage (C16)	Number of customers served by the delivery service within given geographical region	B (↑)

C (The lower the better); B (The higher the better).

It can be seen in Table 4 that among the 16 criteria, the nine criteria are the Benefit (B) category criteria that is the higher the value, the preferable the alternative is. For example, the higher the Logistical Efficiency (Criteria C12), the better thecity logistics measure is. Seven criteria have the cost (C) category that is, the lower the value the preferable the alternative is. For example, the lower the Congestion (Criteria C7), the better is the city logistics measure.

After selection of evaluation criteria and defining of decision hierarchy, the weights of criteria are determined using AHP method. Pairwise comparison matrices are formed in order to determine the criteria weights. The experts from decision making team make their individual evaluations using the scale provided in Table 1 to determine the values of the elements of pairwise comparsion matrices. Geometric means of these values are found to obtain a final pairwise comparison matrix. The weights of the criteria are calculated based on this final pairwise comparison matrix. In the end, calculated weights of the criteria are approved by the committee of decision makers.

3.2. Identify the prospective alternatives/city logistics measures

Four alternatives are considered in this study: Consolidation supplies (A1), Clean urban logistics and goods distribution platform (A2), City freight delivery plan (A3) and Access Timing Restrictions (A4). These alternatives were identified from list of measures related to urban freight logistics best practices, using CIVITAS Resource Center [8] and Search Engine [4].

Under consolidation supplies (A1), goods from large vehicles are consolidated into smaller size clean delivery vehicles for delivery. Consolidation means that different goods are sorted based on the destination.The objectives of this alternative are to reduce the number of small direct deliveries, to reduce congestion levels, to improve environment and living conditions as well as to reduce energy consumption and emissions. This measure have been tested in Stockholm, Sweden.[8]

Clean urban logistics and goods distribution platform (A2) means defining, implementing, promoting and coordinating the modified city center access freight regulations in order to improve the transport and freight delivery.This measure was implemented in Toulouse, France.[8]

The alternative city freight delivery plan (A3) is related to the access-restricted city center where a Limited Traffic Zone (LTZ) already exist. The measure consists of four parts: new access permission procedures and pricing policies to the LTZ; the introduction of low emission vehicles; the decrease of freight vehicle accesses to the LTZ and improved road occupancy and deployment of dedicated loading areas. The objectives are to optimise and develop an effective integration between road pricing policies and technological tools (which helps optimizing delivery routes), to contribute to decrease the number of kilometers travelled to provide the same services and to demonstrate the impact that a regulatory action upon freight distribution can have on urban traffic congestion and pollution level. This measure was implemented in Bologna, Italy.[8]These three city logistics measures are also known asurban distribution center schemes[2].

Under access timing restrictions (A4), delivery vehicles are allowed inside city only during restricted hours for example, between 5–7 am and 9–11 pm to avoid peak hour traffic and congestion. If deliveries are done during these restricted timings, additional charges are involved[2].

3.3. Ranking of the alternatives/city logistics measures

The third step involvesallocation of linguistic ratings to potential alternatives for the selected criteria using scales given in Table 3.

The linguistics terms are then combined with criteria weights (determined using AHP method) and subject to fuzzy TOPSIS (Section 2.2) to generate an overall performance score for the alternatives (city logistics measures).

The alternative with the highest score (the highest Closeness Coefficient) is finally chosen and recommended for implementation.

Presented alternatives/city logistics measures (Section 3.2) are considered in this example. They are consolidation supplies (A1), clean urban logistics and goods distribution platform (A2), city freight delivery plan (A3) and access timing restrictions (A4).

First, we use AHP method in order to calculate the weights of criteria. Geometric means of decision makers evaluations are found to obtain a final pairwise comparison matrix (Table 5). After obtaining the final pairwise comparison matrix, we perform normalization and find the relative weights for each criteria (Table 6).

Table 6. Results obtained with AHP method

Criteria	Weights (wj)	λ_{max}, CI, RI, CR
C1	0.012	
C2	0.071	
C3	0.015	λ_{max} = 18,16
C4	0.026	
C5	0.016	
C6	0.035	
C7	0.035	CI = 0.144
C8	0.147	
C9	0.095	RI = 1.6
C10	0.058	
C11	0.042	
C12	0.112	
C13	0.116	
C14	0.090	CR = 0.09
C15	0.079	
C16	0.050	

Consistency Ratio (Eq.3) of the pairwise comparison matrix is 0.09<0.1 so the weights are consistent and they are used in the selection process of alternatives.

The linguistic ratings of 16 criteria are presented in Table 7. The aggregate fuzzy weights of alternatives are computed using Eq.(6). After obtaining the fuzzy scores,we perform normalization of the alternatives using Eqs.(7) and (8).Then, using the criteria weights calculated by AHPthe fuzzy weighted decision matrix is constructed using Eq.(9), followed by FPISand FNIS using Eqs.(10) and (11). Following to that, we compute the distance of each alternative from FPIS and FNIS using Eqs.(12) and (13).Finally, using calculated distances, the closeness coefficient (CCi) of the four alternatives was computed (Table 8).

Table 5. The pairwise comparison matrix for criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1	1,0	0,2	0,3	0,2	0,1	0,2	0,1	0,2	0,1	0,3	0,3	0,2	0,3	0,5	0,3	0,3
C2	5,0	1,0	5,0	5,0	5,0	5,0	3,0	3,0	0,2	0,3	3,0	0,2	0,3	0,2	0,2	0,3
C3	3,0	0,2	1,0	0,3	3,0	0,3	0,3	0,2	0,2	0,2	0,3	0,2	0,2	0,1	0,2	0,2
C4	6,5	3,0	3,0	1,0	3,0	0,3	0,3	0,2	0,2	0,2	0,3	0,2	0,1	0,1	0,2	0,3
C5	7,0	0,2	0,3	0,3	1,0	0,3	0,3	0,2	0,2	0,2	0,2	0,1	0,2	0,1	0,2	0,2
C6	4,5	0,2	3,0	3,0	3,0	1,0	3,0	0,2	0,2	0,3	0,5	0,2	0,2	0,2	0,2	3,0
C7	7,0	0,3	3,0	3,0	3,0	0,3	1,0	0,3	0,3	0,3	3,0	0,3	0,3	0,2	0,3	0,3
C8	5,0	0,3	5,0	5,0	5,0	5,0	3,0	1,0	5,0	5,0	5,0	3,0	3,0	3,0	3,0	3,0
C9	9,0	5,0	5,0	5,0	5,0	5,0	3,0	0,2	1,0	0,5	3,0	0,3	3,0	0,3	3,0	3,0
C10	3,0	3,0	5,0	5,0	5,0	3,0	3,0	0,2	2,0	1,0	0,3	0,3	0,3	0,3	0,3	3,0
C11	3,0	0,3	3,0	3,0	5,0	2,0	0,3	0,2	0,3	3,0	1,0	0,2	0,3	0,2	0,3	3,0
C12	5,3	5,3	6,5	6,5	7,0	5,0	3,0	0,3	3,0	3,0	5,0	1,0	0,3	2,0	2,0	5,0
C13	3,3	3,0	5,3	7,0	5,0	5,0	3,0	0,3	0,3	3,0	3,0	3,0	1,0	3,0	5,0	3,0
C14	2,0	5,0	7,0	7,0	7,0	5,0	5,0	0,3	3,0	3,0	5,0	0,5	0,3	1,0	0,5	0,3
C15	4,0	5,0	5,0	5,0	5,0	5,0	3,0	0,3	0,3	3,0	3,0	0,5	0,2	2,0	1,0	3,0
C16	3,0	3,0	5,0	3,0	5,0	0,3	3,0	0,3	0,3	0,3	0,3	0,2	0,3	3,0	0,3	1,0

Table 7. Linguistic assessments for the four alternatives

Criteria	Alternatives																			
	A1					A2					A3					A4				
	D1	D2	D3	D4	D5	D1	D2	D3	D4	D5	D1	D2	D3	D4	D5	D1	D2	D3	D4	D5
C1	VG	VG	VG	G	VG	VG	VG	VG	VG	VG	VG	VG	G	F	G	G	G	G	F	G
C2	VG	VG	VG	G	VG	VG	VG	VG	G	VG	VG	VG	G	F	G	VG	VG	G	G	G
C3	VG	VG	VG	VG	G	VG	G	G	F	G	VG	VG	G	G	G	G	G	G	F	G
C4	F	F	F	F	VG	F	F	F	F	F	F	G	G	F	G	VG	VG	VG	VG	F
C5	F	F	F	F	VG	P	P	P	F	P	F	G	G	F	G	VG	VG	VG	VG	F
C6	G	VG	G	G	VG	VP	VP	VP	F	VP	VG	VG	VG	G	G	VG	VG	VG	VG	VG
C7	G	VG	VG	G	VG	P	P	P	F	VP	G	VG	VG	G	G	VG	VG	VG	F	VG
C8	VG	VG	F	F	F	F	F	F	F	F	F	G	G	G	G	VG	VG	VG	F	G
C9	VG	VG	VG	F	G	VP	VP	VP	F	VP	F	G	G	F	G	VG	VG	G	G	VG
C10	VG	VG	F	F	G	G	G	G	F	G	F	G	G	F	G	VG	VG	VG	F	VG
C11	VG	VG	G	G	VG	VP	F	F	F	F	F	F	F	F	F	VG	VG	VG	VG	VG
C12	VG	VG	G	G	VG	VG	VG	G	G	G	G	VG	VG	F	G	VG	VG	VG	F	G
C13	VG	VG	G	G	VG	VG	VG	G	G	G	G	G	G	F	G	VG	VG	VG	F	VG
C14	VG	VG	VG	VG	VG	VG	VG	VG	G	G	VG	G	G	F	G	G	G	G	F	G
C15	F	VG	VG	F	G	G	G	G	F	G	G	G	G	G	G	VG	VG	VG	G	VG
C16	G	G	G	F	G	G	G	G	F	G	G	VG	VG	G	G	G	G	G	F	G

Table 8. Closeness coefficient for the four alternatives

	Alternatives			
	A1	A2	A3	A4
$\tilde{d}_j^*$	0.407	0.439	0.456	0.437
$\tilde{d}_j^-$	0.450	0.431	0.429	0.451
CC_i	0.525	0.495	0.485	0.510

By comparing the *CCi* values of the four alternatives, we find that *A1>A4>A2>A3.* Therefore, alternative A1 (Consolidation supplies) is chosen as the sustainable city logistics measure and recommended for implementation.

4. CONCLUDING REMARKS

A multicriteria approach, which can be based on qualitative information as to the elements of stakeholders judgment and their relative weights considering the main aspects of each sphere of sustainable city logistics - economic, environmental, societal and technical additionaly, could be a useful tool for decision makers associated with urban freight transport.For a successful implementation of this approach is necessary to extend research related to identifying the measures which are subject of evaluation, based on polls of experts. The strength of our approach is the ability to generate solutions under partial or incomplete information. The proposed approach can be practically applied by decision makers in evaluation and selection of city logistics measures.Since the decision making process is sensitive to the number of participants involved and their expertise with the subject, they should be carefully chosen.

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REFERENCES

[1] Albayrak, E., Erensal, Y.C., 2004. „Using analityc hierarchy process to improve human performance“, An application of multiple criteria decision making problem. Journal of Intelligent Manufacturing 15, pp.491-503.

[2]Awasthi, A. and Chauhan,S.S., 2012.„A hybrid approach integrating Affinity Diagram, AHP and fuzzy TOPSIS for sustainable city logistics planning”,Applied Mathematical Modelling, Vol. 36 (2), pp.573-584.

[3] Becker, H.J., Runge, D., Schwedler, U. and Abraham, M., 2008.Commercial Transport in European Cities-How do European cities meet the challenges of commercial transport?, Experiences and case studies from the CIVITAS Programme of the European Commission, Berlin http://www.polisnetwork.eu/uploads/Modules/PublicDocuments/IVP_21.pdf

[4] CIVITAS MIMOSA Search Engine – Urban Freight Logistics, http://www.pas-port.info/#embassy_04

[5] Deviren, D., Yavuz, S., Kilınc, N. 2009. „Weapon selection using the AHP and TOPSIS methods under fuzzy environment“, Expert Systems with Applications, 36(4), pp.8143–8151.

[6] Saaty,T.L. (1980), The analityc hierarchy process. New York: MCGraw-Hill

[7] Taniguchi, E. and Tamagawa, D., 2005. „Evaluating city logistics measures considering the behavior of several stakeholders”, Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp.3062-3076.

[8] Töpfer, A., 2012. Impact evaluation methods inCivitas for urban freight measures, TU, Berlin, http://www.civitas-initiative.org/sites/default/files/Results%20and%20Publications/20120703_CIVITAS_freight_measures_evaluation.pdf

[9] European Commission, 2006. Urban freight transport and logistics - An overview of the European research and policy, http://www.transport-research.info/web/

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CONTRIBUTION TO OPTIMAL CONTAINER FLOW ROUTING BETWEEN FAR EAST AND SERBIA THROUGH SELECTED ADRIATIC PORTS

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Abstract

Container flow should be optimal to ensure proper resource utilization and profitability to consignees. This paper analyzes the supply chain network with primary focus on import container from Far East to Serbia through Rijeka and Kopar nodes, the main gates for the ex Yugoslavia Republic area. An optimization mathematical model, which minimize the time of container import to Serbia, by using different liner shipping services on the sea and truck-rail inland transportation networks is developed. By observing the minimization of time for container import from Far East through selected Adriatic ports it was determined the most optimal route for container import to Serbia. This research is considered to be appropriate for strategic planning at a national level, however, should be also of beneficial to organizations in global container supply.

Keywords: *Optimization, Container, Mathematical model*

1. INTRODUCTION

International container shipping is one of the most dynamic economic sectors of the last few years. The development of container transport in recent years marks a constant intention for increased cargo flows. Projections indicate continued upward trend of container traffic. Global container traffic was 7 times higher in 2011 than in 1990 and the average containership doubled in size during the same period. There are almost 500 liner shipping services providing regularly scheduled service (usually weekly) that enable goods to move between ports along the many trade routes of the world. During the period 1995 - 2011, container trade has increased by almost 5 times between Asia and Europe reaching about 20 million TEUs. The container trade between Asia and Mediterranean is one of the top three world's highest volume arterial trade lanes and on this route 4.37 million TEUs was shipped using 31 different liner shipping services in 2012.

For businesses to gain competitive advantage there is need to shorten delivery time by increasing flow of containers through supply chain nodes. Transport users (consignees) require frequent, accurate and reliable implementation of transport. With the increase in the value of goods increases and the importance of speed transportation, as an important component of the supply chain. Container transport as programmed transport chain caused by the exact time harmonizing transport all participants in the chain. Deviations from schedules (sea, rail, road) leads to irregular deliveries - making delays and bottlenecks.

In this research we developed an optimization model, programmed in MATLAB, which main goal is to minimize the transit time of container import.

Studying literature data we conclude that a small number of researchers investigated time minimization of container flow considering see and land legs together [1, 2, 3].

The rest of this paper is organized as follows: Section 2 describes the problem which is considered in this work while the mathematical model is explained in Section 3. Section 4 reports and analyse the results of the mathematical model. Finally, Section 5 is devoted to conclusions and future developments.

2. PROBLEM DESCRIPTION

We consider an intermodal transportation chain which based on the import - way and composed by two legs. The first one represents maritime transfers from origin port - Shanghai port to gateway ports Rijeka and Koper. The second leg of the chain represents the inland component of the distribution, in which containers are routed from gateways to final destination - Belgrade, by road, rail or barge.

The network is composed by three categories of nodes: origin port (port of loading), gateway ports (ports of discharge) and destination (place of delivery), and two categories of links, maritime and inland. Such elements of the network are described below.

2.1 Nodes

Each node type has its own characteristics:

Origin port - As one of the most important foreign trade partners in container imports from the Far East to Serbia is China with major port - port of Shanghai. It is the world's busiest trading port which handles a staggering 32 million containers a year, carrying 736 million tonnes of goods to far - flung places around the globe.

Gateway ports are connected with origin port, but only by incoming links. From origin port it is possible to reach to gateway port but the opposite is not allowed since here we are addressing only incoming flows. The one of the main

gateways for container import to Serbia are Rijeka and Koper port.
Destination - Serbia is hinterland country with capital city - Belgrade. This region represents the largest percentage of Serbian imports in general. It is connected to the gateway ports with a direct link, representing the shortest path to reach it from that gateway, by truck, rail and barge.

2.2 Links

There are two types of links, maritime and inland, each one with its own characteristics, as described below:
Maritime links are those between origin port and gateway ports. As for intercontinental links, there may be more than one link connecting an origin port to a gateway port, and each such link belongs to a different service with given travel time and frequency depends on different operators (Maersk Line - MSK, Mediterranean Shipping Company - MSC, CMA CGM, Evergreen Line - EMC, China Ocean Shipping Company - COSCO and Hapag - Lioyd).
Inland links are those between gateway ports and place of delivery of containers - Belgrade. There are three available inland transportation modes which could be chosen including truck, railway and barge. Where there are available rail or barge linkages, line-haul may be done by rail or barge before last mile delivery by truck. Without such facilities, containers could also be transported from gateway ports to end - customers all the way by truck.

3. MODEL FORMULATION

In this paper we developed matemathical model which minimize transit time of container import from Shanghai to Belgrade through Rijeka and Koper port.
It is analyzed transit time of container flow from the moment of the ship departure from the port of loading to the moment of the arrival container to the place of delivery in Belgrade, regarding the six different operators, two discharge ports and three different types of services on the see legs. The total time includes: transit time of maritime container flow from origin port to the gateway port, waiting time of containers at the port of discharge (which is included in transit time of inland transport) and inland transit time from the selected port to the Belgrade using different modes of transport.
Let us introduce the following concepts and parameters to be used as input data for the model:

- N set of nodes, let N = S ∪ E ∪ B, while S stands for origin port, E stands for gateway ports and B stands for place of delivery
- A set of arcs connecting an origin to a gateway (first - leg arcs)
- C set of arcs connecting gateways to place of delivery (second - leg arcs)
- I number of operator, $i \in \{1, \ldots, 6\}$
- J number of port, $j \in \{1, \ldots, 5\}$
- S type of service, $s \in \{1, \ldots, 3\}$
- K mode of transport, $k \in \{1, \ldots, 3\}$
- TSE_{ijs} transit time on first - leg arcs (expressed in days)
- TEB_{jk} transit time on second - leg arcs (expressed in days)

and the following variables:

- tt_{ij} binary time variable representing containers flow on first - leg arc, operator i to gateway j, $tt_{ij} \in \{0,1\}$
- tl_{kj} binary time variable representing containers flow on second - leg arc, gateway j, mode of transport k, $tl_{jk} \in \{0,1\}$

The mathematical model can be formulated as follows:

Minimize Time = (

$$\sum_{(i,j)\in A}^{1} TSE_{ijs} * tt_{ijs} + \sum_{(j,k)\in C}^{1} TEB_{jk} * tl_{jk}) \qquad (1)$$

Constraints:

$$\sum_{(i,j)\in A} \sum_{s} tt_{ijs} = 1 \qquad (2)$$

$$\sum_{(j,k)\in C} tl_{jk} = 1 \qquad (3)$$

$$\sum_{i,s} tt_{ijs} = \sum_{k} tl_{jk}, \ \forall j \qquad (4)$$

Corresponding Explanations:

The objective function (1) minimizes total transit time of container import from Shanghai to Belgrade. Constraint (2) defines a single best solution for transit time on the ocean and depends of different type of service. Constraint (3) gives a single best solution for transit time on the second leg - arc. Constraint (4) selects the same port for the first and second leg - arc and represents one route from origin to place of delivery regarding transit time.

4. RESULTS

In this section we analyze the results obtained by our developed mathematical optimization model, which minimize the transit time of container import from Shanghai to Belgrade. Model was programmed in MATLAB and simulations were performed on an Intel Core i7-3612 QM 2.1 GHz computer. We use original input data regarding period July - August 2013.
The results of our investigations are shown below:

Scenario:

The optimal transit time between Shanghai and Belgrade is 29 days using ocean and inland freight together (Fig.1). The operator COSCO use Far East Black Sea Express Service - ABX (Fig.2) from Shanghai to Pireaus, Adriatic Feeder Service - AFS from Pireaus to Rijeka (Fig.3), then continues with truck to the final destination Belgrade. Figure 1 also includes rate per TEU and total distance on the optimal route.

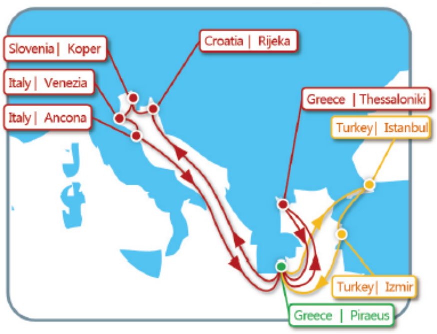
Port of loading	Shanghai
Operator	COSCO
Transshipments	1
Service	ABX / AFS
Route	Shanghai-Ningbo-Yantian-HongKong-Nansha-Singapore-Suez-Pireaus/Pireaus-Thessaloniki-Pireaus-Rijeka
Port of discharge	Rijeka
Mode of transport	Truck
Place of delivery	Belgrade
Opt. transit time	29 days
Rate per TEU	1772 €
Distance	16967 km

Fig. 1 Optimal transit time

Transit Time (Day)

From / To	Piraeus	Kumport	Constantza	Ilyichevsk
Shanghai	22	24	26	29
Ningbo	21	23	25	28
Shekou	18	20	22	25
Singapore	14	16	18	21
Port Kelang	13	15	17	20

Fig. 2 Far East Black Sea Express Service



Adriatic Feeder (AFS)

Port	Time
Piraeus	0
Thessaloniki	2
Piraeus	5
Rijeka	8
Koper	9
Venezia	11
Ancona	12
Piraeus	14

Fig. 3 Adriatic Feeder Service

Total transit time between Shanghai and Belgrade includes:

- transit time between Shanghai and Pireaus - 22 days
- waiting time (for feeder to Rijeka) in Pireaus - 2 days
- transit time from Pireaus to Rijeka - 3 days
- waiting time in Rijeka port - 1 day
- transit time from Rijeka to Belgrade by truck - 1 day

A. Maurizio, M. Simona, and R. Andrea [1] are extended the frequency based approach introduced by Bell et al. [2] to an intermodal network, adding services capacity constraints, loading/unloading and duty check times while empty containers repositioning is not treated. They deal with container assignment optimization on an intermodal network and proposed a linear programming model. Computational results showed the efficiency and the effectiveness of the approach proposed, even on large size instances.

Bell et al. [2] transferred in theirs paper the classic frequency - based transit assignment method of Spiess and Florian [4] to containers demonstrating its promise as the basis for a global maritime container assignment model. In that model, containers are carried by shipping lines operating strings (or port rotations) with given service frequencies. An origin - destination matrix of full containers is assigned to these strings to minimize sailing time plus container dwell time at the origin port and any intermediate transhipment ports.

Similar research in terms of testing the bi - objective optimization minimizing cost and transit time conducted Lam, J. S. L. and Gu, Y. [5] observing import and export container flow to and from inland China. The results and analysis offer managerial insights of the impact of trade-offs between cost and transit time.

5. CONCLUSION AND FUTURE RESEARCH

This paper analyzes the supply chain network with primary focus on import of containers from Far East (Port of Shanghai) to Serbia (city of Belgrade) through selected Adriatic ports - Koper and Rijeka, observing the six world's largest container operators (Maersk Line, Mediterranean Shipping Company, CMA CGM, Evergreen Line, China Ocean Shipping Company and Hapag - Lioyd) with theirs different type of services. Serbia is hinterland country and container import from Far East to Serbia needs to use different transport modes on inland to link shipping transport in the sea leg including railway, barge and truck. Transport users require frequent, accurate and reliable implementation of transport. The main goal of this research is to provide an optimal route with shortest transit time of container import from Shanghai to Belgrade.

We propose a mathematical model, which give us possibility to get reliable data of the minimal transit time, which is main advantage of this model.

The contribution of this paper shows that the experimental results are not only a scientific, since it can be applied in practice. The application of the model is simple. It is recommended to managers who made a policy of the company, in order to improve their businesses following the constant changes in the market and making reliable comparisons.

Further research is needed, because this research is recited only part of the problem. It can be extended in the future and can be imported with a lot of new nodes with the main objective to minimize time. This model can be regarded in future as multi-objective and implemented with two new objectives - transportation costs and emissions.

ACKNOWLEDGMENT

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REFERENCES

[1] A. Maurizio, M. Simona, and R. Andrea, “Formulating a mathematical model for container assignment optimization on an intermodal network,” Procedia - Social and Behavioral Sciences 111, 2014, pp. 1063-1072.

[2] M. G. H. Bell, X. Liu, P. Angeloudis, A. Fonzone, and S. H. Hosseinloo, “A frequency-based maritime container assignment model,” Transportation Research Part B 45, 2011, pp. 1152-1161.

[3] C. L. Robert and J. Payman, “Estimating flow times for containerized imports from Asia to the United States through the Western rail network,” Transportation Research Part E: Logistics and Transportation Review. Volume 48, Issue 1, January 2012, pp. 296-309.

[4] H. Spiess and M. Florian, “Optimal strategies: A new assignment model for transit networks,” Transportation Research Part B: Methodological. Volume 23, Issue 2, April 1989, pp. 83–102

[5] J. S. L., Lam and Y. Gu., “Port Hinterland Intermodal Container Flow Optimisation with Green Concerns,” A Literature Review and Research Agenda, Proceddings of International forum on Shipping, Ports and Airports: Trade, supply chain activities and transports: Contemporary logistics and Maritime issues. 3-5 june 2013. The Hong Kong Polytechnic University, Hong Kong, pp.167-179.

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AIR POLLUTION FROM TRANSPORT

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Abstract

The transport system of one area provides many benefits, but the all technological, economic and environmental impacts despite the progress of science and technology today is still difficult to overcome. The greatest endangering the environment from the means of transport is expressed through the air, making noise and occupation of land and airspace. In this paper, attention is paid to greenhouse gas emissions from transport. Emissions caused by transport accounts for about 13% of total emissions. The use of alternative fuels is a solution which is energy efficient and which reduce the contribution of transport to climate altered, while effectively and efficiently transport goods and people where and when it is needed.

Keywords*: transport, emissions, environmental aspects, alternative fuels*

1. INTRODUCTION

The expression environment means the whole system of natural and anthropogenic objects and phenomena in which the work is done, people are living and resting. Any change to the environment that negative reflects on the natural flow of life and development, and running the environment system from the steady state is degradation or disruption of the environment.
From the aspect of environmental protection a significant negative impact of transport is air pollution. Every spent liter of fossil fuel combustion produces about 100g of carbon monoxide, 30g of nitrogen oxide, 2.5 g of carbon dioxide and many other harmful and toxic substances such as lead compounds, sulfur compounds and solids particles. All of these compounds, to some extent lead to air pollution, either by direct effect on the health or globally, for example, causing a greenhouse effect [1].
The impact of traffic on modern society is immeasurable. Today, the mobility of people, goods and services leads the modern society to "mobile society". All the efforts and improvements in terms of reducing emissions, increasing fuel quality, increase fuel efficiency, even the use of alternative fuels, fade to information of significant increase in the number, strength, and the use of vehicles of all types, particularly motor vehicles. Of concern is the increasing use of personal vehicles compared to the reduction of the use of public forms of transport (bus and rail), which make up less harm to the environment. Each car annually emits three times more harmful ingredients than is its weight. Each year that causes the death of one hundred thousand people.
Emissions of pollutants from vehicles in Europe have tend to decrease, however, in spite of such trends, predictions are that the concentration of gas which is the most usual in the group of greenhouse gases, CO2, will stay high in most urban areas [2].
To reduce the negative environmental impact from traffic, it is necessary to take a series of measures. With the inevitable technical and technological procedures on means of transportation, the most efficient is use of transport policy, both at the global and national level, which must lead in the direction of sustainable development. Measures to improve the system as well as preventive measures are vital in the process of reducing the negative impact of transport on the environment.
During the last twenty years, there were intensive developed of software package that allows the estimation of emissions per kilometer [3].

2. CLIMATE CHANGE AND AIR POLLUTION

To study the impact of the problem of global warming, or climate change parameters in the future, it is necessary to predict the direction and intensity of these changes. In this purpose, a so-called 'Earth model', is used. This model use advanced mathematical approaches and most modern computer technology [4].
Summer temperatures across Europe recorded a uniform increase until 2050. About 1°C-2°C, except in the West where the temperature will rise to around 2°C- 3°C. Additional temperature rise is expected on the border with Russia and the former Soviet Union. Large changes in the average monthly temperature of 8°C- 9°C, will refer to the countries of the Balkan region, Austria, as well as some parts of the Italian Alps.
Winter temperature (January) increases about 1°C-2°C in most parts of Western Europe, but also for 1°C-2°C additional degrees in North and Eastern Europe, which are much cooler and that will cause some extent spared the cruel winter. This upward trend in winter temperatures, that can certainly be said by 2100., will make that a very cold winter in the northern and eastern parts of Europe become much milder. Whole Europe except Scandinavia and parts of northern Germany, Belgium, Scotland and Northern Poland, will record a significant decline in the annual flow of water to 2050. year. This will be the most affected of the Dunav, which flows through Serbia and Bulgaria, on the Sene in France and several rivers in the Iberian Peninsula.
Estimates, based on climate modeling, the temperate scenarios, indicate that the annual temperature in Serbia until the end of the century will increase by 2.6°C. Warming will not be uniform throughout the year; summer will be warmer by 3.5°C, the fall of 2.2°C, 2.3°C for the winter and spring 2.5°C [5].

The transport sector is one of the largest issuers of various chemical compounds (carbon dioxide, nitrogen oxides, carbon monoxide, methane, ozone, etc.) and the polluting particles which affect on climate change [6]. Emissions from transport depend on many parameters. Type of vehicle, engine size, age, fuel, way the vehicle is used all these parameters affect emissions during driving [7].

Much of the city's population is exposed to the levels of emissions that exceed the limit values of air quality prescribed for the protection of human health.

Although, thanks to the introduction of the EURO standards for vehicles, the trend of reducing emissions in the transport is favorable, the share of the transport sector in the emissions of pollutants considered is still significant.

Internal combustion engines emit a series of different pollutants and the emissions are directly dependent on technology vehicles or engines and fuel characteristics. Due to advancing technology for reduction of emissions from vehicles depends on fuel quality, the measures shall include in addition to the standards for vehicle, engine and fuel standards. Emissions consist for the most part of the following elements: the incombustible hydrocarbons, oxides of nitrogen, carbon monoxide, particulates, carbon dioxide, water vapor, sulfur oxides, ozone, oxides of lead and other fuel additives.

Data on emissions of greenhouse gases to transport modes and types of transport are given in Table 1. It may be noted that the values of emissions for road transport is significantly higher compared to rail transport.

GREENHOUSE GAS EMISSIONS				
Traffic group	**TYPES OF TRANSPORT**			
	TRAVEL		LOAD	
	(g / passenger / km) emissions		(g/tona/km) emissions	
	CO_2	**NO_X**	**CO_2**	**NO_X**
Rail transport	3	0,01	2,8	0,004
Road transport	87	0,48	53	0,700

Table 1 - Emissions by modes of transport [8]

Emissions of harmful substances depend on the characteristics of network transport, traffic intensity and type of transportation. These aspects are linked in the following way:

-The structure of network transport determines the spatial distribution of the emission of harmful substances. Centralized network transport has concentrated traffic and because of that emission is centralized too. Dispersed networks can be better at the local level, but requires a larger amount of energy;

-Traffic intensity is determined by the degree (level) of emissions;

-Type of traffic determines the nature of the emission. Not all types of transportation have the same pollutants. Road traffic with the amount of greenhouse gases emitted by road vehicles is far ahead from other industries and causes 90% of the total external costs. In addition to the emissions that have immediate effect and intensified at the local level, some programs have delayed / long-term adverse effects in the form of global warming and climate change. Transport contributes significantly to global climate change. Concentrations of carbon dioxide, methane and nitrous oxide generated by burning fuel in vehicles cause greenhouse gases. Emissions of greenhouse gases (GHG) retained electromagnetic radiation and thus lead to global warming of the earth's surface. Further some of these gases destroying the ozone layer which protects the earth's surface from ultraviolet radiation.

Emissions of CO2 occur in other sectors such as industry, household, power plant but in transport is a significant issue with 27% [9]. Taking into account all the sectors of transport in road transport is the highest CO2 emissions with 72%.

Air pollution as a negative external effect of traffic is a big problem today because it affects many field of human life. Emissions do not directly affect human health but indirectly through the greenhouse effect and global warming affect.

3. COMBUSTION OF FUELS IN MOTOR VEHICLES

Internal combustion engines (IC) used in motor vehicles or for other purposes, are the main sources of certain pollutants. At the global level, they account for over 60% of the emissions of carbon - monoxide, about 50% of the emissions of hydrocarbons and 50% in emissions of oxides of nitrogen [6].

Combustion is the main process during which the chemical energy of the fuel is converted into heat and then into mechanical work in IC engines. Of the total energy that is released during the burning process, about 42% is used to start the vehicle, while the remaining 58% is loss. Basically, when engine has higher efficiency, there are also smaller amounts of harmful exhaust gases. The development and use of new technologies in order to reduce emissions, has led to such advanced solutions that are harmful gas emissions fell by more than 95%.

Combustion is a very complex chemical process, characterized rapid changes in temperature, pressure and concentration of reactive substances. The process of chemical conversion in the combustion chamber is anything but not a simple chemical reaction. Because of that is not yet defined a satisfactory theory of combustion described process in every detail.

In the case of perfect combustion the fuel reacts with the air and products of this combustion are carbon dioxide, water and nitrogen molecules.

fuel (hydrocarbons) + air (oxygen and nitrogen) = carbon dioxide + water + nitrogen molecule

In practice, perfect combustion is not possible. Apart from the basic products of perfect combustion there is formed and oxides of nitrogen, incombustible hydrocarbons, and carbon monoxide.

fuel (hydrocarbons) + air (oxygen and nitrogen) = incombustible hydrocarbons + oxides of nitrogen + carbon monoxide + carbon dioxide + water

The ratio of the amount of air and fuel plays an important role in the efficiency of the combustion process and therefore on emissions, fuel economy and engine performance. If the mixture is richer (more fuel than air for complete combustion), will cause increased fuel consumption and emissions (especially CO and HC). In the case of lean

mixture (more air than fuel for complete combustion), it will be reflected in a lower engine power.
In the research possibilities of alternative fuels should be kept in mind that the cheapest source of energy, and certainly the most desirable. The advantage of the use of oil and its derivatives in transport is primarily at relative easy storage and efficient combustion in IC engines. Other fossil fuels (natural gas, propane and methanol) can also be used in transport, but they are more complicated to storage. For the general application of these types of alternative fuels requires much greater investment plant for distribution in relation to conventional fuels. Smaller energy efficiency compared to petrol induces a need for greater distribution capacity.

4. ALTERNATIVE FUELS

More and more attention is paid to the application of alternative fuels in transport and because of that every day there is a more recent result in this field. The best known alternative fuels are biofuels (ethanol or biodiesel), hydrogen and electricity. There are also various studies in terms of construction and implementation of hybrid vehicles. These studies are aimed to reduction the greenhouse gas emissions, including the most carbon dioxide and reducing the use of existing fossil fuel reserves. Larger investments are needed in this area to help at the earliest time that is possibly to receive adequate and useful results.
Alternative fuels in the form of refined petroleum attracted considerable attention because of the defect of oil reserves, increasing oil prices and the need to reduce emissions pollutants.
Biofuels such as ethanol or biodiesel can be obtained by fermentation of sugar cane, corn, cereal, etc. Restriction to the application of this type of fuel is a great need for utilization of land for cultivation and harvesting of these plants. For example, it is estimated that one hectare of wheat products of less than 1000 liters of fuel per year, representing a single energy of a passenger car, which exceeds 10,000 km per year. This restriction stems from the limited capability to absorb solar energy, which is transformed in the process of photosynthesis. Such low productivity cannot successfully satisfy the needs of the transport sector.
Hydrogen is often mentioned as an energy source for the future, because it is twice energy efficient than gasoline. Restriction to the application is a great energy consumed in the production, transfer and storage of hydrogen. Hydrogen production requires electricity. Hydrogen-powered vehicles require from two to four times more energy compared to an electric car, a big problem in service represents the flammability of this gas.
Electricity is also considered as an alternative fuel. The main obstacle in the application of electric cars is the overcoming great distances and reaching speeds which conventional vehicles have. Because of the need charging an electric car cannot be used for distances greater than 100 km, a speed achieved so far does not exceed 100 km / h.
The recent development of hybrid vehicles (combination of internal combustion engine and electric battery) is a favorable combination of energy efficiency by providing electric power battery and greater distance transporting providing by conventional engines.

5. CONCLUSION

Strong demographic growth, which mainly burdens the major cities of the developing world, represents a serious challenge to the operation of their public transport. The effects of intense climate change in recent decades are reflected in almost all parts of the world. More often disaster due to bad weather concerns the human society, but also there is a willingness to continue to mitigate the climate change or prevent. For this purpose it is necessary to reduce emissions of greenhouse gases, and which concentration in the atmosphere suddenly increased, primarily as a result of the use of fossil fuels in transport and industry.
Actuality topics of energy efficiency, on the one hand and the greenhouse gas emissions that affect the greenhouse effect, on the other, resulted in a series of studies aimed at finding optimal solutions to these problems. When it comes to the transport sector, one of the main measures to achieve this goal is the diversion of cargo flows to more environmentally friendly transport sectors as well as environmentally friendly fuel.
In this issue includes all factors that can in any way have contact with the vehicle from production to the end of the service life of the vehicle. For efficient and environmentally friendly transport development in Serbia, it is necessary to create appropriate institutional, technical and technological base.

REFERENCES

[1] Vladimir Papić, “Determination of the emission of gaseous pollutants originating from road traffic using Corpet IV model of the European Agency for the Environment,” Institute of Transport and Traffic Engineering, University of Belgrade, Faculty of Transport.

[2] EEA, “Greenhouse gas emission in Europe: a retrospective trend analysis for the period 1990-2008,” Copenhagen, 2011.

[3] EEA,” COPERT IV software tool,” Copenhagen, 2009.

[4] Mirjana Laković, Slobodan Laković, Predrag Živković, “Effects of Global Warming on Thermal Power Plant Performances”, Symposium Power plants, Vrnjačka banja, Symposium proceedings on CD, 2008, Book of apstracts pp. 90-91

[5] Popović, Đurđević, Živković, Jović, Jovanović,“Climate Change in Serbia and the expected impact of "Ministry of Energy, Development and the Environment.

[6] Sanja Ilić, "The role of railways in sustainable development", Diploma thesis, Faculty of Mechanical Engineering Niš, 2012.

[7] Živković, Ilić, Tomić, Vukić, Stevanović, Stevanović, Ogrizović, “AIR POLLUTION ESTIMATION ON THE CITY OF NIŠ TERRITORY,” International Symposium Power Plants, Vrnjačka Banja, Serbia, October 2010.

[8] Ministry of Transport and Maritime Affairs, "The program of renewal of Montenegrin carrier fleet environmentally advanced vehicles", 2011.

[9] International Union of Railways (UIC),”Rail Transport and Environment”, Facts & Figures, June 2008.

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TRANSPORT AND DEPOSITION OF SLAG AND ASH

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Abstract

Because of the massive combustion of coal in the power plants there are large quantities of energy waste in the form of ash, slag and gypsum. For the proper functioning of the power plant it is necessary continuous transport of slag and ash. There are several systems for removal of slag and ash from the power plants. Considering their influence on the production of electrical energy it is necessary to choose an adequate system for transport and disposal. In this paper can be seen the theoretical basis of certain systems and measures to be taken to protect the environment from the negative impacts of slag and ash.

***Keywords**: transport, disposal, slag, ash, power plant.*

1. INTRODUCTION

Coal as an energy source has marked economic and political development of Europe in the 19th and 20th centuries. At the beginning of the 21st century the energy from coal represents 25% of the total energy produced in Europe and it is the most important individual energy source. [1] Serbia is one of the European countries, where coal is the predominant source of energy. Confirmation for this statement is obtained if it we look at electricity production, more than 74% of electricity is obtained from burning coal. Out of the total annual coal production in Serbia, in power plants burns 96%, while the remaining part is selling as coal for industry and for domestic heating.

Facility for the preparation, transportation and ash disposal is the final link in the chain of electricity production in power plants. Amount of annually produced energy waste in the world exceeds the amount of one billion tonnes. In Serbia the annual production ash and slag is about 7 million tonnes. In addition, ash and slag are characterized as inert, hazardous and non-hazardous waste, while gypsum is classified as non-hazardous waste. Depending on the coal mine deposits, the type and quality of coal, the degree of dedusting and the quality of combustion facility, quantity of ash and slag that remains after the production of electricity is between 15% and 26%.

One of the main environmental problems in the production of electricity is the transport and disposal of ash and slag from power plants. In order to solve these problems power plants use systems for transport and disposal. The purpose of these systems is to remove slag generated in the combustion chamber and ash separated from the smoke gases, from the power plant, often at considerable distances (up to 10 km). Solving the problem of transport and depositing is possible by introducing modern technologies, with better organization and promotion of environmental protection measures. [2]

2. PRODUCTION OF SLAG AND ASH

Coal is the mineral raw material composed of solid materials (organic and inorganic mineral matter), liquid (water) and gaseous (volatiles) phase. Coal can be divided on combustible and incombustible part.

Combustible part consists of solid organic substances and volatiles, and noncombustible part consists of moisture and ash. The consequence of burning a large amounts of coal is a large amount of the solid inorganic materials - ash and slag. After combustion in boilers of thermal power plants, smoke gases are purified of fly ash particles in the electrostatic filters. Separated ash mixes with water in a defined ratio and it is transported on the open ash disposal site. [3]

From the aspect of depositing the essential division is on slag and ash. The ash is a mixture of a boiler ash and fly ash. Slag separates out due to its specific characteristics, particularly size and the deposition rate, which significantly influence on the choice of transport system.

In industrial practice, the term "ash" means solid incombustible residue that is separated during combustion of coal in boilers of power plants and heating plants. By the place of separation, there are different types of "ash". In the thermal power plants, where is applied classical combustion system of pulverized coal there is a difference between:

- slag, the biggest incombustible residue of combustion, which is separated at the bottom of the boiler,
- boiler ash, separated from the boiler with the smoke gases, by the influence of gravity the ash is deposited and stays bellow the smoke gas channel and below the air heater,
- electrofilter ash or fly ash, the smallest particles which are separated from the smoke gases, a separation from the smoke gases is performed in the electrofilters. In the power plants where coal combustion is performed in a fluidized bed, separates layer ash mixture that represents a combination of the above-mentioned types of ash.[4]

3. THE CHOICE OF LOCATION FOR SLAG AND ASH DISPOSAL

Disposal site is a technical object whose start of the life cycle is clearly defined and it starts with a consideration of possible (potential) sites, but there is no clear time limit for the completion of the life cycle. The life cycle begins with the selection of locations for future disposal sites and planning activities that are essential for a successful and safe service.

The disposal site exploitation can be technically simplified and economically acceptable by choosing a good location. The choice of location represents the starting phase of design and construction, this phase is partly overlapped with the phases of the selection and exploitation. Disposal site is considered as a "live" object because the construction (upgrading and extension) and the exploitation performs at the same time and it is necessary constant work on projects for further construction.The last phase is called termination of work and closure, this is specific because the period of work termination can be clearly defined, but the closure lasts for many years and the time is not defined. Disposal site capacity is expressed through the total usable volume, and the time period over which site can be used. There is no general rule that defines the size of a disposal site, but installed equipment (transportation system, drainage system, a system for receiving and return water transport, etc.) should be fully amortized for 15 to 25 years. Transport of energy waste from a thermal power plant to the disposal site represents a technical, technological, and economic problem. Therefore, it tends to be closer to the facility where the waste is generated. It is easier to organize work and staying for workers who perform exploitation at the site when it is closer to the facility where waste is generated. Due to the possibility or needs for expansion of facilities it is necessary to take care about the location of the site. It should be remembered that the relocation of the disposal site is extremely difficult and expensive so it is not recommended.

Due to the large number of factors affecting the choice of location for the disposal site of energy waste, this is one of the most sensitive engineering problems.

Grounds for determining the location is the ownership of the land, which is potentially a space for the formation of the disposal site, and funds available for the land acquisition.When the last two items are successfully solved, the location of the disposal site should be done taking into consideration factors that can be grouped in five categories:

- technical - technological,
- urbanistic,
- environmental,
- sociological,
- economic.

In considering mentioned factors always is involved compliance with current legislation. [5]

Fig.1 Ash disposal site of TPP "Костолац Б"

4. TRANSPORT TECHNOLOGY DEPENDING ON TYPE OF SLAG AND ASH

The amount of ash and slag, which should be taken from the power plant depends on the fuel consumption, method of combustion and efficiency of the filters. Required hour capacity of the system for the removal of slag (kg/h) is determined by the formula:

$$G_{š} = 0.01 \cdot B \cdot (A^P + q_4 \cdot \frac{Q_H^P}{32.7} \cdot \left[1 - \alpha_{un} \cdot (1 - \frac{\eta_{ef}}{100})\right]$$

B	- fuel consumption [kg/h]
A^P	- dustiness of fuel [%]
q_4	- heat loss due to the unburned fuel [%]
Q_H^P	- lower heating value [MJ/kg]
32.7	- lower heating value of carbon [MJ/kg]
α_{un}	- the dust in gases
η_{ef}	- degree of filtering

Based on the type of ash and transport technology, there are three basic systems of the technological transportation process of ash and slag:

- internal transport, i.e. system for collecting ash and slag inside the main production facility,
- external transport, i.e. system for ash and slag transportation from the main production facility to the disposal site,
- depositing, i.e. the final step in which the collected and transported ash and slag safely depositing on the specially selected and prepared ground.

Internal transport: Internal transportation system includes a pneumatic transport system for boiler ash and fly ash from the exhaust to the collection silos; supporting systems for pneumatic transport such as compressed air system; the silos equipment for ash collection, which includes systems for dedusting, fluidization bottom of the silos, fly ash dosing in transportation system and loading into tank trucks.

External transport: This system depends on how it is resolved internal transport. If from the inside of the main production facility system mixes water, ash and slag then the external transport is fully defined as hydraulic. If as internal transport is applied dry pneumatic transport there is the possibility to choose the most suitable type of external transport: dry - mechanical and pneumatic and the wet - hydraulic.

Depositing: Dry and mechanical external transport dictate terms of dry depositing and forming of dry disposal site. The use of hydraulic transport basically offers two options: depositing in the form of rare hydromixture and as dense hydromixture.

5. SLAG AND ASH TRANSPORT

Transport of slag and ash can be:

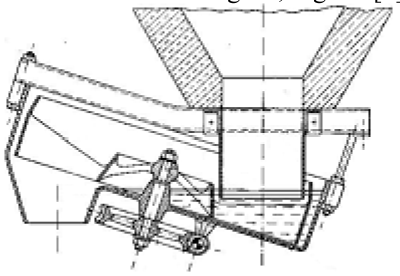
- mechanical,
- pneumatic,
- hydraulic,
- mixed.

The choice of the system is determined by a number of factors:

1. quantity of ash and slag,
2. safe and economically profitable system for ash and slag transport,
3. costs of exploitation and the complexity of handling,
4. sanitary-hygienic working conditions,
5. the existence of suitable sites for catching and removal of ash from thermal power plants,
6. properties of slag and ash (acidity, granular composition),
7. the existence of sufficient quantities of consumable water.

5.1 Mechanical transport of slag and ash

In older power plants with less power of the boiler, slag and ash were thrown directly below the boiler and transported to the disposal site. With the increasing power of facilities, in order to avoid problems of hygiene and protection of employees, under the opening for discharge of slag were introduced water-filled container in which the slag is falling. After mixing with water, the mixture is thrown out by rotating mechanism in the wagons, Fig. 2. [6]



Slika 2. Wet slag remover

For transport of slag and ash can be used trucks (different versions and capacity), and conveyors.

Fig. 3 shows the trucks for transport of wet ash. It can be trucks with trailers and tanks. Trailer of the truck has specifically designed cover to protect loaded ash during transport. After loading the cover is mechanically pulled on the trailer, and on arrival at the place of unloading cover is opened in the same way.

Fig. 3 Trucks for transport of wet ash

Conveyors are more often used to transport slag than ash. The reasons for this are related to problems with the prevention of air pollution. Fig. 4 shows the conveyors for transport of slag, and the pipelines for internal transport of ash. In all cases, when mechanical transport is applied, before being loaded into a transport vehicle must be done soaking or wetting the ash. The degree of wetting depends on the characteristics of ash and the availability of water, usually humidity is in the range of 10 to 30%.

Fig.4 Transport of slag and ash

The most critical stage in the handling of dry ash by using mechanical systems of transportation is the phase of unloading at the disposal site. Because of the duration of the transportation cycle often case is that ash dries causing formation of dust in the wider area around the unloading site. In recent times the mechanical systems are replaced with new hydraulic and pneumatic systems.

5.2 Pneumatic transport of slag and ash

Pneumatic removal of slag and ash is achieved with air for whose movement can be used ejectors or vacuum pumps. The most used schemes are with vacuum (sucking) steam ejectors. Slag from each bunker goes to the crusher where it is crushed up to 35 minutes. Work of receiving device for slag and ash is analogous to the work of an ordinary cyclone. Transported slag and ash are catching in the bunker and the gases with steam ejector goes into the chimney. For normal operation of the system the concentration of ash and slag in the mixture must be in the appropriate range. Usually, for the diameter of the pipe 90-120 mm air speed should be 30-35 m/s at the concentration: 4 - 7 kg of slag and 1 kg of ash per 1 kg of air. The higher values correspond to higher speeds and bigger pipeline diameter. The main disadvantage of this system is the impossibility to transport slag and ash at a distance greater than 150-200 m. Often this system is used as a backup system for hydraulic systems because of pollution due to the use of cyclones.

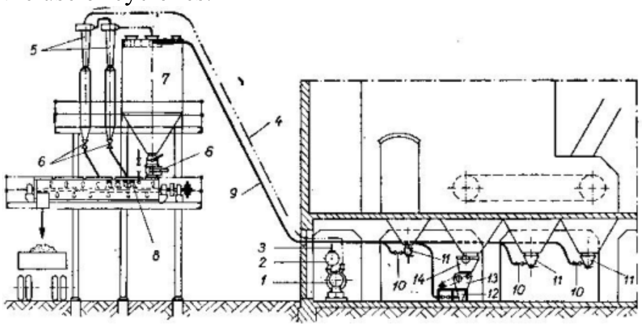


Fig.5 Pneumatic transport with a vacuum pump

1- vacuum pump	8- worm gear for wetting
2- water separator	9- pipeline
3- outlet	10- suction nozzle
4- air pipeline	11- suction container
5- fine dust separators	12- suction chamber
6- drain valve	13- slag crusher
7- ash storage	14- funnel for slag

5.3 Hydraulic transport of slag and ash

Hydraulic ash disposal means that after a brief mixing the ash in the form of hydromixture is transported to the disposal site where it is unloaded by different methods:

- transport and deposition as rare hydromixture,
- transport and deposition as dense hydromixture

Transport and deposition as rare hydromixture: Rare hydromixture generally means that the ratio of water : ash = 10:1 or the participation of water is even more. This is a very comfortable system operation as it requires no special technological discipline, care and automation, but it is a big waste of water and energy, there are a lot of problems with maintenance of static and ecological stability of the dump.
Transport and deposition as dense hydromixture:
Dense hydromixture means that the ratio of water and ash content is about 1:1, and that this ratio is strictly controlled. These systems include the strict technological discipline and the introduction of highly sophisticated systems of automatic control density. The maximum permitted volume concentration depends on the type of pump that is used for the transport of mineral raw material and the characteristics of transported materials. [7]
There are the following hydraulic systems for transport of slag and ash:

- free fall,
- slurry pumps.

Also, these systems can be divided into high-pressure and low-pressure systems. The system of free fall can be applied in a suitable type of reliefs and short distance between power plant and the disposal site. It belongs to the low-pressure hydraulic transport of slag. Slag goes in a special water-filled chamber below the boiler where the slag is quenched with water which is injected into the chamber. Quenched slag sliding across the floor to the antechambers through the grid, which prevents the passage of large pieces (larger than those that can be raised with slurry pumps) in the channel, located below the grid.
Fly ash from the boiler channels, from the dust collector and from the chimney mixes with water and discharges into the common drainage channel. Dimensions of drainage channels, which should have a round bottom with a minimum drop of 2.5%, should be determined so that the speed of the hydromixture (water, slag, and ash) is less than 2 to 3 m/s. Water quantity which is injected into the channel varies depending on the characteristics of the slag, between 7 and 20 times the quantity of transport ash and slag. This kind of system is shown in Fig. 6.

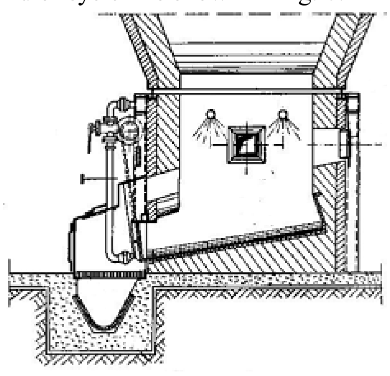


Fig.6 Chamber for slag separation [8]

In systems with slurry pumps a hydromixture of water and slag is transported by pipeline to a receiving station, where performs separating pieces of metal and slag pieces bigger than 40 mm. Impellers of slurry pumps have a small number of (usually 4) back bent blades. These pumps have a low degree of efficiency (35-40%) and they are very often out of order. Therefore, in order to ensure safe operation, it is necessary that there are at least three batteries of pumps - working, spare and one in the process of repair.
Slag and ash in free fall through the channels come to the bunkers. The slope of channels is not less than 1.8% of slag and 1% of ash. Flushing the ash with water is continuously and flushing the slag is periodically 1-2 times per shift in order to save water. The water pressure in front of the nozzle for ash is 2-3 bar and 5-10 bar for slag. In the lack of water, system with overflow reservoir is applied. It is a concrete pool which is divided into three parts, part for slag, ash and clean water. In the first part comes mixture of ash and slag. In the first part stays slag, in the second ash, and in the third part water which goes back on the reuse. By using the elevators and wagons wet slag and ash is transported to the disposal site. The disadvantage of this system is the transportation of the wet slag, which can freeze in the winter, as well as the large dimensions of the pool. Transportation pipelines are made of steel pipes diameters 200 - 500 mm. Their number is equal to the number of steam generators.
In the process of choosing the type of transport should be paying attention on following:

1. size of the pieces and the quantity of transported slag and ash,
2. characteristics and quality of slag and ash,
3. length of the transportation route,
4. the possibility of using slag and ash,
5. energy consumption in the transportation process.

6. INFLUENCE OF DISPOSAL SITE ON THE ENVIRONMENT

The issue of safe depositing can be considered from two aspects : technical and ecological. From an ecological point of view, the main problems related to ash and slag depositing are connected to:

- air pollution,
- surface water and ground water pollution,
- soil pollution.

Improving the conditions for environmentally stable depositing of energy waste can be considered in three groups of measures for the protection:

- reduction of source pollution,
- preliminary protection measures,
- subsequent protection measures.

Reduction of pollution from the disposal site involves activities that the European Community is characterized as "preventive waste reduction" and "recycling". For ash and slag sites these activities include:

- selective excavation of coal,
- cleaning coal before combustion,
- increasing the efficiency of combustion equipment,
- finding potential ash users.

In the first two cases it is about mining operations and activities and accordingly to that, it is clear that the "producers" of ash and slag (coal-fired power plants) have no direct influence. However, as users of coal they can and should participate in defining and planning these works. Increasing the efficiency of combustion equipment and finding potential ash customers are activities that directly depend on the power plant and its organization.
Previous measures of protection can very effectively reduce impact, on the environment, to a minimum, while at the same time investments are slightly higher. This group of protective measures is based on engineering solutions, but can not be achieved without broad support not only of the community, the population in the region, but also engineers from the mine. Previous measures of protection include the following activities:

- choice of rational technology of transport and depositing,
- optimization of the disposal site size,
- selection of suitable locations for forming disposal site,
- space preparation for depositing.

Subsequent protection measures have the least effect and require major investments, but they are necessary if we want to preserve peace of people living in the region of the disposal site. Subsequent measures include the following activities: [9]

- maintenance of disposal site on maximum allowed size,
- sprinkling the bare portion of disposal site with water or with suspensions of different composition,
- forming the biological cover.

7. CONCLUSION

In the past years, power plants invested significant funds in the modernization and construction systems for transport and disposing of slag and ash. The aim of reconstruction of these systems is to replace the existing systems with environmentally more favorable technological solution.
One of the modern systems has been already mentioned system of transporting and depositing in the form of a dense hydromixture. Depositing of ash and slag in the form of dense hydromixture (ash: water = 1:1) contribute to the preservation of a healthy environment in the area of thermal power plants.
The advantages of this technological process are:

- smaller surface for depositing,
- a smaller quantity of water,
- no pollution of surface and groundwater,
- significant reduction of air pollution
- reduction of soil pollution,
- rational electricity consumption,
- increased stability of the disposal sites due to the smaller water quantities.

In addition to the cost and conditions of work that must be achieved, the system for transport and depositing of slag and ash is defined by the conditions that must be satisfied in terms of environmental protection.

REFERENCES

[1] European Association for Coal and Lignite, (2003). Europe and the Coal Industry

[2] Ignjatović D., 2001, Određivanje eksploatacionog kvaliteta uglja za sagorevanje u termoelektranama Nikola Tesla, Zbornik radova 33. oktobarskog savetovanja, Bor

[3] Dragan M. Dramlić, Predrag S. Milutinović, Zoran J. Gršić, Dušan D. Joksimović, Zoran B. Velikić, Stefan D. Dramlić, Branislav D. Vulević, „Sistem za automatsko sprečavanje podizanja pepela sa namenskih deponija”,SIMTERM, 2009.

[4] Dinko Knežević: „Odlaganje industrijskog otpada“, skripta, verzija 1.16

[5] Dinko Knežević: „Odlaganje industrijskog otpada“, skripta, verzija 1.12

[6] Mirjana Laković (2012). Predavanja na master akademskim studijama iz predmeta Termoelektrane, Mašinski fakultet, Univerzitet u Nišu

[7] Dinko Knežević, Branislav Miković, Predrag Lazić, Igor Miljanović, „Ash and bottom ash hydromixture transport,” Faculty of Mining and Geology, Belgrade

[8] Mihajlov J., „Termoelektrane, projektovanje i izgradnja“, Tehnička knjiga, Zagreb, 1965.

[9] Dinko Knežević: „Odlaganje industrijskog otpada“, skripta, verzija 1.15

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SKEWING LOADINGS IN THE SCOPE OF MATERIAL FATIGUE PHENOMENA OF CRANE STRUCTURE AND TRAVELLING MECHANISM COMPONENTS

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Abstract

Taking fatigue into account is an inevitable step in crane design process according to EN, and crane SHM (structural health monitoring) as well. Fatigue analysis in engineering design and estimation of components/structure remaining life-time, demands profound knowledge on the character of changes, intensity and occurence frequency of loadings in crane real operation conditions. As norms still have no actual answer concerning the influence of crane skewing forces upon crane structure life-time, the aim of the paper is to point out the importance of skewing forces permanent monitoring, as a part of crane SHM strategy, especially when a crane is "critical machine" for corresponding technologic processes (e.g. harbor crane).

Keywords*: cranes, skewing forces, SHM (structural health monitoring), harbor cranes*

1. INTRODUCTION

Crane skewing is an inevitable phenomenon and it takes place especially in cranes travelling along large span rail-tracks (e.g. gantry & bridge cranes). It is caused by unequal distribution of wheel vertical loadings and forces resisting to travelling among the crane endtrucks and resulting unequal driving wheels wear, deformations of crane and rail-track structures, unsynchronized operation and different mechanical characteristics (torque-rpm) of electric motors and brakes in independent crane travelling drives, a whole lot of errors/imperfections in crane design, during manufacturing/mounting of crane driving components, structure and rail-track, etc.

First research papers considering the tribology problems of crane wheel-rail system, motion mechanics and corresponding loads date back to 1960-ies [1, 2]. Experimental results pointed out their stochastic character and numerous factors exerting influence on their magnitude [1, 2, 3]. Later developed kinetostatic model has been integrated into DIN 15 018-1 in 1974, and later into EN 13 001-2 & EN 15 011.

Fatigue consideration is absolutely inevitable in crane driving mechanisms and supporting structure proof of competence according to newly adopted ENs, demanding profound knowledge of character of changes, intensity and occurrence frequency of relevant loadings. ENs in effect contain detailed models and procedures for defining the skewing load values for characteristic cases, but no guide lines concerning the corresponding values in real working conditions. According to previous norms, crane skewing forces were classified as occasional loadings, but new EN 15 011 classifies them under certain circumstances as regular, including them in fatigue strength proofs of wheel assembly and crane supporting structure [12].

Increased intensity of world logistic flows causes ever growing importance of larger crane condition monitoring in important harbors all over Europe and world [13, 14, 15]. In European river ports there is a lot of cranes manufactured 30 years ago. In Danube ports on Balkan quay cranes are averagely 40 years old, similar situation is e.g. in Croatian sea ports [16]. Meanwhile, apart from the fact that these cranes were designed according to obsolete technical rules, working conditions and demands on operation have been significantly changed. So, more frequent failures are to be expected. But, nowadays the supranational transportation systems are ever more demanding in respect of SCRAMP parameters (safety, cost, reliability, availability, maintainability, productivity). In the project TR 35036 [4] research activities concerning harbor system permanent monitoring as a part of the supranational general IT system, network connected with European environment, included the study of possibilities and justification of gantry and quay cranes (including their skewing forces) permanent monitoring.

2. NEGATIVE CONSEQUENCES OF SKEWING LOADS EFFECT

Frequent acting of skewing forces during crane travelling causes occurence of various damage forms of wheels and other components of crane travelling mechanisms, crane structure, rails, and rail-track supporting structure. The most frequent are wheels and rails damages, Fig. 1.

Significant wear of a crane wheel flange is easy to see in practice (Fig. 1.a). especially e.g. in bridge cranes which attend mostly to one workshop side, causing contact of rail head mostly with the same wheel flanges. Also a rail head side wear emerges from relevant lateral loads and slip-friction forces in contact points rail head-wheel flange (Fig. 1.a, e). If a flange is excessively thinned down, this can cause its fracture (Fig. 1.b).

Skewing loads can cause rail ends deformation in points of rail joints (Fig. 1.c). Wheel flanges and crane guiding lateral rollers (if any) repeatedly come across and keep colliding with deformed rail ends, thus causing severe impacts upon the crane structures.

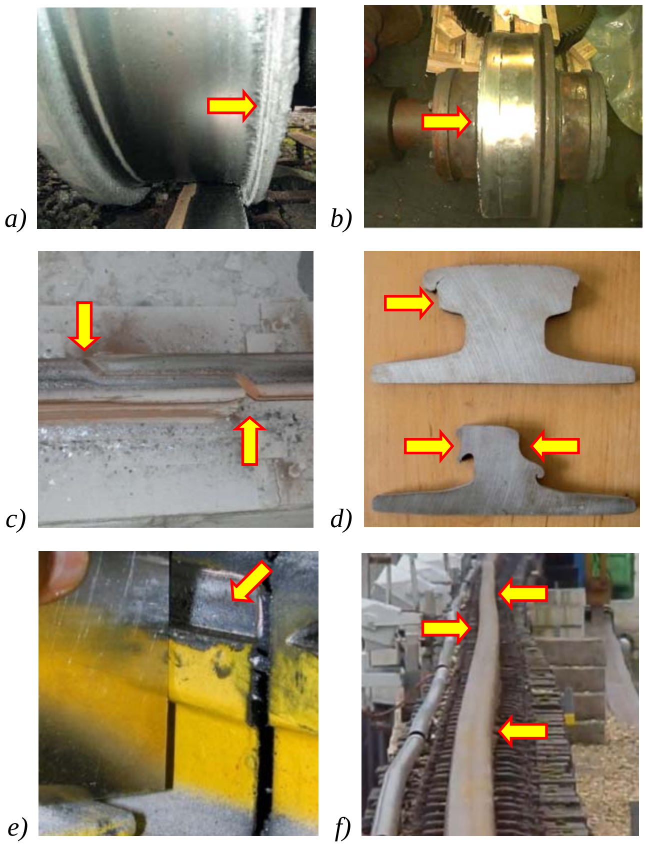

Fig. 1 Examples of consequences of skewing loads acting: a) unequal crane wheel flanges wear [5]; b) fracture of weared crane wheel flange [6]; c) rail joint deformation; d) deformation of rail head form A, DIN 536-1 [7]; e) rail head side wear [8]; f) crane track rail deformation [9]

High temperatures, e.g. in steel-plants, combined with vertical wheel loads and lateral wheel or guiding roller loads can cause severe rail head deformation (Fig. 1.d).

Gantry crane rail track sections deformation (Fig. 1.f) is usually caused by large lateral loads due to irregular guide means mounting or inadequate skewing angle limiters.

As already mentioned, it is not possible to completely eliminate crane skewing, but crane and rail-track structure design according to recommended tolerances, proper guide means usage/mounting and adequate skewing angle limiters considerably reduce the skewing loads intensity.

4. SKEWING FORCES: TO BE CLASSIFIED AS REGULAR OR OCCASIONAL LOADS?

First norm concerning crane steel components and rail track calculation was DIN 120 from 1936, and remained in effect 4 decades, eventually substituted with DIN 15 018 in 1974. For a long period large majority of national norms kept a simple procedure for defining the reaction forces lateral to the crane travelling or troley traversing direction according to FEM 1.001. Calculation model in DIN 15 018 is based on the longlasting experimental research and gives the thorough explanation of the model used for defining the skewing forces. Not long after that, this procedure was addopted also in ISO 8686-1 and FEM 1.001, and later in European norms EN 13 001-2 and finally in EN 15 011.

According to [10], crane/troley skewing forces are generally classified into the occasional loads (Fig. 2) and load combination B (in case of skewing limiting system even in C) [11], i.e. left out of crane structure fatigue calculations. As *occuring frequency and skewing loading intensity depend primarily on the crane/troley type and configuration, working conditions and irregularities emerged during crane wheels and rail track installation* [10]. Consequently, in certain cases skewing forces occurence frequency defines whether they are regular or occasional loads (Fig. 2), but no further data concerning

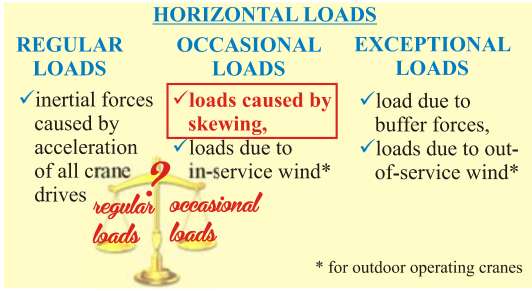

Fig. 2 Classification of horizontal loads, [10]

5. SKEWING FORCES MONITORING MODULE AS A CRANE MONITORING SYSTEM PART

Machine and structure monitoring was realized 25 years ago. Sensors built in construction/machine assembly and hardware & software systems for data transfer & processing enable its life-time monitoring. Such systems have already been integrated in "*critical machines*" (interruption of such machine operation causes the suspension of very important or dangerous processes), also in cranes in nuclear plants or of large capacity. Aside from enabling detection, localizing and estimation of damage level, they supply data necessary for prognostic procedures of reliability and structure fatigue analysis, i.e. for the remaining life-time anticipation, maintenance planning etc. When applied on structures, such procedure is denoted as *Structural Health Monitoring* (SHM), its definition can be found in [17].

Cranes of various types in sea and river harbors with intensive traffic also belong to "critical machines". Their reliability and availability are of the primary importance for the efficient and undisturbed harbor load transfer process.

Certain ways of crane condition monitoring has been already considered in few European and world projects, e.g. CRANESInspect, Eureka Robcrane Project etc. In [4] authors have considered the possibilities of forming the appropriate crane monitoring system in the Danube harbors in Serbia. Main aim of the project is to develop the Danube harbor crane monitoring system harmonized with the supra-national European network for the Danube harbors, but in the same time corresponding to actual demands of Serbian river harbors. The aim is to develop technical solutions which are applicable also for similar cranes in various industrial branches. According to the plan, the system is to be implemented on the crane in the harbor of Novi Sad. Validation of certain system parts functionality was tested on a bridge crane capacity 3,2 t, with independent travelling drives, Faculty of technical sciences, scheme in (Fig. 3).

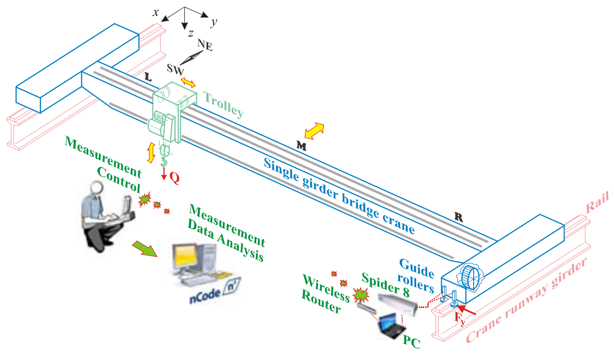

Fig. 3 Skewing force values measurement system

An example of a crane guiding horizontal rollers forces record for one crane travelling action is given in Fig. 4.

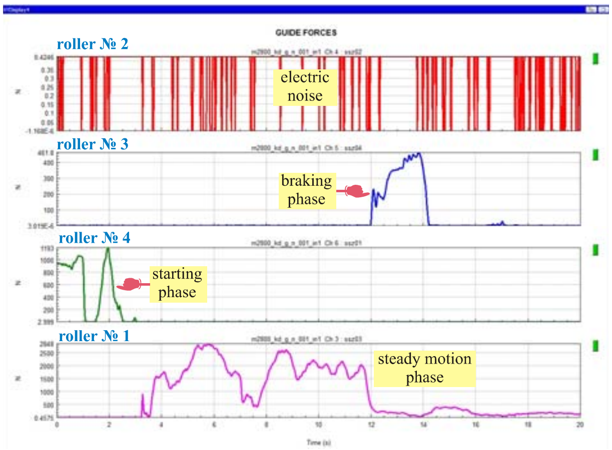

Fig. 4 Skewing force vs. time presented in nCode (trolley position R, mains supply, load mass m_Q = 2 800 kg)

Measurement data were transfered into the common data base in previously outlined form of variable guiding rollers forces time histories and processed in the software package *nCode*. Time histories were prepared for further processing (noise and undesirable signal parts were removed, signal record parts put together into longer records, when required, corresponding transformations carried out). Needed analyses were easy and effectively realised in *nCode GlyphWorks*, e.g. measured data were statistically processed and histograms automatically calculated, showing the occurance frequency of various intensity loadings. Results are presented in a form of generated report (Fig. 5), containing the most important informations. Forming a chain of mutually connected software tools (*Glyphs*) in *nCode*, the structure life-time is easily obtained.

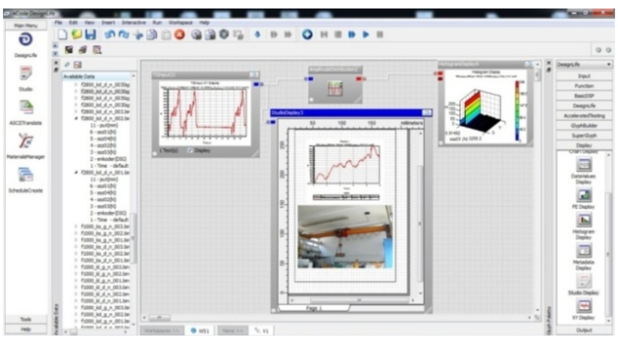

Fig. 5 Generating report on analyzed measurement results by means of nCode software tool "Studio Display"

Basic aims of crane skewing monitoring in [4] are:

- expanding the contemporary knowledge on occurence frequency and changes in skewing forces character,
- defining the influence of skewing forces in real working conditions upon the fatigue damage of crane and rail track structures & components, i.e. further development of calculation models for defining skewing loads, and
- analysis of justification of skewing loads monitoring under various conditions and necessity of developing the simple effective module for permanent measurement of lateral forces on cranes belonging to "critical machines".

6. IMPORTANCE OF A HARBOR CRANE CONDITION MONITORING

In the next period proactive maintenance of "*critical machines*" will dominate. Important variables (e.g. vibration level in mechanical power transmission devices, force values in ropes, stress values in relevant points of crane structure etc.) shall be monitored permanently or in defined time intervals, on machine operating in real working conditions.

Permanent cranes condition monitoring in their real working conditions using appropriate integrated monitoring system, can provide data useful for: crane users, especially crane maintenace engineers; institutions authorized for periodical crane inspection and testing; crane designers and manufacturers; and standardization bodies.

Acquired data analysis provides a lot of informations for the crane maintenance staff, helping in: prediction of failure occurence possibility; localization of emerged damage; finding out causes and observing damage progress; comprehending possible regularities during damage growth; and scheduling crane maintenance activities (replacement of certain assembly parts, rotating parts balancing, machine overhaul etc.). Further data transfer and processing depends on harbor organization, technical equipment, connections with authorited bodies etc. Basic scheme is given in Fig. 6.

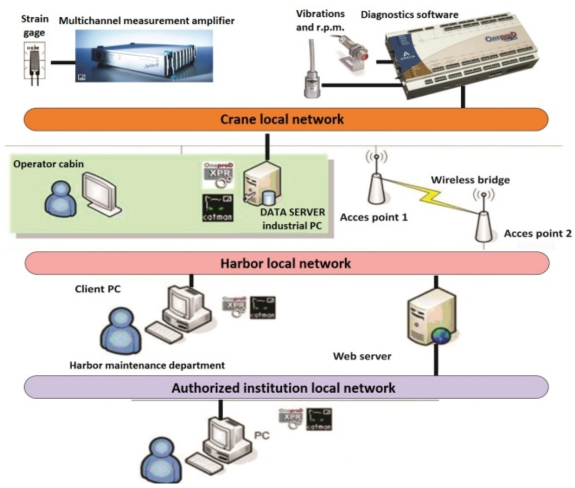

Fig. 6 Scheme of crane monitorig system, [4]

In the era of ever raising level of all relevant harbor parameters, a deep insight into the real condition of harbor cranes is very important for the harbor management. So, cranes monitoring data have to be promptly integrated in the information system of harbor operative segment (Fig. 7).

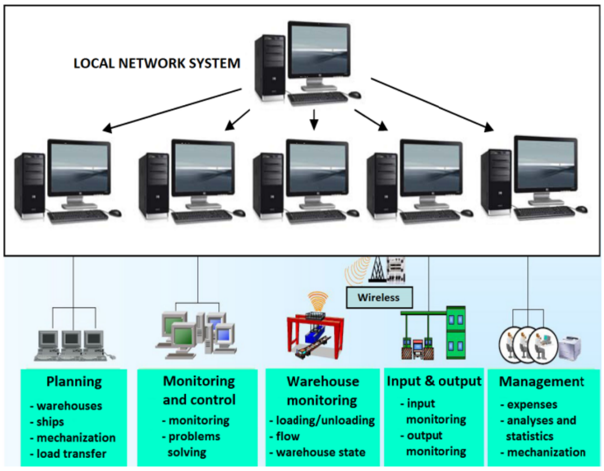

Fig. 7 Information system of harbor operative segment, [4]

7. CONCLUSIONS

In the first line, permanent crane operation monitoring enables effective user's management reactions to alarming situations and accidents connected with cranes, raising the maintenance organization level, as well as a safety level. Apart from this, it also gives a lot of data necessary for impoving the fatigue damage calculations and thus life-time prediction of crane structure and components and their rail-track supporting structure.

Due to bridge and gantry cranes skewing during travelling along rail-tracks and their inappropriate driving and guiding systems, lateral forces arise and often cause various damage forms of rails and their supporting structures, crane wheels and structure. European norms in effect contain detailed models and procedures for defining the skewing load values for characteristic cases, but no guide lines concerning their values in real working conditions.

Calculated values of loads sometimes considerably differ from measured values, due to various assumptions, simplifications and limitations, numerous influencing parameters and unsufficiently explored problems. Today, concerning crane design, this especially applies to the crane skewing forces and their influence upon the crane structure and components fatigue damage.

Thus, permanent crane operation monitoring according to SHM system practice is necessary for identifying the real character of these loads and their effects. By processing the acquired measured data, new scientific and technical information can be obtained, which can initiate the development of new calculation models or the improvement of the models and procedures already well-known in technical literature.

All the data obtained by monitoring represent also a valuable feedback for crane designer and manufacturer.

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REFERENCES

[1] G. Pajer, M. Scheffler, P. Gräbner, G. Adam and F. Kurth, Unstetigförderer 1, Berlin: Technik, 1989, pp. 101-112.

[2] M. Scheffler, K. Feyrer and K. Matthias, Fördermaschinen (Hebezeuge, Aufzüge, Flurförderzeuge), Braunschweig: Vieweg, 1998, pp. 96-112.

[3] H.-O. Hannover, Fahrverhalten von Kranen - Ein ABC der Spurführungsmechanik, Düsseldorf: VDI-Verlag, 1974, pp. 19-83.

[4] M. Georgijević and others, Research project TR 35036 Application of IT in harbours of Serbia - from machines monitoring to the network system of EU environment, supported by Serbian Ministry of Science and Technological Development, Novi Sad: Fakultet tehničkih nauka, 2011-13.

[5] W. Baumann, "Messtechnik zur Krananlagen-Prüfung" in Hebezeuge und Fördermittel, vol. 4, Berlin: Huss Medien, 2005, pp. 256-259.

[6] www.hoistmagazine.com (accessed on February 12. 2014.)

[7] R. Thoß, "Steuerbare Einwirkungen auf Kranbahnen" in Stahlbau, vol. 1, Berlin: Ernst & Sohn, 2011, pp. 39-45.

[8] C. Seeßelberg, "Zum Entwurf von Kranbahnträger für Laufkrane" in FRILO-magazin, Stuttgart: Friedrich+Lochner GmbH, 2005, pp. 20-30. (Available from www.frilo.eu)

[9] www.demagcranes.de (accessed on February 05. 2014.)

[10] EN 13 001-2: Crane safety-General design - Part 2: Load actions, Brussels: CEN, 2011, pp. 21-25.

[11] EN 15 011: Cranes - Bridge and gantry cranes, Brussels: CEN, 2011, pp. 19-25.

[12] V. A. Kopnov, "Fatigue Life Prediction of the Metalwork of a Travelling Gantry Crane" in Engineering Failure Analysis, vol. 6, Oxford: Elsevier, 1999, pp. 131-141.

[13] C. Hongyan, Z. Longbiao, H. Xi, Z. Yihui, "Structural Health Monitoring System of Gantry Crane Based on ZigBee Technology", in Proceedings of Third International Conference on Digital Manufacturing & Automation (Guilin, China), Washington: IEEE Computer Society, 2012, pp. 801-804.

[14] B. Iung, G. Morel and J. B. Léger, "Proactive maintenance strategy for harbour crane operation improvement" in Robotica, Cambridge: Cambridge University Press, vol. 21, 2003, pp. 313-324.

[15] W. Zhixin, H. Xiong and C. Zhaoneng, "Study of Remote Condition Monitoring and Assessing on Quayside-Container-Cranes" in Proceedings of 1st WCEAM, London: Springer-Verlag, 2006, pp. 898-903.

[16] Č. Dundović and I. Kolanović, "Ocjena i tendencije razvitka prekrcajnih kapaciteta hrvatskih morskih luka" in Pomorski zbornik, Rijeka: Društvo za proučavanje i unapređenje pomorstva republike Hrvatske, vol. 39, 2001, pp. 137-152.

[17] C. Boller, F.-K. Chang and Y. Fujino (eds), Encyclopedia of Structural Health Monitoring - Vol. 1, Chichester: John Wiley & Sons, 2009, pp. 1-2.

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UTILIZATION OF AN INTERMITTENT MOTION MECHANISM FOR ENERGY HARVESTING FROM VEHICLE SUSPENSIONS

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Abstract

This paper presents the utilization of a mechanism with intermittent motion for converting mechanical energy from shock absorbers of vehicle suspensions to electrical energy. The applied mechanism consists of a rack, a pair of gears, and an intermitent system for performing one-way rotational movement. The basic idea is to convert input linear motion of a rack joined to a shock absorber to output rotation motion of the intermittent system connected to an electric generator. In this paper, the proposed converting system was modeled using the SolidWorks software, while the SolidWorks Motion module was used for the motion analysis of the system. To simulate the behavior of the system in real conditions and obtain angular velocities of the output member, three cases with different time dependent lows of motion of the shock absorber were researched. The results show that angular velocities of the output member of this mechanism type could be used for driving an electric generator, so that the proposed way is adequate for energy harvesting from shock absorbers of vehicle suspensions.

***Keywords**: Mechanism, Intermittent motion, Shock absorber, Energy harvesting, CAD.*

1. INTRODUCTION

Modern life and business without transport of people, goods and services is unimaginable. For that purpose, vehicles as automobiles, trucks and other, are widely used. Increasing of demands for transportation leads to increasing number of vehicles, what further leads to increasing of fuel and energy demands. Enhancement of fuel consumption directly affects to increasing environmental pollution. On the other side, modern vehicles, especially automobiles, are comprehensive mechatronic systems which consist many of combined systems with tasks to reduce fuel consumption, increase safety, comfort etc. [1] However, vehicles manufactures directly and indirectly make efforts to reduce fuel and energy consumption with increasing comfort, using of new or improving of current systems.

It is well-known that one of the systems, which affects on increasing comfort on vehicle, is suspension. The primary function of suspension system on vehicle is to reduce the vibration disturbance from road roughness, acceleration, deceleration, etc. in order to achieve better ride comfort and to maintain good tire–ground contact force for better vehicle handling and mobility. One of the most important parts of this system is shock absorber. Many researchers and companies are paying special attention on development and designing of shock absorbers. From the beginning, models of the shock absorbers were developed with springs, hydraulic, hybrid and pneumatics, which are known as passive absorbers. In order to cross over the permanent tradeoff between quality of ride and road handling, semi-active and active suspension systems have been proposed over the past several decades. [2]

On the other side, besides combustion process in engines, one of the great energy losses in vehicles is the dissipation of kinetic energy by shock absorbers in the suspension system, caused by road irregularity and vehicle acceleration or deceleration. Possibility of using this energy (which is otherwise dissipated) was explored two decades ago. The regenerative shock absorber, which utilizes the dissipated kinetic energy by the vehicle's suspension system, was proposed in [3]. This type of shock absorber, converts linear motion and vibration, inducted by road roughness and vehicle motion, into energy which can be used, for example, as electricity. Using of energy which is generated by regenerative shock absorber can increase fuel efficiency by reducing the electrical demand to the car alternators and, thus, reduce the engine’s workload, without affecting to the comfort of the vehicle. [2].

Many authors explored different principles and mechanisms of converting motion and vibration of shock absorber into useful energy. In [4] authors carried out two experiments using optimally designed regenerative electromagnetic shock absorbers , in order to determine the effectiveness of efficiently transforming kinetic energy of shock absorber into electrical power. It was concluded that, with a set of optimized regenerative shock absorbers, the average vehicle on the average road driving at about 70 km/h might be able to recover up to 70% of the power that is needed for such a vehicle to travel on a smooth road at that speed. The authors in [5] developed theoretical model of retrofit regenerative shock absorber and showed with experiment, that this type of shock absorber can recover the vibration energy from vehicle suspension at high efficiency with relatively low weight, and without loss of ride comfort. Furthermore, Li et al. presented in [2], a retrofit rack-pinion-based electromagnetic regenerative shock absorber which is designed, produced and tested in real conditions. The experiment results were showed that the generated voltage reflects the road irregularities well. Generated power can be obtained from four energy-harvesting shock absorbers when the vehicle travels at 48 km/h on a fairly smooth campus road. In [6], comparation of utilization of rotary and linear electromagnetic generator in order to use energy from shock absorbers in vehicles was discussed. Authors in this paper made two models of energy harvester mechanisms and then analyze both of energy absorption and comfortability of vehicle which was modeled as quarter car. Based on obtained results, it was concluded that both of energy harvester mechanisms increase comfort and vehicle handling than conventional suspension. Linear electromagnetic shock absorber harvests much of energy than angular. Besides this, it also makes vehicle more comfort and good in handling, but, the construction is more complex. However, efficiency use of shock absorber energy can be increased with new structures and mechanisms.

On the other side, development and producing of systems, such as this, requires complex approach. This approach includes use of CAD software for modeling and analysis which leads to faster prototype development [7, 8]. As result of application of this approach, development and producing times and costs are reduced with constantly increasing of quality.

This paper presents application of developed mechanism in process of harvesting shock absorber energy. With proposed mechanism, linear motion of vehicle shock absorber (caused by vehicle acceleration or deceleration and road irregularity) can be converted into rotation. In order to use kinetic energy of shock absorber as much as possible, this kind of energy converting is desirable, because mechanical energy in form of rotation can be very simple converted to other form of energy, for example, in electricity, using common electrical generator.

As the CAD software, SolidWorks was used for modeling and its module Motion, for analyzing the proposed mechanism. Mechanism consists of stand with gears, pins and rack, and subassembly system for one-way rotation. Vertical motion of the rack, i.e. its displacement, represents motion of vehicle shock absorber in real condition. Depending on the rack displacement, angular velocity of the output member was obtained for three cases - when change of the rack displacement is linear, sine and random time depended function, i.e. stochastic, which is the most suitable to the real conditions of shock absorber motion. Time intervals for all of three cases were t=12 s.

2. DEVELOPMENT PROCESS OF MECHANISM

A development of proposed mechanism had two phases:

- Modeling in SolidWorks software;
- Analysis of the mechanism motion with obtaining the angular velocity of the output member.

I. Modeling in SolidWorks software

Nowadays, modern engineering is unimaginable without use of the CAD software. Whether, there is development of a new product, or existing product that has to be tested in environment with specific conditions that can cause damage, CAD software is indispensable tool, that helps to reduce design time, and lower the final product cost. In addition, virtual prototyping is a useful tool for visualization of the prototype product. FEM and motion analysis can be used to simulate behavior of the product under certain circumstances, in almost real conditions. In this paper, SolidWorks software was used for modeling and analysis of the proposed mechanism.

Based on the multibody systems theory [9] mechanical part has been defined as a set of bodies joined by joints. Depending on the degrees of freedom, these joints allow rotary or rectilinear movement. Using SolidWorks, the mechanical part that consists of many independent parts, was modeled. These parts have been assembled in one assembly using mates, between parts, which represent joints. Mechanical part consists of stand, on which set of gears, pins, rack and subassembly system for one-way rotation, have been attached (Fig. 1).

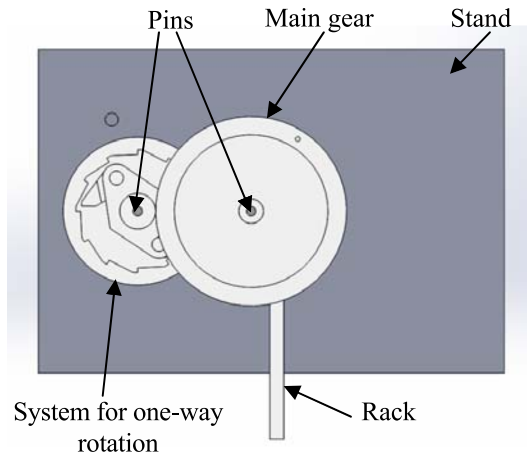

Fig. 1 Mechanism

Subassembly system for one-way rotation consists of mechanism for intermittent motion that has been connected to the main gear via central gear of the mechanism. Central gear is rigidly connected to the central member. Mechanism has two wings that are connected to the central member. When central member rotates, wings spread under the influence of centrifugal force and hook the output member of the mechanism and rotate it (Fig. 2).

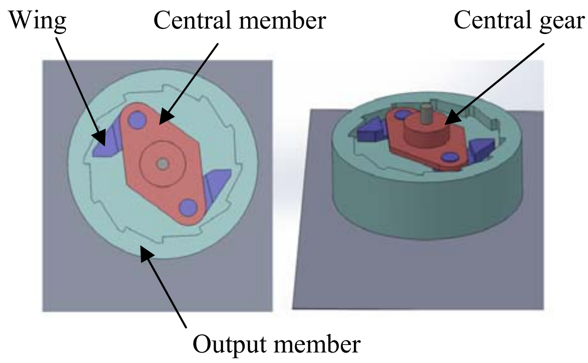

Fig. 2 System for one-way rotation

The main gear is connected to the rack on the right side of the whole assembly (Fig. 4), while, on the left side of the assembly, the main gear is connected to the central member of the system for one-way rotation. When the rack moves up and down, it rotates the main gear. Rotation of the main gear causes the rotation of the central member which spread the wings under the influence of centrifugal force and hook output member. Then, wings and output member of the mechanism rotate together. When central member moves in opposite direction (rack is moving in opposite way), wings collapse and do not have contact with the output part of the mechanism. With the movement of the rack, as the driving element, with the stroke ±15 mm, various angular velocities can be obtained at the output.

I. Analyzing of Angular Velocity

Converting linear motion, i.e. vertical motion of shock absorber, to rotation is goal of this mechanism, because rotating can be converted to other form of energy, for example electricity, very simple, using of common electrical generator. Electricity can be used for headlights, charging vehicle battery etc., in order to reduce vehicle fuel consumption. Because of that, analyze of angular velocity as output of this mechanism, depending to vertical motion (displacement) of shock absorber is necessary for fulfill overview of efficiency of proposed mechanism.

In order to obtain the angular velocity of the output member of the proposed mechanism, when the rack is moving, SolidWorks Motion module was used. With this module, the motion of moving parts can be analyzed in various ways. To simulate the contact behavior between moving parts contact boundary condition was used. First contact was set between central member and two wings (Fig. 3 a) in the mechanism for intermittent motion, while the second contact was set between the wings and output member (Fig. 3 b). As an input, virtual linear motor (actuator) was attached at the rack, in order to simulate vertical motion of shock absorber in real conditions (Fig. 4).

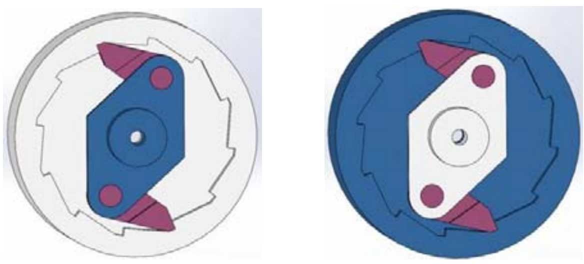

Fig. 3 Contact between: a) central member and two wings; b) two wings and output member

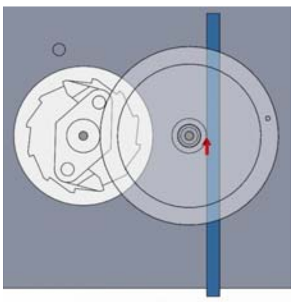

Fig. 4 Setting the input (virtual linear motor) at the rack

Totally three cases with different time dependent lows of motion of the rack (time intervals for all cases were t=12 s) were investigated. First case was with linear low of motion as is shown in Fig. 5. For this kind of motion of the rack, the obtained angular velocity of the output member is shown in Fig. 6.

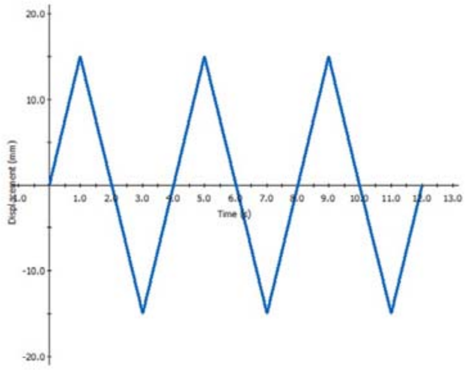

Fig. 5 Displacement diagram (linear low of motion) of the rack

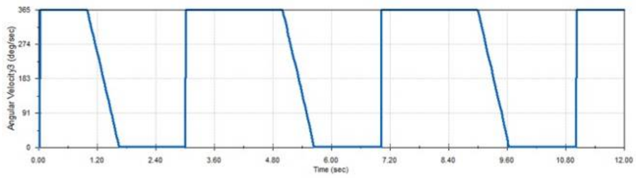

Fig. 6 The angular velocity diagram of the output member for the linear low of motion of the rack

The second investigated case was with sine low of motion (Fig. 7). The obtained angular velocity of the output member for this case is shown in Fig. 8.

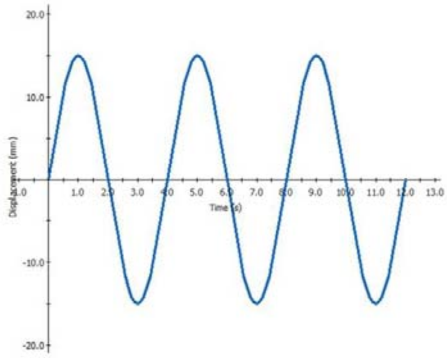

Fig. 7 Displacement diagram (sine low of motion) of the rack

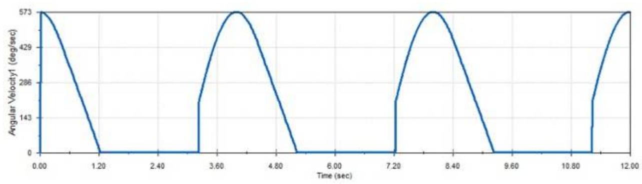

Fig. 8 The angular velocity diagram of the output member for the sine low of motion of the rack

To simulate the random behavior of the shock absorber, for the third case, function with random values was used (Fig. 9). This case corresponds to the motion of the shock absorber in real conditions. This function was generated using the MatLAB software and introduced into the SolidWorks

Motion module. In Fig. 10, angular velocity of the bottom part for the rack random motion is shown.

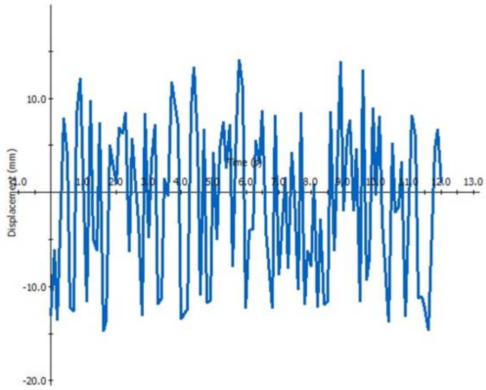

Fig. 9 Displacement diagram of the rack for the random generated function

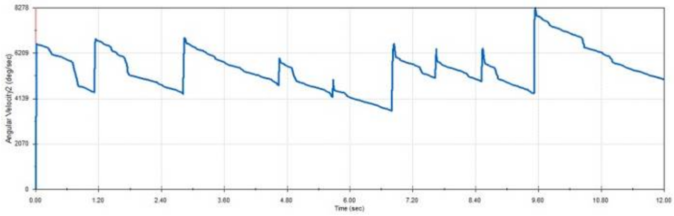

Fig. 10 The angular velocity diagram of the output member for the random law of motion of the rack

3. CONCLUSION

In this paper, harvesting of shock absorber energy using of mechanism for intermittent motion is presented through two phases. Because of possibility for using kinetic energy of shock absorber, caused by vehicle acceleration or deceleration and road irregularity, mechanism for converting linear motion of shock absorber into rotation is developed and modeled in SolidWorks software, as the first phase of development process.

However, rotation, as a form of mechanical energy can be converted to the electricity using simple electrical generator. Generated electricity can be used directly on the vehicle for electrical devices and generally for reducing of fuel consumption through decreasing engine workload. Solid Works module Motion is used to obtain the angular velocity of the output member (second phase of development process). The angular velocity is very important for process of converting rotation into electricity. Depending on the vertical motion (displacement) of the rack as an input, which represents behavior of the shock absorber in real conditions, angular velocity of output member is obtained in three cases: linear, sine and random motion of rack. In the first and second cases, results of analysis showed that angular velocity exists when rack displacement value are positive, what is expected for input defined on this way. Otherwise, value of angular velocity is zero, because there is no rotation of output member because wings are collapsed. However, for the third case, when motion of rack is defined as a random time dependent function, i.e. stochastic, which represents motion of the shock absorber in real condition, angular velocity exists in some interval, but value is constantly positive. This result is desired, because it shows that energy of shock absorber (which is otherwise dissipated) can be used for converting in some other form. Based on the results of analysis, it can be concluded that proposed mechanism showed results which represent good starting point for further research in this field.

REFERENCES

[1] M. Pavlović, M. Milošević, D. Stamenković, A. Stefanović, and V. Pavlović, "Automotive mechatronic systems," Proceedings of 15th Symposium on Thermal Science and Engineering of Serbia - SIMTERM 2011, pp. 792-801, Sokobanja, Serbia, 2011.

[2] Z. Li, L. Zuo, G. Luhrs, L. Lin, and Y. Qin, "Electromagnetic Energy-Harvesting Shock Absorbers: Design, Modeling, and Road Tests," IEEE Transactions On Vehicular Technology, vol. 62, no. 3, pp. 1065-1074, March 2013.

[3] Z. Li, L. Zuo, J. Kuang, and G. Luhrs, "Energy-Harvesting Shock Absorber with a Mechanical Motion Rectifier," Smart Materials and Structures, accepted for publication.

[4] R. B. Goldner, P. Zerigian, and J. R. Hull, "A Preliminary Study of Energy Recovery in Vehicles by Using Regenerative Magnetic Shock Absorbers," SAE Technical Paper Series, May 2011.

[5] L. Zuo, B. Scully, J. Shestani, and Y. Zhou, "Design and characterization of an electromagnetic energy harvester for vehicle suspensions," Smart Materials and Structures, vol. 19, 2010.

[6] A. I. Sultoni, I. N. Sutantra, and A. S. Pramono, "Vibration Energy Harvesting on Vehicle Suspension Using Rotary and Linear Electromagnetic Generator," The Journal for Technology and Science, vol. 24, no. 1, April 2013.

[7] V. Pavlović, M. Milošević, M. Pavlović, and G. Djordjević, "Use of CAD software in developing mechatronic medical devices on example of Treadmill," Proceedings of International Scientific-expert Conference INFOTEH-JAHORINA 2012, Vol. 11, pp. 517-521, East Sarajevo, Bosna and Hercegovina, 2012.

[8] N. D. Pavlović, N. T. Pavlović, M. Milošević, S. Jovanović, D. Jovanovič, V. Pavlović, and M. Pavlović, "Sistem za promenu napadnog ugla lopatica vetrogeneratora," Tehničko rešenje, Mašinski fakultet u Nišu, 2012.

[9] I. Vişa, M. Comşiţ, ''Design of the Linkages-type Tracking Mechanisms by using MBS Method,'' Proceedings of 12-th IFToMM World Congress, Besançon, 2007.

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SOFTWARE DEVELOPMENT FOR OPTIMAL SYNTHESIS OF SLEWING PLATFORM DRIVE MECHANISM OF MOBILE MACHINE

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Abstract

In this paper is performed analysis of the components of slewing platforms drive mechanisms and given the algorithm of the sofrtware to their optimal synthesis.

***Keywords**: slewing platforms drive*

1. INTRODUCTION

Manipulators of mobile machines represent a transmission of the kinematic chain machine that connects the support and movement mechanism member with executive members - machine tools. The primary function of the manipulator is to enable active work tools on the subject of work in a particular working area of machines. Depending on the shape of the work area, manipulators kinematic chain can be planar or spatial configuration. Spatial manipulators provide the necessary spatial manipulation of machine. Spatial working area is usually achieved the first member link - slewing platform and support and movement mechanism by slewing joint with a vertical axis relative to the support surface machines. Relying on the surface the support and movement mechanism is relatively stationary member relative to a slewing platform that can realize unlimited range of rotation in both directions around vertical axis of the joint.

2. DRIVE ANALYSIS

To drive the slewing platform is used to drive mechanisms with hydraulic motor c_{22} (sl.1 b,v) and reducing gear c_{23}, whose housing is securely connected to the skeleton of platform, output shaft has a gear wheel c_{24} conjugated with ring gear c_{25} of axial bearing.

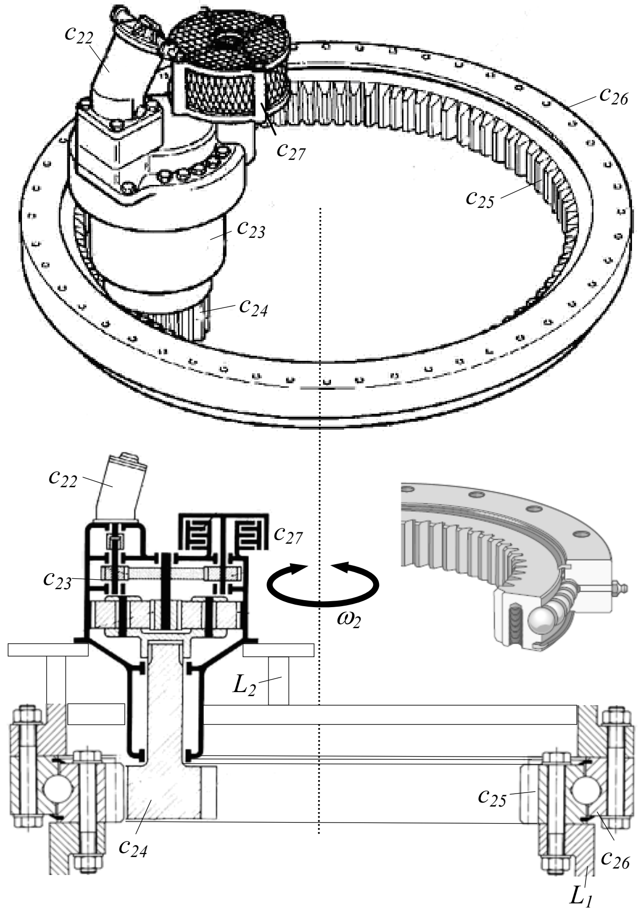

Figure 1. Slewing platforms drive of mobile machine

In principle, drive components of slewing platform create planetary mechanism where the rotation of the output gear reducer c_{24}, with angular velocity ω_{24} as satellites and the drive member, also turns slewing platform L_2, with angular velocity ω_2, as a carrier of the satellite (reducer), whereby the toothed wreath c_{25} a bearing as a central stationary gear is attached to the support and movement mechanism of machine.
The input parameters of platform drive are the pressure p and flow Q of hydraulic motors, and the output parameters are number of revolutions n_2 and moment M_2 of slewing platform, linked the following transfer functions:

$$n_2 = \frac{n_m}{i_r \cdot i_l} = \frac{1000 \cdot Q}{q_m} \eta_{mv} \frac{1}{i_r \cdot i_l} \tag{1}$$

$$M_2 = M_m \cdot i_r \cdot \eta_r \cdot i_l \cdot \eta_l = \frac{(p - p_o) q_m}{2\pi} \eta_{mm} \cdot i_r \cdot \eta_r \cdot i_l \cdot \eta_l \tag{2}$$

where: n_m, M_m - number of revolutions and moment of hydraulic motor, q_m - specific flow of the hydraulic motor, i_r, η_r - transmission ratio and the efficiency degree of reducing gear, i_l, η_l - transmission ratio and the efficiency degree of toothed pair of gear and bearing [1].

Transfer function slewing platforms drive show that for the same input parameters can achieve the same output parameters with less specific flow of hydraulic motor and large reducer transmission ratio and vice versa. Distinguished are three typical variations slewing platforms drive.

Variant I. - Drive with slow speed high torque hydromotor c_{22} (Fig.2a) in which the output shaft mounted small gear c_{24} which directly engages with the toothed wreath axial bearing. The total transfer function of the drive is achieved with a relatively high specific flow slow speed radial piston hydromotors.

Variant II. - Drive with high speed axial piston hydromotor c_{22} (sl.2b) and two-stage or three-stage gear c_{23}. The derived as a separate solution so that the hydromotor and gear selected independently and among themselves harmonized. In these drives stands out conceptual design of kinematics gear with one pair of cylindrical gears and one or two planetary sets and special derivative for drum brakes c_{27}.

Variant III. - Drive with high speed axial piston hydromotor c_{22} (sl.2b) and two-stage or three-stage gear c_{23}, derived as a one module. Kinematics of gear creates one, two or three planetary sets. Hydraulic motor with custom shape housing that the most part located within the gearbox and thus partially protected while reducing the total size of the gear. Brakes drive with fins c_{27} hydraulic activated, located in the gear unit housing on the output shaft of the hydraulic motor.

The total transfer function drive variants II and III is achieved by increasing the transmission gear ratio considering relatively low specific flow axial piston motors. The latest solutions slewing platform drive have axial piston motors with integrated control-activation, security and non-return valves (sl.2d). Control valves allow quiet (gradually) startup platforms, without impact, so it can achieve favorable characteristics 1,2,3,4 (fig. 2) changes in hydromotors pressure p and flow Q, depending on the command pressure p_{st} system of the machine [1]. Slewing platform drive of mobile machine can build open or closed circuit in hydrostatic system of the machine. In closed circuit (fig.3) change direction of slewing platform is achieved through two-way hydraulic pump c_{21} which control is realizes command c_{28}.

Slewing bearings of slewing platform drive are large size, which can accommodate axial, radial loads which act either separately or combined in any direction. Slewing bearings (Fig. 1a) consist of an inner ring, outer ring and rolling elements - balls or cylindrical rollers - which are separated by a spacer polyamide. Rolling elements can be arranged in one, two or three rows (single-row, double-row or three-row). One of the rings is toothed and has hole for connection with support and movement member [2].

Components of slewing drive mechanism of the mobile machine platform manufacture specialized world manufacturer with many models of variant solutions and characteristics.

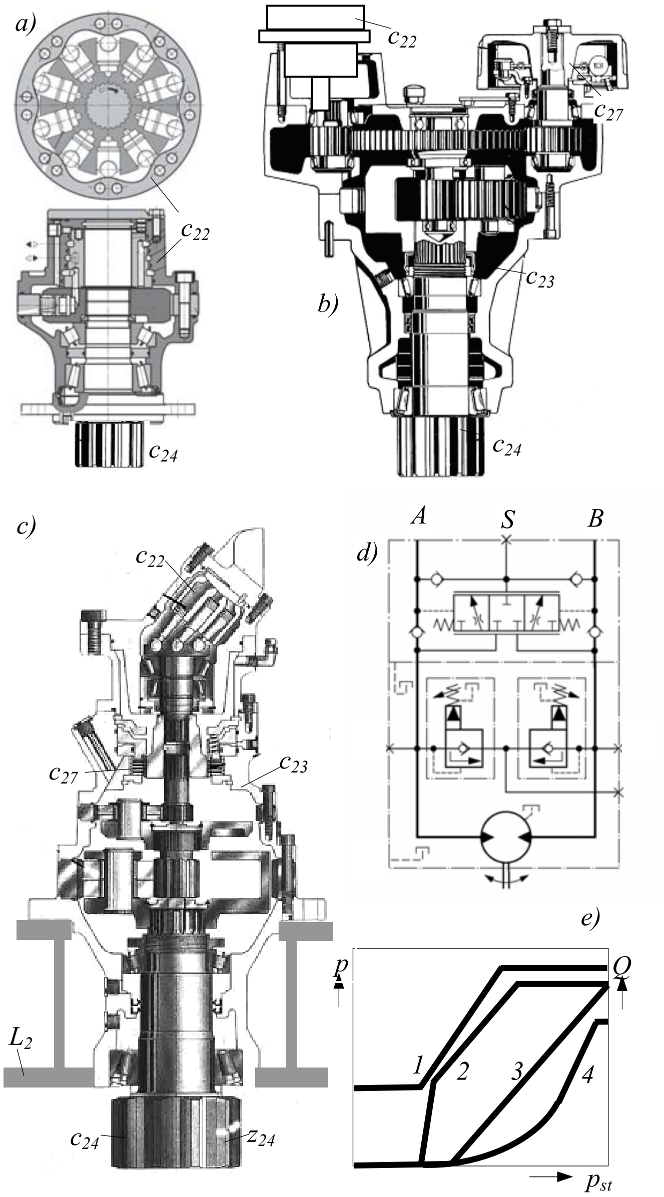

Figure 2. Solutions gear of slewing platform drive [1]

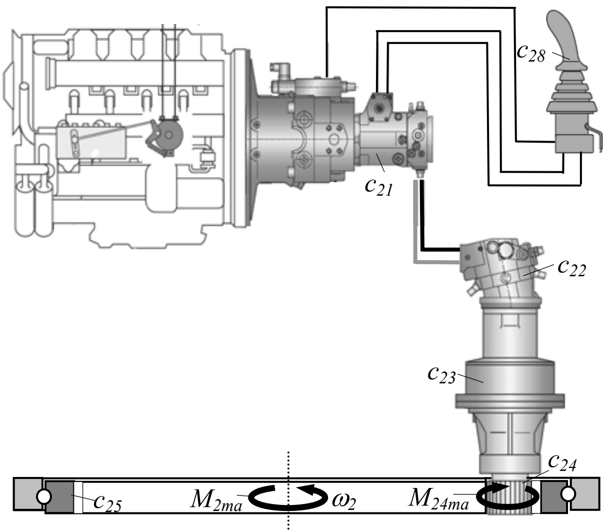

Figure 3 Drives of slewing platforms with closed hydrostatic circuit

3. THE SYNTHESIS OF THE DRIVE MECHANISM

Based on the given parameters of the function, the synthesis of the complete drive mechanism of a hydraulic excavator slewing platform is performed by the following procedure:

a) selection of the concept drive solution, b) selection of the slewing bearing based on a detailed analysis of loads in the whole working area of the machine, c) definition of attachment elements and elements of the support movement structure to which the bearing is attached, d) selection of the hydraulic pump, hydraulic motor and slewing drive reducer.

In this paper is developed software for the synthesis of the drive mechanism for the concept corresponds to the analyzed variant III. Under the synthesis implies defining the size of the specific flow hydraulic pump, specific flow hydraulic motor and gear drive transmission ratio. Where the known size of the slewing bearing the previously determined on the basis of detailed analysis of loads depending on the type of mobile machines and their working conditions [3].

The choice of slewing drive components from a set of available sizes is done using the developed software based on a given set of quantities:

$$P_o = \{J_{2max}, n_{2max}, t_u, z_{25}, n_{en}\} \tag{3}$$

where: J_{2max} - the maximal moment of inertia of the platform and links of manipulator's linkage for axis of rotation of machine's platform *[kgm2]*, n_{2max} - maximal speed platform *[min^{-1}]*, t_u - desired acceleration time platform *[s]*, z_{25} - number of teeth toothed wreath selected slewing bearing, n_{en} - number of revolutions diesel engine machines at maximum power *[min^{-1}]*.

The software contains the available file: hydraulic motor D_m reducer D_r and hydraulic pump D_p (Fig. 4).

The file of available hydraulics motor consist set of quantities:

$$D_m = \{q_m, m_m, J_m, \eta_{mm}, \eta_{mv}, p_{m\,max}, n_{m\,max}\} \tag{4}$$

where: q_m - specific flow of the hydraulic motor *[cm3]*, m_m - mass of hydraulic motor *[kg]*, J_m - moment of inertia of the hydraulic motor *[kgm^2]*, η_{mm}, η_{mv} - the mechanical and volume efficiency of hydraulic motor, p_{mmax} - maximum allowable pressure *[MPa]*, n_{mmax} - number of revolutions hydraulic motor *[min^{-1}]*.

The file of available hydraulics reducer consist set of quantities:

$$D_r = \{i_r, m_r, J_r, \eta_r, M_{r\,max}, z_{24}\} \tag{5}$$

where: i_r - transmission ratio of reducing gear, m_r - mass of reducer *[kg]*, J_r - moment of inertia of the reducer *[kgm^2]*, η_r - the efficiency of the reducing gear, M_{rmax} - maximal moment of reducer, z_{24} - number of teeth of gear wheel on output shaft of the reducing gear.

The file of available hydraulics pump consist set of quantities:

$$D_p = \{q_p, m_p, J_p, \eta_{pm}, \eta_{pv}, p_{p\,max}, n_{p\,max}\} \tag{6}$$

where: q_p - specific flow of the hydraulic pump *[cm^3]*, m_p - mass of hydraulic pump *[kg]*, J_p - moment of inertia of the hydraulic pump *[kgm^2]*, η_{pm}, η_{pv} - the mechanical and volume efficiency of hydraulic pump, p_{mmax} – maximum allowable pressure *[MPa]*, n_{mmax} - number of revolutions hydraulic pump *[min^{-1}]*. At the beginning of the software determines the maximum angular acceleration $\ddot{\theta}_2$ of platforms:

Table 1. Driver groups and service time categories to FEM [4]

Service time category				T 2	T 3	T 4	T 5	T 6	T 7	T 8
Assumed average service time per day in hours				0.25 - 0.5	0.5 - 1	1 - 2	2 - 4	4 - 8	8 - 16	>16
Theoretic service life in hours				400 - 800	800 - 1600	1600 - 3200	3200 - 6300	6300 - 12500	12500 - 25000	25000 - 50000
Collective load class				**Driver group with K factor**						
Collective groups	L 1	low	Maximum loads occur only in exceptional cases; low loads are present at all times	M 1 0.90	M 2 0.90	M 3 0.90	M 4 0.90	M 5 0.95	M 6 1.05	M 7 1.2
	L 2	medium	Low, medium and high loads are present for roughly equal periods of time	M 2 0.90	M 3 0.95	M 4 0.95	M 5 1	M 6 1.15	M 7 1.30	M 8 1.50
	L 3	high	Loads are always near the maximum	M 3 1.05	M 4 1.05	M 5 1.10	M 6 1.25	M 7 1.40	M 8 1.60	M 8 1.80
	L 4	very high	Always maximum loads	M 4 1.25	M 5 1.30	M 6 1.45	M 7 1.65	M 8 1.85	M 8 2.10	M 8 2.40

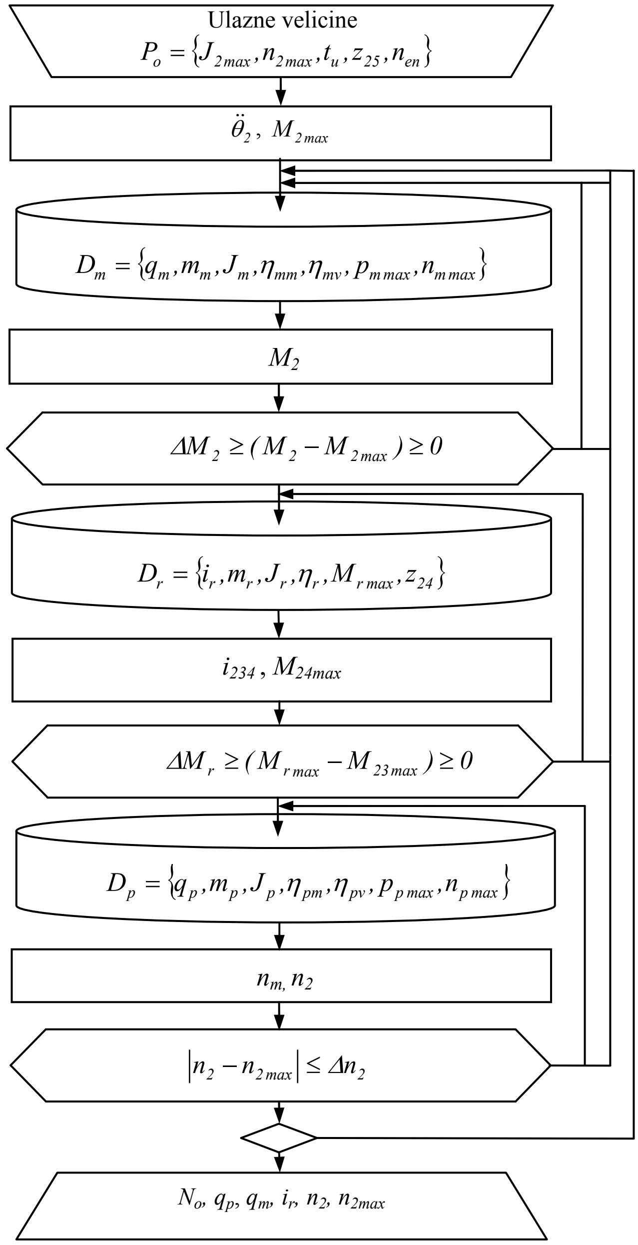

Fig.4 Software algorithm for optimal synthesis of slewing platform drive mechanisms of mobile machine

$$\ddot{\theta}_2 = \frac{n_{2max} \cdot \pi}{30\, t_u} \tag{7}$$

and then maximal moment which has to overcome the resistance of the platform n the phase of initial accelerated revolution:

$$M_{2max} = k \cdot J_{2max} \cdot \ddot{\theta}_2 \tag{8}$$

Table 2. Possible variations of slewing platform drive mechanism of hydraulic excavator

Possible variations of drive	Spec. flow of the hydraulic pump	Spec. flow of the hydraulic motor	Transmission ratio reducer	Given number of platform revolutions	number of platform revol.	Total mass of drive	Time acceleration platf.
	$q_p\,[cm^3]$	$q_m\,[cm^3]$	i_r	$n_{2max}\,[min^{-1}]$	$n_2\,[min^{-1}]$	$m_{c2}\,[kg]$	$t_u\,[s]$
1	75	32,0	110,29	6,0	5,75	275	1,39
2	75	80,4	43,90	6,0	5,81	349	1,41

where: k - is coefficient of moment increasing due to other resistances which occur during the turning (wind resistance, frictional resistances in axial bearing), Table 1.

For the selected gear size, first to determine the gear ratio between the inner toothed wreath of slewing bearing with the number of teeth z_{25}, and gears on the output shaft gear with number of teeth z_{24}:

$$i_l = \frac{z_{25} - z_{24}}{z_{24}}, \tag{9}$$

and then maximal moment of reducer output shaft of slewing drive:

$$M_{24max} = \frac{M_{2max}}{i_l} \tag{10}$$

with the check whether the calculated moment in the specified limits with respect to the permitted output moment:

$$\Delta M_r \geq (M_{rmax} - M_{24max}) \geq 0 \tag{11}$$

where: ΔM_r - given permissible deviation of moments.

With satisfaction of the previous conditions, for selected size of hydraulic motors, is determined moment of motors:

$$M_{mmax} = \frac{(p_{max} - p_o)\cdot q_m}{2\pi}\cdot \eta_{mm} \tag{12}$$

and slewing platform moment:

$$M_2 = M_{mmax}\cdot i_r \cdot \eta_r \cdot i_l \cdot \eta_l \tag{13}$$

with the check whether the slewing platform moment in the specified given limitation :

$$\Delta M_2 \geq (M_2 - M_{2max}) \geq 0 \tag{14}$$

where: ΔM_2 - given permissible deviation of moments.

If the previous condition filled, with choice of hydraulic pump sizes is determines the hydraulic pump flow:

$$Q_{p\,max} = \frac{q_p \cdot n_{en}}{1000}\eta_{pv} \tag{15}$$

then, number of revolutions hydraulic motor:

$$n_{mmax} = \frac{1000\cdot Q_{max}}{q_m}\eta_{mv} \leq n_{mmax} \tag{16}$$

and number of platform revolutions:

$$n_2 = \frac{n_{mmax}}{i_r \cdot i_l} \tag{17}$$

with the check whether the calculated number of revolutions in the limits of permissible deviation with respect to given number of platform revolutions:

$$\left|n_2 - n_{2max}\right| \leq \Delta n_2 \tag{18}$$

where: Δn_2 - given permissible deviation of of platform revolutions.

At the output of the software are obtained a possible variant solutions of slewing drive mechanism with data of selected the hydraulic pump, hydraulic motor and reducer. From the set of possible solutions, the optimal solution is selected according to the criteria of minimum mass of components of the drive and the minimum time acceleration platforms.

As an example of using the developed software gives the results (Table 2) synthesis of the drive mechanism of hydraulic excavator mass $m = 16000\ kg$ equipped with backhoe manipulator. From the set of 51 possible solutions offered by the company Bosch Rexroth, are singled out only two solutions drive.

CONCLUSION

Analysis of the concept of slewing drive mechanism of mobile machine indicates the number of alternative solutions components drive which produce specialized world manufacturers. For optimum synthesis of mechanisms developed software that enables selection of optimal variant from a set of possible solutions using the following criteria: minimum drive mass and minimum acceleration of slewing platform. Results show that the synthesis of the slewing drive mechanism of mobile machinery should strive choice to hydraulic motors with smaller specific flow and higher transmission ratio of gear.

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REFERENCES

[1] D. Janosevic (2006) Designing mobile machines, Faculty of Mechanical Engineering, University of Nis, ISBN 86-80587- 44-3 (COBISS.SR-ID 136572428), Serbia

[2] Slewing bearings SKF catalogue 2012.

[3] V. Jovanović, D. Janošević, N. Petrović, “Analysis of axial bearing load of a rotating platform drive in hydraulic excavators”, Tehnički vjesnik/Technical Gazette 2013., 1330-3651, Univerzitet u Osijeku, Fakultet u Slavonskom Brodu, No.2, Vol.21

[4] Hahrentriebe Hydrotrac GFT, Mannesmann Rexroth.

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EFFECTS OF USING A SUPPLEMENTARY COMPONENT GENERATED BY A CATALYTIC REACTOR ON THE COMBUSTION OF THE PRIMARY FUEL OF A LOADED DIESEL GENERATOR

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Abstract

The research of this paper covers the analyses of the combustion of the primary fuel with the addition of the supplementary component generated by the catalytic reactor that uses the heat of the exhaust gases for its catalytic function on a single cylinder diesel engine of an electric generator under load for powering an electrical heating device. The results of the research indicate that the use of the supplementary component for the combustion of the primary diesel fuel leads to the reduction of harmful and toxic substances emission in the exhaust gases and improves the energy value of the fuel mixture and the combustion process. The proposed system requires no maintenance or adjustment because the amount of the produced supplementary component is directly proportional to the engine load. It can be upgraded to any existing internal combustion engine and it requires neither modification of the engine nor additional loading of the vehicle electrical system.

Keywords: *Catalytic Reactor, Diesel Engines, Energy efficiency, Ecology.*

1. INTRODUCTION

Diesel engines are one of the most commonly used types of mobile drives. They are widespread in vehicles (automobiles, trucks, submarines, ships, and in a wide variety of aircraft and locomotives) and construction machinery. They are used as a more efficient replacement for stationary steam engines in heavy equipment and electric generating plants. Diesel engines have a primary use in agricultural machinery and industrial sector. These wide fields of usage of diesel engines have entailed a high consumption of diesel fuel. The depletion of petroleum reserves and increasing demand induce a steep rise in fuel prices as well. On the other hand, their exhaust emissions are harmful to natural environment and living beings [1,2]. Much effort is being paid worldwide to reduce the diesel exhaust contaminants: carbon monoxide (CO), hydrocarbon (HC), carbon dioxide (CO_2), nitrogen oxides (NO_x) and particulate matter (PM) [3]. One solution that is being imposed is resorting to the use of renewable fuels: biodiesel fuels and vegetable oils. [4-6]. Another way is installation of modern mechatronic automotive systems characterized by embedded electronics and software for changing and improving diesel engine operating parameters [7,8]. There are recent advances in the combustion of water fuel emulsion which consists of base diesel fuel and water doped [9,10].

Moreover, one more possible way to reduce the exhaust emissions and increase the fuel efficiency of the combustion process of diesel fuel in existing diesel engines is mixing a certain amount of hydrogen with intake air as a supplementary component for enhancing the combustion of the primary diesel fuel [11,12]. There are systems working on the principle of the electrolysis that could be installed at vehicles with diesel engines producing a mixture of oxyhydrogen (a ratio of 2:1 hydrogen:oxygen) that may also be referred to as Brown's gas or HHO gas [13,14]. The electrolysis is one the most important processes for the industrial production of hydrogen and tends to become even more important in the future [15]. Hydrogen can be produced from water, except by the electorysis, as well as by a thermolysis, thermochemical cycle, ferrosilicon method, photobiological water splitting, photocatalytic water splitting, biohydrogen routes and xylose [16]. However, one of the successful application that has been claimed working well and giving a significant increase in reducing exhaust emissions and increasing fuel efficiency is the “reforming” technology based on a special “reactor” patented by the inventor Paul Pantone as a Multi-Fuel Processor (PMC - Processeur Multi-Carburants) [17]. One of the successful replications of this technology that processes the water through the PMC reactor is the G Pantone system (G – Giller, the name of the inventor) [18,19]. It represents an efficient catalytic reactor of the supplementary component containing hydrogen, obtained by passing some vacuum made water vapor through the PMC reactor heated by the exhaust pipe, which mixed with the primary fuel improves the energy value of the combustion process giving reduction in primary fuel consumption, reduces pollution, increases engine life and reduces noise levels [20].

In this paper an experimental research of effects of using a supplementary component generated by a catalytic reactor developed using the G Pantone technology on the combustion of the primary fuel of a loaded single cylinder diesel engine of an electric generator is presented.

2. THE DESCRIPTION OF THE TESTED SYSTEM WITH THE INTEGRATED CATALYTIC REACTOR

The tested catalytic device Reactor S-1 is intended to be retrofitted in all types of internal combustion engines regardless of the primary fuel: diesel, gasoline, liquefied petroleum gas LPG or compressed natural gas CNG. One catalytic reactor meets the needs of engines up to 2000 cm^3. For high-volume engine it is enough to make combination and multiplication of catalytic reactors for every additional 2000 cm^3. The appropriate combination of catalytic devices influences the multiplication of the quantity of the generated supplementary component.
The basic unit of the catalytic devices Reactor S-1 is with a circular cross section and it is threaded on each end for easy installation. The outer part of the reactor is made of steel, while the interior of the reactor is made according to the technology of catalytic devices. The outer diameter of the reactor equals 0.017 m and the length of the reactor is 0.110 m. The weight of the reactor is 0.210 kg. The basic unit of the tested catalytic device Reactor S-1 is shown in Fig. 1.

Fig. 1. The basic unit of the catalytic device Reactor S-1

The experimental research of effects of adding a supplementary component generated by the tested catalytic reactor Reactor S-1 on the combustion of the primary fuel at a diesel internal combustion engine of an electric generator was done on the examined system consisting of:
- a single cylinder diesel engine,
- the basic unit of the tested catalytic reactor Reactor S-1,
- a bubbler representing a distilled water tank,
- a diffuser of the supplementary component placed on the engine air intake part,
- two tubes, the first one for transporting humid air from the bubbler to the reactor and the second one for transporting the generated supplementary component from the reactor to the engine air intake part.

The complete examined system for testing the catalytic device on the test diesel engine DMB 3 DM 515 is shown in Fig. 2 The basic unit of the catalytic reactor is installed in the exhaust system of the test engine, Fig. 3. The diffuser of the generated supplementary component is inserted into the hole on the engine air intake part, Fig. 4. The operation principle of the catalytic reactor system is shown schematically in Fig. 5. Due to the vacuum forming in the intake part of the engine, a "bubbling" is provided in the tank with water. That means, there is the suction of a certain amount of the ambient air into the tank with the distilled water, called "bubbler", through the one-way valve forming the humid air by passing through the water. Further, the humid air goes into to the catalytic reactor, which is heated by the exhaust gases from the engine. By passing over the heated inner part of the catalytic reactor, the supplementary component is generated by catalytic reactions from the humid air. For the catalytic reactor to be able to perform its catalytic function it is necessary to be the operating temperature at the exhaust system of about 300 ^{0}C. The generated supplementary component is further leaded into the intake manifold and the engine combustion chamber. There it is mixed with air and atomized primary fuel and the mixture is ready for the combustion process.

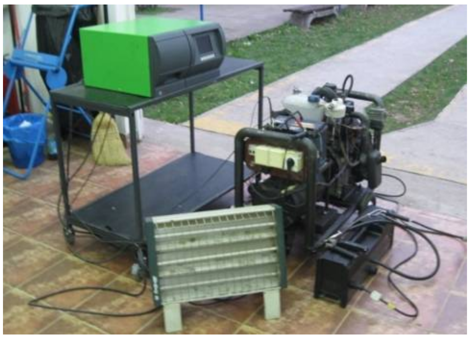

Fig. 2. The complete examined system for testing the catalytic device

Fig. 3. The tested catalytic device in the exhaust system of the test engine

Fig. 4. The installation position of the diffuser

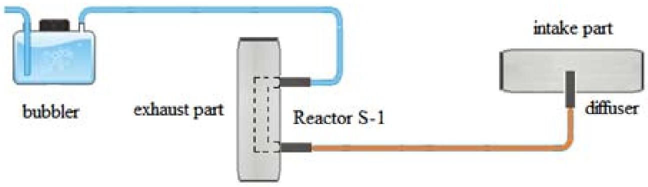

Fig. 5. The operation principle of the catalytic reactor system

The main characteristics of the test diesel engine DMB 3 DM 515 are shown in Tab. 1.

Tab. 1. The main characteristics of the test diesel engine DMB 3 DM 515

Engine label:	DMB 3 DM 515
Engine type:	single cylinder diesel engine
Cylinder number:	1
Cylinder diameter:	85 mm
Piston stroke:	91 mm
Capacity:	515 ccm
Compression ratio:	17,5 : 1
Power at 3000 min^{-1} according to ISO 1585:	9,2 kW
Max torque at 2000 min^{-1}:	37,5 Nm

3. THE MEASURING EQUIPMENT

The measuring equipment that was used for the measuring purposes for analyzing effects of using the supplementary component generated by the catalytic reactor embedded in the exhaust pipe of the examined configuration of the test diesel engine DMB 3 DM 515, shown in Fig. 2, is presented in Fig. 6 on the block diagram of the test configuration. The measuring equipment consisted of: exhaust-gas measuring device BOSCH BEA 250 (RPM's of the engine crankshaft, oil temperature of the engine, concentrations of CO, CO_2, HC, O_2 and values of the Air-Fuel equivalence ratio λ), smoke-opacity measuring device BOSCH BEA 150 (degree of opacity) and infrared thermometer FLUKE 66 (for the temperature measuring on the exhaust part where the catalytic reactor was built).

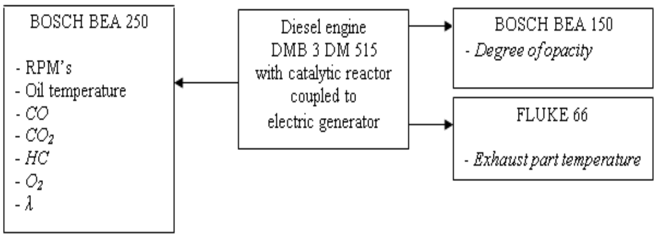

Fig. 6. The block scheme for testing the catalytic device

The exhaust-gas and smoke-opacity measuring devices were calibrated before the experiment by using the standard mixture of gases. The main characteristics of the measuring devices used in this test are given in Tab. 2.

Tab. 2. The main characteristics of the measuring devices

BOSCH BEA 250			BOSCH BEA 150		
parameter	unit	range	parameter	unit	range
RPM's	min^{-1}	100÷12000	Degree of opacity	%	0÷100
Oil temp.	°C	-20÷150	Environmental temperature:		5÷40 °C
CO	% vol	0÷10	Supply Power:		220V AC
CO_2	% vol	0÷18	FLUKE 66		
HC	ppm	0÷9999	parameter	unit	range
O_2	%	0÷22	Temp.	°C	-32÷600
λ		0.5÷9,999	Environmental temperature:		0÷50 °C
Environmental temperature:		5÷40 °C	Supply Power:		9V DC
Supply Power:		220V AC			

4. EXPERIMENTAL RESULTS

During the research ten measurement cycles were carried out. The study was conducted in two test phases.

In the first test phase the engine was operated without load and six measurements were conducted. The RPM's of the crankshaft were maintained at three levels: 1000, 2000 and 3000 min^{-1}. At each of the defined RPM's the test engine operated without and with the supplementary component generated by the catalytic reactor for enhancing the combustion of primary euro diesel fuel. In addition to the RPM's of the crankshaft the temperature of the engine oil and the temperature of the engine exhaust part were controlled. The characteristics of the exhaust gases, the results for carbon monoxide CO, carbon dioxide CO_2, unburned hydrocarbons HC, oxygen O_2, coefficient of excess air λ and degree of opacity, were recorded. In parallel with the measurement of the composition of the exhaust gases, the measurement of the consumption of the primary euro diesel fuel was performed. The consumed fuel quantities were kept track for the time of 5 minutes. The measuring results of the first research phase are shown in Tab. 3 and Tab. 4 for the test engine operating without and with the supplementary component respectively.

Tab. 3. The measuring results of the first test phase for the test engine operating without the supplementary component

RPM's (min^{-1})	Exhaust part temp. (°C)	Engine oil temp. (°C)	CO (%)	CO_2 (%)	HC (ppm)	O_2 (%)	λ	Deg. of opacity (%)	Cons. (ml)
1000	103	65	0.116	1.7	94	18.28	>5	34.2	101
2000	141	67	0.135	2.47	152	17.41	>5	42.8	158
3000	248	71	0.202	4.08	180	15.01	3.256	47.2	271

Tab. 4. The measuring results of the first test phase for the test engine operating with the supplementary component

RPM's (min^{-1})	Exhaust part temp. (°C)	Engine oil temp. (°C)	CO (%)	CO_2 (%)	HC (ppm)	O_2 (%)	λ	Deg. of opacity (%)	Cons. (ml)
1000	105	66	0.108	1.86	74	18.18	>5	12.4	101
2000	143	68	0.130	2.75	123	16.98	4.823	15.9	158
3000	265	72	0.187	4.29	154	14.71	3.128	18.5	271

For better detecting differences of the test engine combusting the mixture of intake air and diesel and intake air, diesel and the supplementary component, the results of Tab. 3 and Tab. 4 are displayed graphically, Fig. 7.

By analysing the results presented in Fig. 7 of the experimental research of the test engine operating without load, the following conclusions can be derived. Considering the engine, it is distinguished that temperatures of the exhaust part (a) and oil in the engine (b) slightly increase when combusting the mixture of intake air, diesel and the supplementary component. For the exhaust gases the following have been observed: concentrations of CO (c) and HC (e) decrease for combusting the mixture of intake air, diesel and the supplementary component, with the significantly smaller amounts of the HC component. In accordance with these, the concentrations values of CO_2 (d) are higher for combusting with the supplementary component than for the case without it. The combustion of the mixture of intake air, diesel and the supplementary component leads to decrease values of the concentration of O_2 (f) and the coefficient of excess air λ (g) in relation to the engine operation with the primary fuel - diesel. The most important result was obtained for the observation of diesel particulate matter as the main parameter ecological regulations for diesel engines. It is highly noticed (h) that the values of the degree of opacity for the combustion process of the mixture of intake air, diesel and the supplementary component obtained at the test engine are significantly smaller compared to the mixture without the supplementary component.

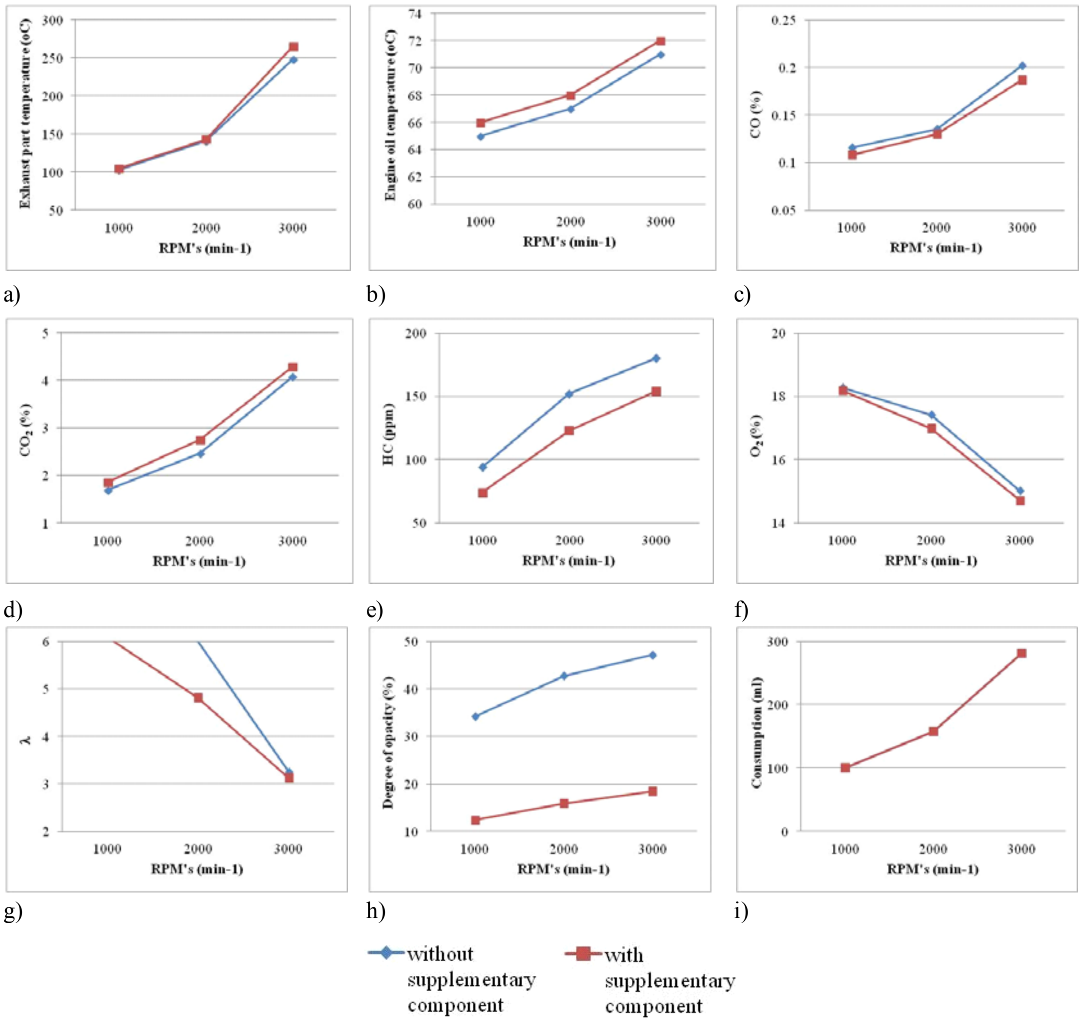

Fig.7. Graphically displayed test results of the engine operating without load

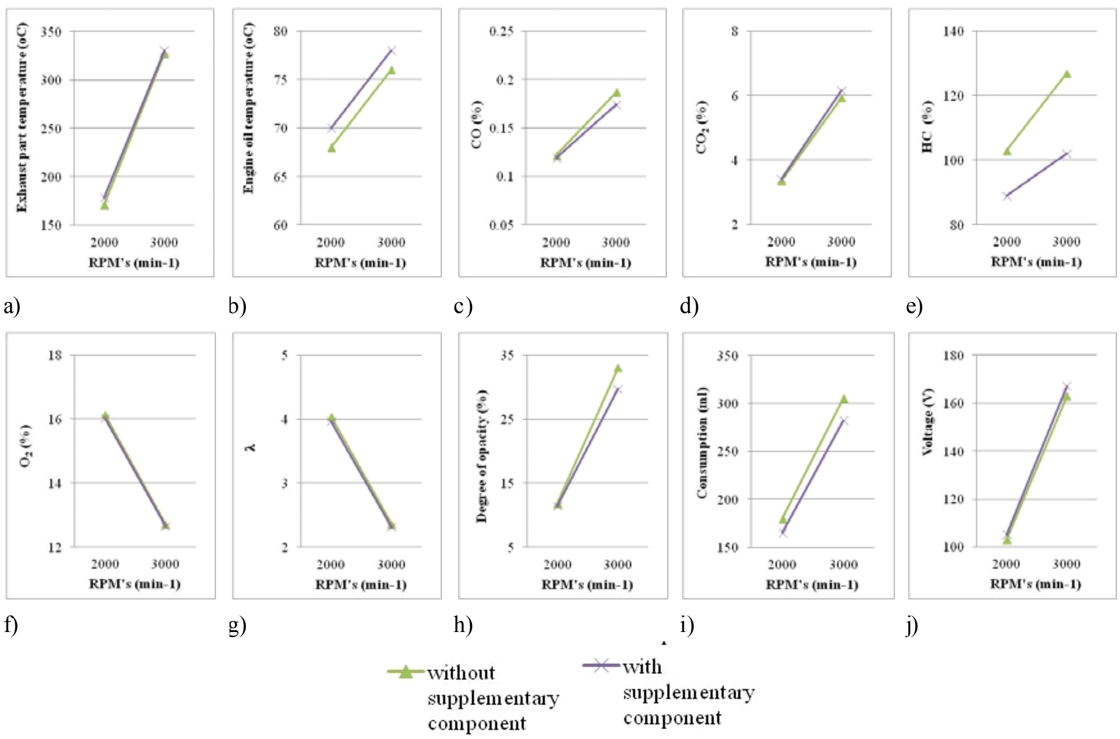

Fig. 8. Graphically displayed test results of the engine operating with load

During the research of the consumption of the primary fuel – diesel, for the time of 5 minutes and for the operating conditions without load for the test engine, it was not possible to determine the difference between the case combusting the mixture of intake air and diesel, and then the mixture of intake air, diesel and the generated supplementary component (i). All these facts point to the conclusion that the combustion process with the help of the supplementary component is more complete and efficient process effecting the quality of the exhaust gases resulting in reduction of pollution.

In the second test phase the engine was operated with load and four measurements were conducted. The load conditions for the test engine was performed by connecting a thermal consumer, an electric heater with the power of 2 kW, to an electrical generator of the installed power of 5kW joined by a couple to the crankshaft of the test engine for converting mechanical energy to electrical energy. In this phase of the test it was provided for the engine crankshaft to rotate with 2000 and 3000 min^{-1}, and all the parameters that had been analyzed in the previous phase were measured as well, with the addition of the voltage at the output of the electric generator. The measuring results of the second research phase are shown in Tab. 5 and Tab. 6 for the loaded test engine operating without and with the supplementary component respectively. It is necessary to mention that, for the consumption determination, for engine crankshaft RPM's of 2000 min^{-1} the consumption of the primary fuel was determined for the time of 5 minutes, while for RPM's of 3000 min^{-1} the measurement time of the consumption of the primary fuel was reduced to 4 minutes due to extreme loads to which the engine was exposed to.

Tab. 5. The measuring results of the second test phase for the loaded test engine operating without the supplementary component

RPM's (min^{-1})	Exh. part temp. (°C)	Eng. oil temp. (°C)	CO (%)	CO_2 (%)	HC (ppm)	O_2 (%)	λ	Deg. of opacity (%)	Cons. (ml)	Volt. (V)
2000	171	68	0.122	3.35	103	16.14	4.04	11.8	180	103
3000	327	76	0.187	5.94	127	12.71	2.353	33.0	305	163

Tab. 6. The measuring results of the second test phase for the loaded test engine operating with the supplementary component

RPM's (min^{-1})	Exh. part temp. (°C)	Eng. oil temp. (°C)	CO (%)	CO_2 (%)	HC (ppm)	O_2 (%)	λ	Deg. of opacity (%)	Cons. (ml)	Volt. (V)
2020	178	70	0.119	3.43	89	16.04	3.966	11.4	165	105
3030	330	78	0.174	6.16	102	12.64	2.308	29.7	282	167

The first fact that can be noticed from Tab. 5 and Tab. 6 is that RPM's of the loaded test engine crankshaft are slightly higher in the case of combusting intake air, diesel and the supplementary component.

For better detecting differences of the loaded test engine combusting the mixture of intake air and diesel and intake air, diesel and the supplementary component, the results of Tab. 5 and Tab. 6 are displayed graphically, Fig. 8.

According to the results presented in Fig. 8 of the experimental research of the test engine operating with load, the following conclusions can be derived. Considering the engine, it is repeated that temperatures of the exhaust part (a) and oil in the engine (b) are slightly increased for combusting the mixture of intake air, diesel and the supplementary component. For the exhaust gases the similar as for the operation of the test engine without load can be observed: concentrations of CO (c) and HC (e) decrease for combusting the mixture of intake air, diesel and the supplementary component, with the significantly smaller amounts of the HC component. In accordance with these, the concentrations values of CO_2 (d) are higher for combusting with the supplementary component than for the case without it. However, for the combustion of the mixture of intake air, diesel and the supplementary component at the loaded test engine there is an insignificant decrease of the concentration of O_2 (f) and the coefficient of excess air λ (g) in relation to the loaded engine operation with the primary fuel – diesel, which is different from the case without load. Also, there is a different behavior of the loaded test engine in the observation of diesel particulate matter. It can be noticed (h), that the values of the degree of opacity for the combustion process of the mixture of intake air, diesel and the supplementary component obtained at the test engine operated with load are slightly smaller compared to the mixture without the supplementary component, unlike the case for the unloaded test engine where this reduction was significant. For the loaded test engine it was possible to determine the difference of the consumption of the primary fuel – diesel for the operating conditions combusting the mixture of intake air and diesel, and then the mixture of intake air, diesel and the generated supplementary component. According to the results of the diesel consumption test for combusting the mixture of intake air and diesel, adding the generated supplementary component to the mixture of intake air and diesel resulted in fuel economy (i). For the case of the loaded test engine the saving of the primary diesel fuel was around 10%. Better results of the output voltage (j) of the electric generator for the case of combusting intake air, diesel and the supplementary component are the consequence of higher RPM's of the engine crankshaft for that case. All these facts point as well to the conclusion that the combustion with the help of the supplementary component results in better quality of the exhaust gases and in fuel savings regardless of the engine load.

5. CONCLUSION

In this paper the experimental research of the composition of the exhaust gases as well as the consumption of primary fuel of a loaded single cylinder diesel engine of an electric generator operating without and with adding the supplementary component for improving the combustion of the primary fuel generated by a catalytic reactor is presented. From the analyzed results, it can be concluded that the addition of the supplementary component for the combustion of the primary fuel improves the energy value of the fuel mixture and the combustion process leading to the reduction of harmful and toxic substances emission in the exhaust gases and less consumption of the primary fuel, for both regimes of operation, without and with load.

Moreover, higher values of the output voltage of the electric generator were obtained for the case of combusting intake air, diesel and the supplementary component which was the consequence of increased RPM's of the engine crankshaft.

The researched catalytic reactor is able to be used on any type of internal combustion engines (diesel/petrol), both for new and old generations. By an appropriate combination of the basic units of the catalytic reactor it is possible to obtain adequate response in the quantity of the generated supplementary component for combustion of the primary fuel corresponding to different capacities of engines vehicles. The installation is easy, as well as the removal. It does not require modification of engine feed/fuel injection systems. There is no additional load on electronic systems of adapted vehicles. The system is completely self-regulating, the engine sucks a certain amount of humid air required for that operating mode which, by passing through the reactor, becomes the supplementary component for the combustion of the primary fuel, so the system uses all the generated supplementary component and it is not necessary to store it. Hence, the amount of the produced supplementary component is directly proportional to the engine load. The proposed system after installation requires no additional maintenance other than periodic refueling of clean distilled water in the bubbler.

REFERENCES

[1] Wargo, J., Wargo, L., Alderman, N., The Harmful Effects of Vehicle Exhaust: A Case for Policy Change, Jane Bradley, Environment and Human Health Inc., 2006

[2] Lu, J., Environmental Effects of Vehicle Exhausts, Global and Local Effects: A Comparison between Gasoline and Diesel, School of Business and Engineering (SET), Halmstad University, Halmstad, Sweden, 2011

[3] Rossman, R.E., The Effect of Vehicular Emissions on Human Health, Yale-New Haven Teachers Institute, Yale University, New Haven, Connecticut, USA, 2009

[4] Torres-Jimenez, E., Dorado, M. P., Kegl, B., Experimental Investigation on Injection Characteristics of Bioethanol-Diesel Fuel and Bioethanol-Biodiesel Blends, Fuel, Volume 90, Issue 5, 2011

[5] Stefanović, A., Diesel Engines with Fuel Based on Vegetable Oils, Monograph, Mechanical Engineering Faculty, University of Niš, Niš, Serbia, 1999

[6] Kegl, B., Hribernik, A., Experimental Analysis of Injection Characteristics Using Biodiesel Fuel, Energy Fuels, Volume 20, Issue 5, 2006

[7] Dieterle, W., Mechatronic systems: Automotive applications and modern design methodologies, Annual Reviews in Control, Volume 29, 2005

[8] Bauer, H., Diesel-Engine Management, Bosch Reference Books, Wiley, 2004

[9] Santilli R.M., A new gaseous and combustible form of water, *International Journal of Hydrogen Energy*, Volume *31, Issue 9,* 2006

[10] Kadota, T., Yamasaki, H., Recent advances in the combustion of water fuel emulsion, *Progress in Energy and Combustion Science*, Volume *28, Issue 5,* 2002

[11] Premkartikkumar, S.R., Annamalai, K., Pradeepkumar, A.R., Effectiveness of oxygen enriched hydrogen-HHO gas addition on DI diesel engine performance, emission and combustion characteristics, *Thermal Science*, *OnLine-First 00*, 2013

[12] Yilmaz, C.A., Uludamar, E., Aydin, K., Effect of hydroxy (HHO) gas addition on performance and exhaust emissions in compression ignition engines, *International Journal of Hydrogen Energy*, Volume *35, Issue 20,* 2010

[13] Brown, Y., Arc-Assisted Oxy/Hydrogen Welding, US patent number 4081656, 1978

[14] Milenković, M., Milošević, M., Stamenković, D., Pavlović, M., Research of Effectiveness of HHO Production for Use in Internal Combustion Engines, Proceedings of 16th SIMTERM, Sokobanja, Serbia, 2013

[15] Momirlan, M., Veziroglu, T. N., Current status of hydrogen energy, *Renewable Sustainable Energy Reviews*, Volume 6, Issue 1-2, 2002

[16] Hydrogen production, http://en.wikipedia.org/wiki/Hydrogen_production

[17] Bowers, B., *et al.*, Multi-Fuel Fuel Processor and PEM Fuel Cell System for Vehicles, SAE Technical Paper, 2007-01-0692, 2007

[18] Fuel Saving and Pollution Cutting Retrofitting Modifications, Panacea-BOCAF On-Line University,

[19] http://www.panaceatech.org/FuelSaving&PollutionCutting Modifications.pdf

[20] Pantone Motor, Panacea-BOCAF On-Line University, http://www.aktion-kehrwoche.com/de/wpcontent/uploads/2010/06/pantone_motor.pdf

[21] Milošević, M., Pešić, J., Nikolić, B., Milenković, M., An Experimental Research of Effects of Adding a Supplementary Component Generated by a Catalytic Reactor on the Combustion of the Primary Fuel at Internal Combustion Engines, Proceedings of 16th Symposium on Thermal Science and Engineering of Serbia SIMTERM 2013, Sokobanja, Serbia, 2013

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DYNAMIC ANALYSIS OF THE Z-BAR LOADER WORKING MECHANISM

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Abstract

This paper presents the mathematical model and program for the dynamic analysis of wheel loader with the Z-bar working mechanism. Dynamic analysis determined an inertial force and rotational inertia torque of centar of mass for the members of kinematic chain of the machine by Newton-Euler equations. As an example, the results of dynamic analysis are given for the wheel loader whose mass is 15000 kg and volume of bucket is 2.7 m^3

Key words: *Z-bar linkage, wheel loader, dynamic analysis*

1. INTRODUCTION

For general configuration of the kinematic chain of the wheel loader with Z-bar working mechanism, a mathematical model and calculation, is developed for a detailed kinematic and dynamic analysis of machine parameters. The observed general configuration of kinematic chain consists of: the rear L_1 (Fig. 1) and front L_2 moving mechanism and the manipulator with arm L_3 and bucket L_4.

This paper presents a part of research and developed program related to the dynamic analysis of the loader.

2. MATHEMATICAL MODEL

Defined mathematical model of the loader kinematic chain is based on general theorems of mechanics. The members of the loader kinematic chain builds kinematic pairs of fifth class - rotary joint with one degree of freedom.

The member of loader kinematic chain L_i is determined in its local coordinate system $O_i x_i y_i z_i$ with set of a geometric and dynamic sizes:

$$L_i = \left\{ \tilde{\boldsymbol{e}}_i, \tilde{\boldsymbol{s}}_i, \tilde{\boldsymbol{t}}_i, m_i, \tilde{\boldsymbol{J}}_i \right\} \tag{1}$$

where is: - $\tilde{\boldsymbol{e}}_i$ - orientation of an axis of joint O_i with whom the member L_i is connected to previous member L_{i-1}, $\tilde{\boldsymbol{s}}_i$ - position vector of the joint center with whom the member L_i is conected to forward member L_{i+1}, intensity of vector $\boldsymbol{s}_i$ represents the kinematic length of member, $\tilde{\boldsymbol{t}}_i$ - position vector of center of mass m_1 of member chain L_i in absolute coordinate system, $\tilde{\boldsymbol{J}}_i$ - moment of inertia tensor of member. Values that is tagged with "wave" above the mark, are defined in the local coordinate system of members. The mathematical model is designed to allow the numerical simulation of working task of the loader operational cycle to determine the kinematic and dynamic parameters of the kinematic chain and the drive mechanism of machine. [1][2].

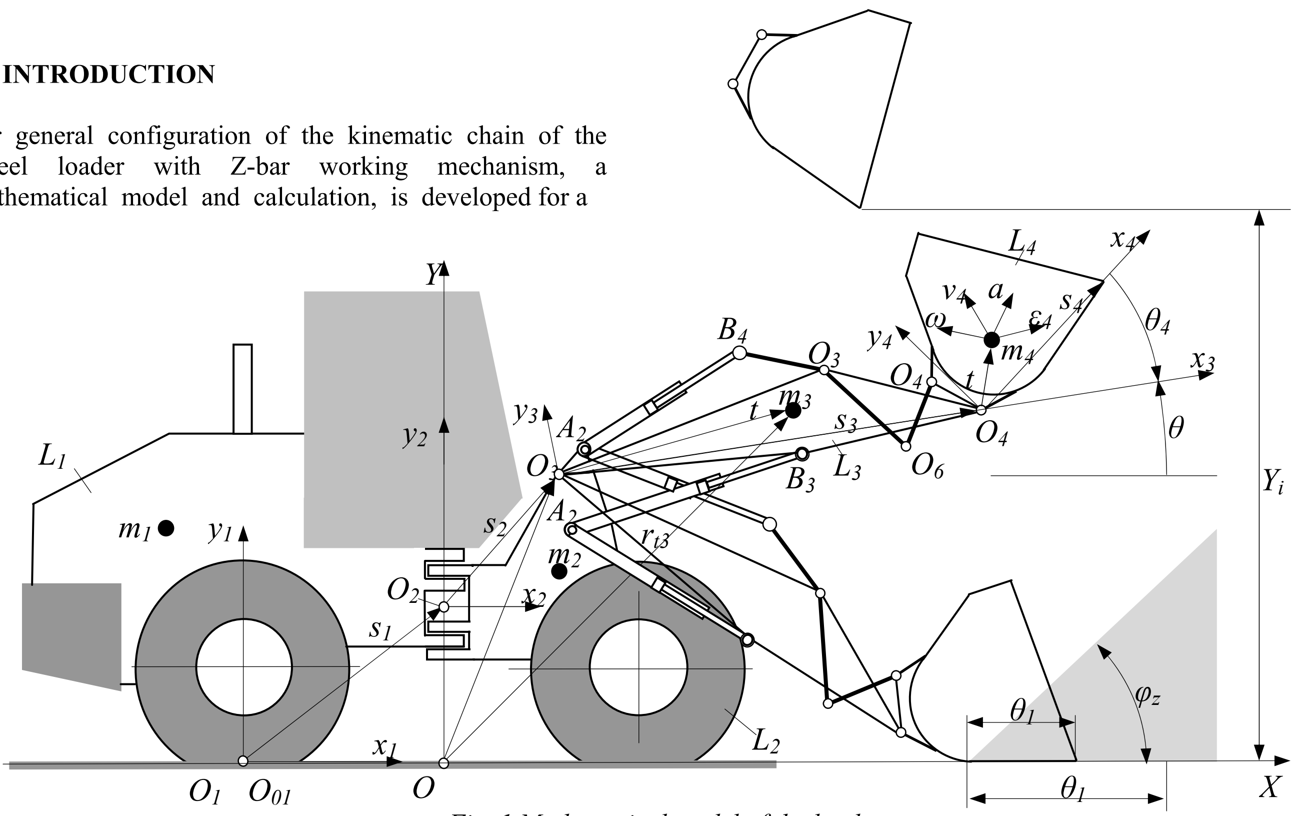

Fig. 1 Mathematical model of the loader

The simulation starts from a set of given values:

$$P_u = \{V, b_4, \rho_z, \varphi_z, Y_i, t_c\} \tag{2}$$

where is: V - volume of bucket, b_4 - width of bucket, ρ_z - angle of material slope, Y_i - unloading height, t_c - time of manipulative task.

The work of loader is characteristic in that the manipulative tasks are numerous and cyclic but with the same operations structure. However, at each cycle, a operation have different parameters.

For ease defining, each parameter of the manipulative task is marked with index ij, where index i denotes the number of the kinematic chain member that carrier operations with the index j.

The manipulative task that is analyzed in this paper consists of the following operations:

- loading the material with bucket ($j=1$),
- lifting the material to a certain height ($j=2$), and
- unloading the bucket ($j=3$).

Kinematic chain corresponds to the next inner (generalized) coordinates by given parameters and coordinates of path of manipulative task:

$$\theta_i = \{\theta_1, \theta_3, \theta_4\} \tag{3}$$

where is: θ_1 - penetration lenght of bucket, respectively the relative angle position of the loader in relation to the surface, θ_3 - relative angle position of arm L_3 relative to the x - axis of the previous member L_2, θ_4 - relative angle of the bucket L_4 relative to the x - axis of the previous member L_3.

The generalized coordinates determine position of the members of kinematic chain L_3 and L_4, relative to an absolute coordinate system, and they are:

$$\varphi_3 = \theta_3 \tag{4}$$

$$\varphi_4 = \theta_3 + \theta_4 \tag{5}$$

The inner coordinates of operations j of manipulative task corresponds to a specific range of motion of each kinematic chain member L_i:

$$\delta_{ij} = \theta_{ij4} - \theta_{ij1} \tag{6}$$

where is: δ_{ij} - movement range of the members i and the operation j, θ_{ij1}, θ_{ij4} - inner coordinates of the member position L_i, on start $k=1$ and on end $k=4$ of operation j.

For each member L_i of the kinematic chain and for each operation j the phase time are given: a) time t_{ij1} of beginning of the operation and the start of acceleration (Table 1), b) end time t_{ij2} of acceleration, c) beginning time t_{ij3} of deceleration, d) end time t_{ij4} of operation and end of deceleration.

The members of loaders kinematic chain, which are carriers of certain operations manipulative task, with a known range of motion, given phase times and adopted the character of the motion change, corresponding to a certain maximum speeds are:

$$\dot{\theta}_{ijm} = \frac{2\delta_{ij}}{(t_{ij3} + t_{ij4}) - (t_{ij1} + t_{ij2})} \tag{7}$$

according to which are define the rest inner coordinates of

Table 1. Speed and acceleration of member L_i

Change of speed		
$\dot{\theta}_{ij}$	$\frac{\dot{\theta}_{ijm}}{2}\left[1 - cos\left(\frac{t - t_{ij1}}{t_{ij2} - t_{ij1}}\right)\pi\right]$	$t_{ij1} \le t \le t_{ij2}$
	$\dot{\theta}_{ijm}$	$t_{ij2} \le t \le t_{ij3}$
	$\frac{\dot{\theta}_{ijm}}{2}\left[1 + cos\left(\frac{t - t_{ij3}}{t_{ij4} - t_{ij3}}\right)\pi\right]$	$t_{ij3} \le t \le t_{ij4}$
Change od acceleration		
$\ddot{\theta}_{ij}$	$\frac{\dot{\theta}_{ijm}}{2}\frac{\pi}{t_{ij2} - t_{ij1}} sin\left(\frac{t - t_{ij1}}{t_{ij2} - t_{ij1}}\right)\pi$	$t_{ij1} \le t \le t_{ij2}$
	0	$t_{ij2} \le t \le t_{ij3}$
	$-\frac{\dot{\theta}_{ijm}}{2}\frac{\pi}{t_{ij4} - t_{ij3}} sin\left(\frac{t - t_{ij3}}{t_{ij4} - t_{ij3}}\right)\pi$	$t_{ij3} \le t \le t_{ij4}$

state: speed $\dot{\theta}_{ij}$ and acceleration $\ddot{\theta}_{ij}$ of kinematic chain members at any time of manipulative task (Table 1)[3][4][5].

As an example, the inner coordinates of the members L_1 and L_2 at the operation of loading material ($j = 1$) aree:

$$\theta_{11} = \begin{cases} \theta_{111} = 0 \ \ \forall \ t = t_{111} \\ \theta_{114} = \left(\dfrac{2V}{b_4 \cdot tg\varphi_z}\right)^{0,5} \ \ \forall \ t = t_{114} \end{cases} \tag{8}$$

The vectors of: position of the center of the joint $\boldsymbol{r}_i$, the center of mass $\boldsymbol{r}_{ti}$ of kinematic chain members and the center of the cutting edge of the bucket $\boldsymbol{r}_w$, relative to an absolute coordinate system are determined by the equations:

$$\boldsymbol{r}_i = \sum_{j=1}^{i-1} A_{jo}\tilde{\boldsymbol{s}}_j \tag{9}$$

$$\boldsymbol{r}_w = \sum_{j=1}^{4} A_{jo}\tilde{\boldsymbol{s}}_j \tag{10}$$

$$\boldsymbol{r}_{ti} = \boldsymbol{r}_i + A_{io}\tilde{\boldsymbol{t}}_i \tag{11}$$

where is: A_{jo}, A_{io} - transformation matrix for the transformation of a vector from the local to the absolute coordinate system.

The kinematic values of the kinematic chain members of loaders are: linear v_i and angular velocity ω_i and linear a_i and angular accelerations ε_i of chain member L_i, and they are determine relative to an absolute coordinate system with recursive equations [6]:

$$\boldsymbol{\omega}_i = \boldsymbol{\omega}_{i-1} + \dot{\theta}_i\, \boldsymbol{e}_i \tag{12}$$

$$\boldsymbol{\varepsilon}_i = \boldsymbol{\varepsilon}_{i-1} + \ddot{\theta}_i\, \boldsymbol{e}_i + \dot{\theta}_i(\boldsymbol{\omega}_i \times \boldsymbol{e}_i) \tag{13}$$

$$\boldsymbol{v}_i = \boldsymbol{v}_{i-1} - \boldsymbol{\omega}_{i-1} \times \boldsymbol{r}_{i-1,i} + \boldsymbol{\omega}_i \times \boldsymbol{r}_{i,i+1} + \dot{\theta}_i \boldsymbol{e}_i \tag{14}$$

$$\begin{aligned} \boldsymbol{a}_i &= \boldsymbol{a}_{i-1} - \boldsymbol{\varepsilon}_{i-1} \times \boldsymbol{r}_{i-1,i} - \boldsymbol{\omega}_{i-1} \times (\boldsymbol{\omega}_{i-1} \times \boldsymbol{r}_{i-1,i}) + \\ &+ \boldsymbol{\varepsilon}_i \times \boldsymbol{r}_{i,i+1} + \boldsymbol{\omega}_i \times (\boldsymbol{\omega}_i \times \boldsymbol{r}_{i,i+1}) + \ddot{\theta}_i \boldsymbol{e}_i + 2\dot{\theta}_i(\boldsymbol{\omega}_i \times \boldsymbol{\varepsilon}_i) \end{aligned} \tag{15}$$

The dynamic values of the kinematic chain L_i member of loader are the inertial force F_i, rotational inertia torque M_i, they are determined for of the center of mass, using the Newton-Euler equations:

$$\boldsymbol{F}_i = -m_i \boldsymbol{a}_i \tag{16}$$

$$\widetilde{\boldsymbol{M}}_i = -\widetilde{J}_i \widetilde{\boldsymbol{\varepsilon}}_i + \left(\widetilde{\boldsymbol{\omega}}_i \times \widetilde{J}_i \widetilde{\boldsymbol{\omega}}_i\right); \quad \boldsymbol{M}_i = A_{io} \cdot \widetilde{\boldsymbol{M}}_i \tag{17}$$

3. ANALYSIS

Based on predefined mathematical model, program (Fig.3) was developed which provides a detailed dynamic analysis of the kinematic chain members by simulation of given manipulative tasks.

As an example, using the developed software, dynamic analysis of kinematic chain members was performed of wheel loaders with Z-bar manipulator, mass of loader is 15000 *kg* and a volume of bucket is 2.7 m^3.
Simulated manipulative task, consisted of next operations: loading of material, transport of affected material and unloading at a given height.
This paper presents results of bucket dynamic analysis.

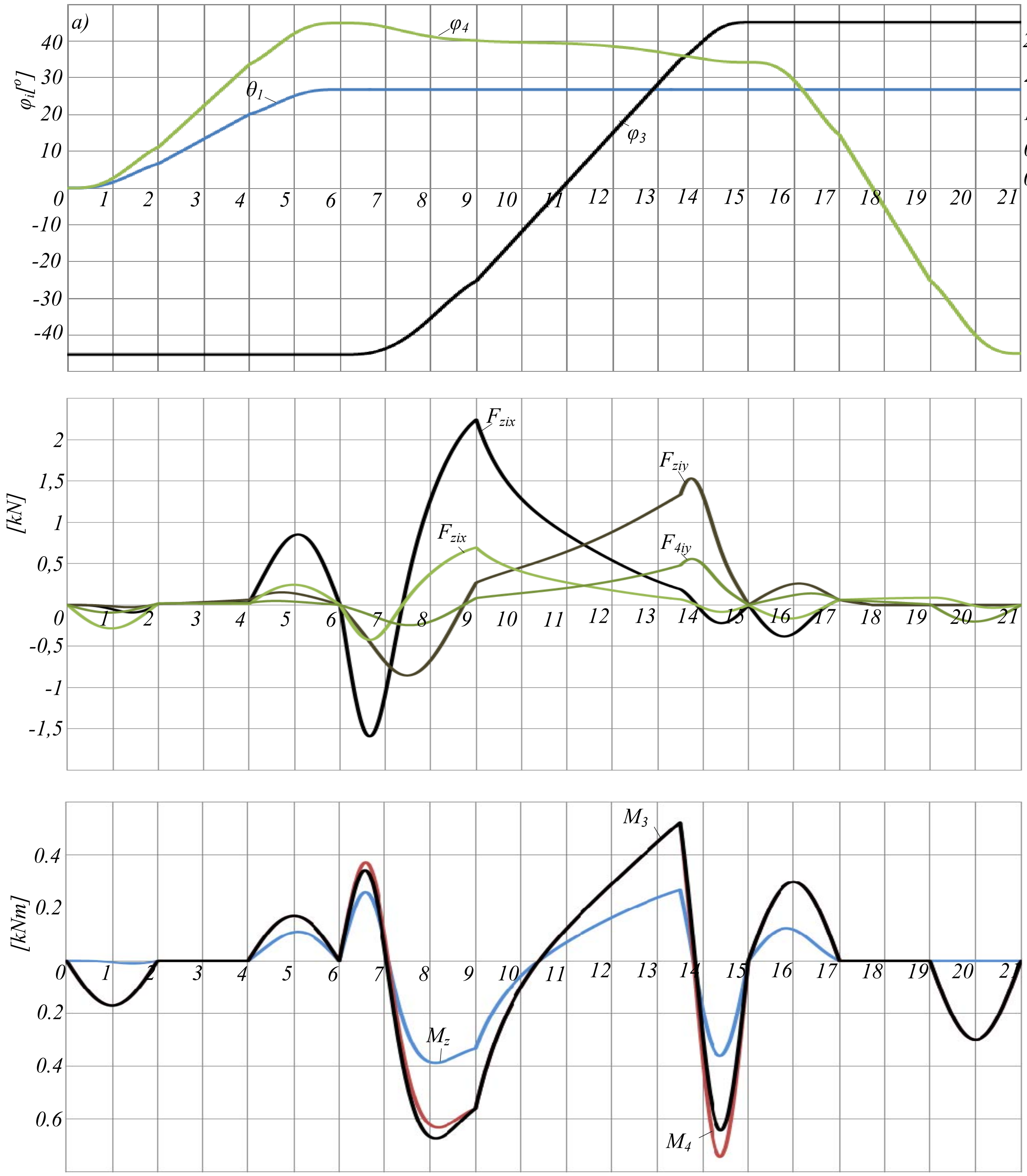

Fig.2 Dynamic analysis of wheel loader: a) change of generalized coordinates, b) change of inertial force, c) change of rotational inertia torque components

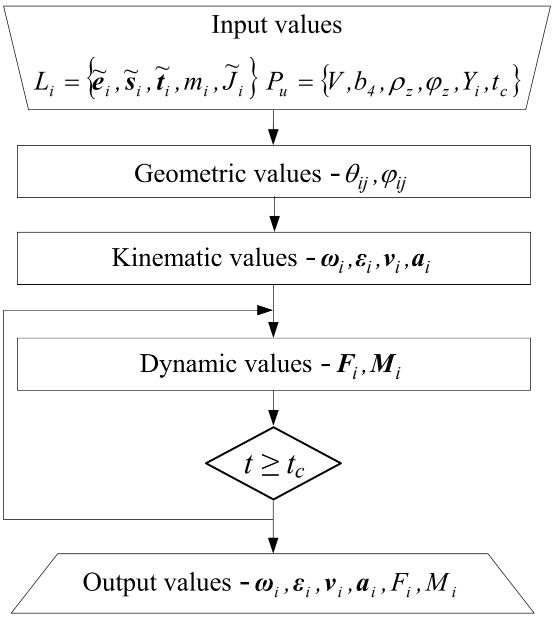

Fig. 3 Algoritram of developed programs

The changes of generalized coordinates of kinematic chain members (Fig.2a) shows that at loading it comes to simultaneous movements of the moving mechanism members L_1 and L_2 and the bucket rotation L_4.The operation of lifting a loaded material on given height is accomplished by movement of arm L_3 and depending on movement of bucket L_4.

Bucket rotation, while arm is lifting, occurs because the drive mechanism of bucket is dependent on drive mechanism of arm with aim to maintain the bucket in a position where there is no spilling materials when arm is lifting. Unloading operations are carried out only by running buckets [7][8].
Analysis of obtained results shows that the biggest inertial forces (F_{zi}) (sl.2b) causing mass of affected land at the beginning of a transport operation and that the largest rotational inertia torque (M_3) (Fig. 2c) occur at arm at the end of transport operation.

4. CONCLUSION

The wheel loaders models of all sizes have predominantly Z-bar working mechanism. This type of working mechanism provides easy manipulation of the material, transport and unloading of materials. Since the drive mechanism of bucket dependent on drive mechanism of arm, when arm is lifting comes to correction of the bucket so that a materials does not spilling out from the bucket. Moreover Z-bar mechanism allows to achieve higher digging forces with smaller sizes of hydraulic cylinders of bucket drive mechanism.

In the development of wheel loaders is necessary kinematic and dynamic analysis of kinematic chain members and drive mechanisms analysis of the machine in order to evaluate compliance of the setted requirements which are related to the Z-bar working mechanism.
For these reasons, here are developed a mathematical model and program for detailed kinematic and dynamic analysis of all members of the kinematic chain during simulated manipulative task which consists of operations: loading, transport and unloading of materials.

ACKNOWLEDGEMENT

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REFERENCES

[1] H. Dresig, and F. Holzweissig, "*Dynamics of machinery*," Springer, Berlin, London, 2010.
[2] D. Janošević, "Projektovanje mobilnih mašina," Faculty of Mechanical Engineering University of Niš, 2006.
[3] R. Filla, "Quantifying Operability of Working Machines", Linkoping Studies in Science and Technology Dissertations, No 1390, Linkoping 2011.
[4] R. Filla, an J. O. Palmberg, "Using Dynamic Simulation in the Development of Construction Machinery". The Eighth Scandinavian International Conference on Fluid Power, Tamper, Finland, Vol.1, pp 651-667, May 7-9, 2003
[5] R. Filla, "An Event-driven Operator Model for Dynamic Simulation of Construction Machinery". The Ninth Scandinavian International Conference on Fluid Power, Linkoping, Sweden, June 1-3, 2005.
[6] V. Potkonjak, "Роботика", Naučna knjiga, Belgrade, 1989.
[7] J. Shen, G. Wang, Q. Bi, and J. Qu, "A comprehensive genetic algorithm for design optimization of Z-bar loader working mechanism". Journal of Mechanical Science and Technology Vol.11, No.27pp. 3381~3394, june 2013.
[8] M. D. Worley, and V. La Saponara, "A simplified dynamic model for front-end loader design" Proc. IMechE Vol. 222 Part C: J. Mechanical Engineering Science, SAGE, pp. 2231-2249, 2008.
[9] A. A. Shabana, "Dynamics of Multibody Systems", Cambridge University Press, London, 2010.
[10] R. N. Jazar, "Theory of Applied Robotics", Springer, 2010.
[11] R. Featherstone, "Rigid Body Dynamics Algorithms", Springer, 2008.

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STRESS DETERMINATION IN REINFORCED I-SECTION BOTTOM FLANGE OF SINGLE GIRDER CRANE

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Abstract

Rapid development of industry has brought to a growing need for installation of single girder bridge cranes and monorail tracks. "I" section has been recognized as the most appropriate one for the main girder. Limitations in their usage can appear due to the loss of lateral stability or occurence of local stress increase under trolley wheels when total stresses go beyond the limit values. The paper considers the references of number of authors for calculating the stress in the zone of wheel and section contact in order to determine its carrying capacity. Comparison was made between obtained and finite element method (FEM) results and experimental researches. On the base of comparison, designers were given the references that can be of great importance for choice of calculation method from the point of determining the maximum stress values of "I" section bottom flange.

Keywords: *I-section, single-girder crane, bottom flange stress, crane runway.*

1. INTRODUCTION

With growth of industry and widening of production capacities there is a greater need for installation of single girder bridge cranes or monorail tracks which serve the production plants. In order to establish this transport system, its static calculation must be done. Static calculation is defined by certain technical regulations. These regulations are not the same in all countries, so a difference appears in the calculation way of single girder bridge cranes and monorail track structures. Common is the fact that bottom flange, upon which trolley runs, is critical for dimensioning the I-section (Figure 1).

In the paper the analysis was done of bottom flange stress of standard INP section with reinforcement and reccomendation was given for its stress determination.

At points below the wheel, the biaxial bending of flange profile appears, so there occurs biaxial stress state that is superimposed with stresses of global loading (Figure 2) [1].

These girders are usually made from various types of I sections with additional reinforcement (Figure 3a) or without it (Figure 3b). The paper considers the case of bottom flange reinforcement (Figure 3a). The aim of the research in this paper is comparative analysis of the results of bottom flange local stresses values obtained using different expressions recommended in literature and regulations. Regardless of its great influence, lateral stability of the bottom flange was not considered in the paper. Lateral stability influence is of special significance if it comes to the cranes of bigger span an capacity.

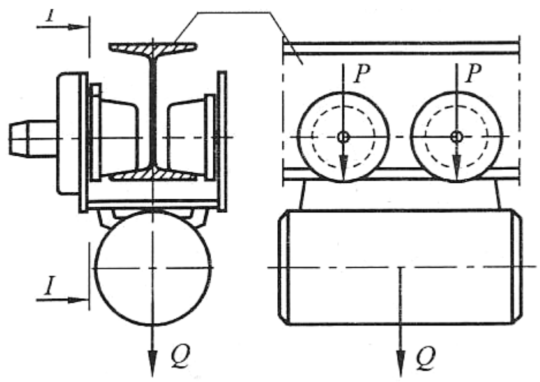

Fig. 1 Wheel-track contact

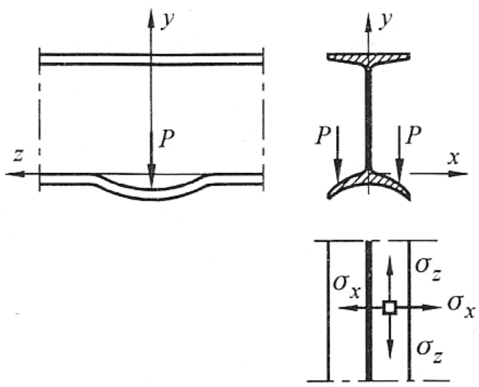

Fig. 2 Biaxial local stresses on flange

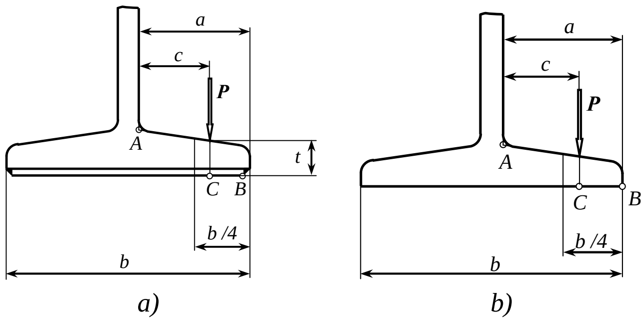

Fig. 3 Review of bottom flange characteristic points

2. RECOMMENDATIONS FOR CALCULATION OF I-SECTION BOTTOM FLANGE

Bottom flange local stresses depend on 3 parameters:

-trolley wheel pressure force (*P*),

-wheels position related to profile edge (*a*-*c*) and

-bottom flange thickness below the wheel (*t*).

Contact of wheel and flange is near the flange outer edge. In a local perspective, the flange is subjected to bending. We usually use Mendel's expression for calculating the local stress, according to standard JUS C.B3.131 [1-3]. Bottom flange stresses depend on point location.

Stresses in point "A" read:

$$\sigma^A_{x,l} = \pm k_{A,x} \cdot \frac{P}{t^2}$$

$$\sigma^A_{z,l} = \pm k_{A,z} \cdot \frac{P}{t^2} \qquad (1)$$

$$\sigma^A_z = \sigma_1 \cdot \frac{y_A}{y_{max}}$$

Stresses in point "C" read:

$$\sigma^C_{x,l} = \mp k_{C,x} \cdot \frac{P}{t^2}$$

$$\sigma^C_{z,l} = \pm k_{C,z} \cdot \frac{P}{t^2} \qquad (2)$$

$$\sigma^C_z = \sigma_1$$

Stresses in point "B" read:

$$\sigma^B_{z,l} = \pm k_{B,z} \cdot \frac{P}{t^2}$$

$$\sigma^B_z = \sigma_1 \qquad (3)$$

Coefficients (by Mendel) given in previous expressions depend on relations of values *c* and *a* (Figure 4).

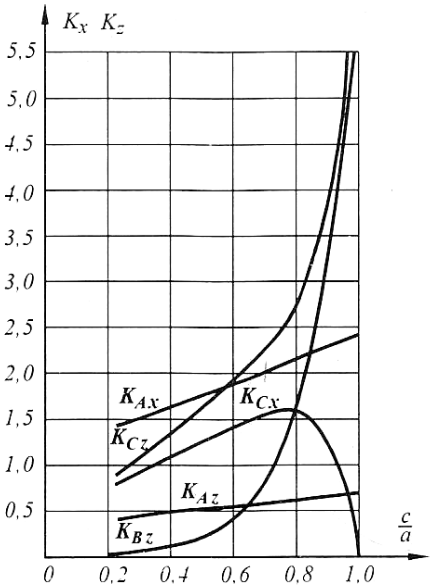

Fig. 4 Bottom flange bending coefficients [2]

Expression that is often used is stress check by swiss recommendations B1[4-5]. By this recommendation bending moment M_x should taken by the section 1-1 which has width *2.2 a* (Figure 5). On base of that we get the expression:

$$\sigma_x = \frac{M_x}{W_x} = \sigma_{z,1} \qquad (4)$$

Standard Euronorm EN 1993-6: 2007(E) [6] defines three characteristic sections for calculation (Figure 6).

Characteristic section lines are:

-"0"-line in connection between web and flange plate,

-"1"- wheel loading line,

-"2"-flange outer edge.

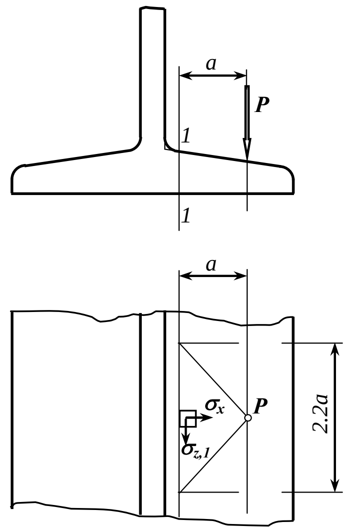

Fig. 5 Characteristic points for calculation [4]

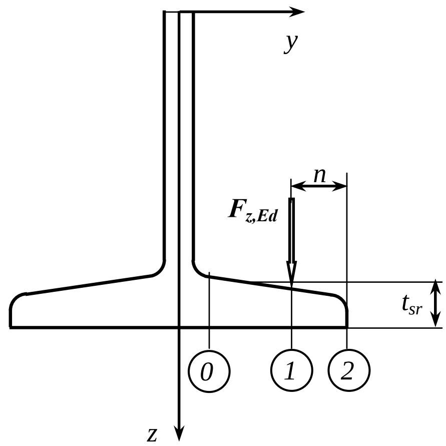

Fig. 6 Characteristic sections for calculation [6]

Calculation method depends on trolley wheels distance. If the trolley wheels distance is not less than *1.5 b* (*b*-flange width) bending stresses are:

$$-\sigma_{\sigma x,Ed} = c_x \cdot \frac{F_{z,Ed}}{t_1^2} \qquad (5)$$

$$-\sigma_{\sigma y,Ed} = c_y \cdot \frac{F_{z,Ed}}{t_1^2} \qquad (6)$$

- $\sigma_{\sigma x,Ed}$ - longitudinal bending tension,

- $\sigma_{\sigma y,Ed}$ - transverse bending tension,

- t_1 - belt thickness in section under force.

Coefficients (c_x , c_y) depend on cross section in which the stress is calculated as well as on parameter μ :

$$- \mu = \frac{2n}{b - t_w}, \tag{7}$$

- t_w - web thickness.

Abramovič [7] defined the expression which totally matches the recommendations regulated by Euronorm [6], difference is only in marks in the picture. By [7], coefficients (c_x , c_y) can be obtained by reading from diagrams shown in Figure 7, where axis *x* matches axis *y* in Fig. 6, and axis *z* to axis *x*. Parameter λ matches parameter μ.

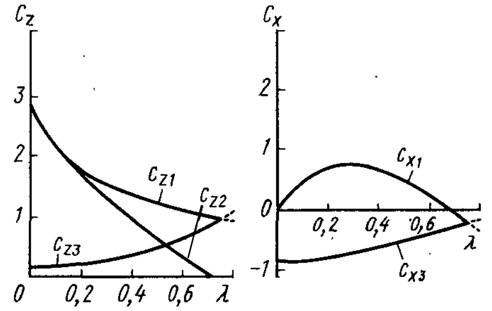

Fig. 7 Diagrams for coefficients determination [7]

When bottom flange is reinforced by a plate of thickness t_2, obtained stresses in previous expressions are corrected by coefficient *k* which depends on relation of thicknesses t_{sr} and t_2 (Table 1).

Table 1.

t_{sr} / t_2	0,25	0,5	1,0	2,0 & more
k	0,85	0,75	0,6	0,5

By Alexandrov [8] three points are referential for the calculation. Layout of points matches Mendel's methodology, i.e. the standard JUS C.B3.131 (Figure 8).

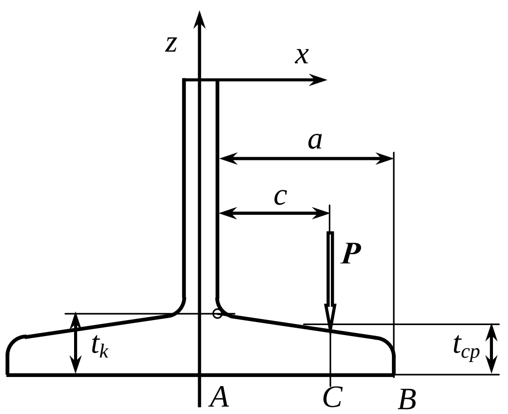

Fig. 8 Characteristic points for calculation [8]

Local bending stresses are:

$$- \sigma_x = \pm \frac{k_1 \cdot P}{t_k^2} \text{ - in plane } xy, \tag{8}$$

$$- \sigma_y = \pm \frac{k_2 \cdot P}{t_k^2} \text{ - in plane } yz, \tag{9}$$

Sign "+" relates to point "A", and sign "-" to point "C".
Local bending stress at flange end, parallel to plain *yz*, is:

$$- \sigma_{y,cb} = \pm \frac{k_3 \cdot P}{t_{cp}^2} \ . \tag{10}$$

By Ricker [9-10] there are three points that respond to the method shown in [8], where expressions for stress calculation match those given in Euronorm [6].
Besides the local stress increase, a number of authors dealt also with researches of girder lateral stability [11-17].

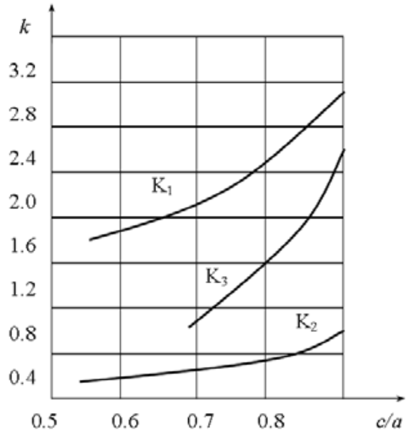

Fig. 9 Diagrams for coefficients determination [9]

3. EXPERIMENTAL STRESSES DETERMININATION

Verification and comparison of obtained results using the previously mentioned recommendations was carried out by experimental examination. Single girder crane that was examined has the following technical characteristics:

-Loading capacity *Q=5 t,*
-Bridge span *L=11,7 m,*
-Longitudinal distance of trolley wheels *b=300 mm,*
-Electric winch type Balkancar T10632.

Girder cross section is shown in Figure 10.

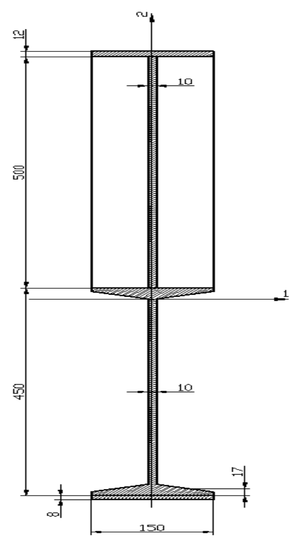

Fig. 10 Girder cross section

Strain gauges layout is shown in Figure 11. In figure 12 the strain gauges positions are shown in relation to the edge of flange. Strain gauges middle line 2-3 matches the middle line of strain gauge 6.

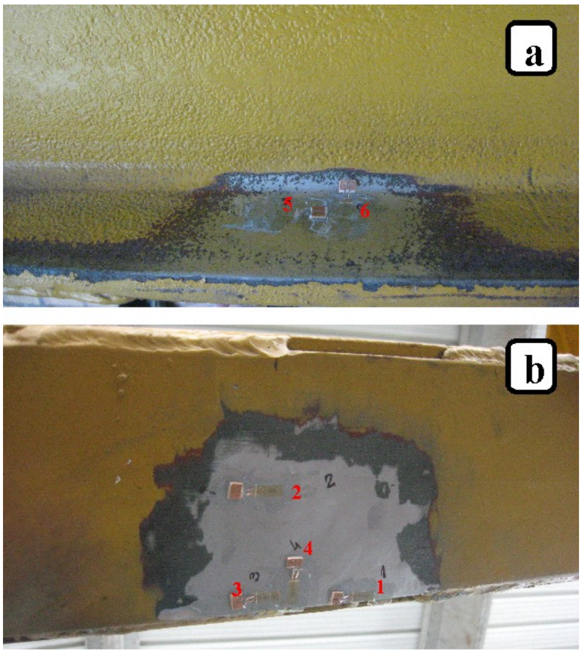

Fig. 11 Strain gauges locations on bottom flange a) inner side b) outer side

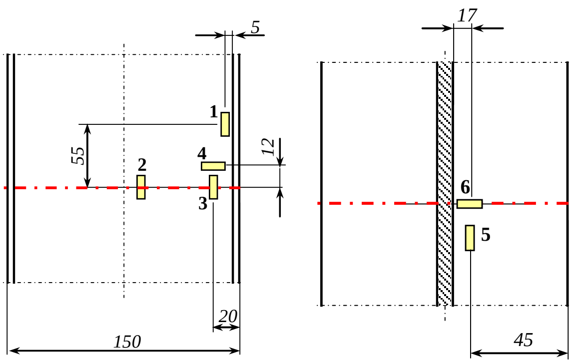

Fig. 12 Strain gauges locations on bottom flange a) inner side b) outer side

Measurings were done for three cases (Figure 12):

-first wheel is distant 150 mm from the line 2-3,

-first wheel is above the line 2-3,

-line 2-3 is between the wheels.

To compare the results with previously mentioned recommendations, the results for the case when the wheel is above the line 2-3 will be analysed in the paper.

At experimental examination there was used the strain guage of following characteristics:

-type LA-22 10/120,

-resistance R=120 Ω ±0.5 %,

-constant K=2.05±1%.

Scheme of measuring equipment chain is shown in Figure 13.

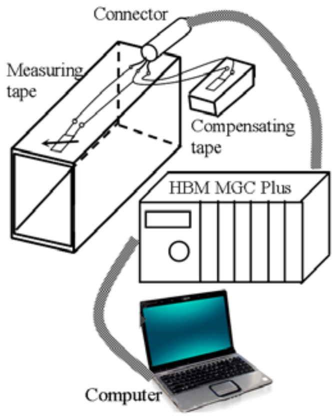

Fig. 13 Scheme of measuring equipment

4. STRESS DETERMINATION USING THE FINITE ELEMENT METHOD

Verification and comparison of obtained results of previously mentioned recommendations was also done by finite element method (FEM). Techical features of single girder crane on which the examination was done are given in section 3. 3D model of single girder crane was formed by synthesis of all structural parts. Model represents a continuum discretized by ten-nodal tetrahedral elements.

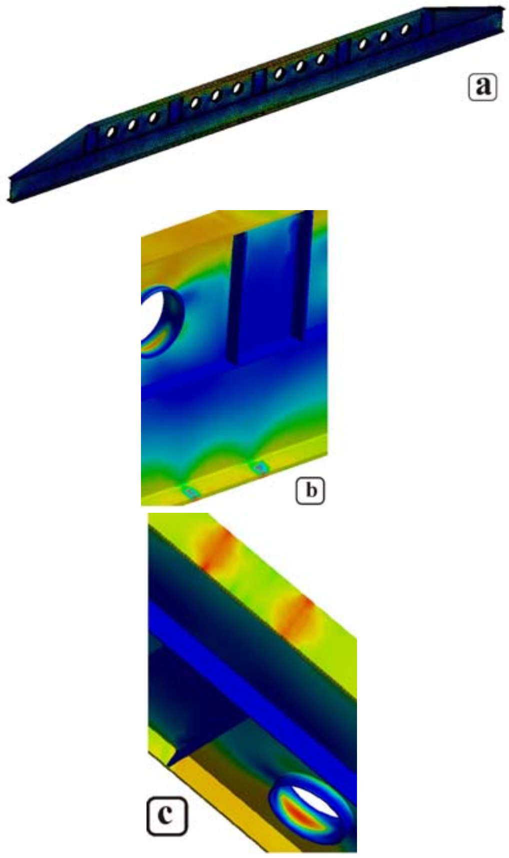

Fig. 14 Stress distribution: a) main girder b) bottom flange – inner side c) bottom flange – outer side

5. COMPARATIVE PRESENTATION OF STRESSES

Evaluation of results obtained using some of recommended expressions can be done by comparing with results obtained by experimental examination and FEM method. Comparison was done for points "C", "A"and "B", and results are shown in tables 2,3&4 respectively. Axis *z* is directed along axis of main girder, while axis *x* is directed transversely to it.

Table 1

Stress in "C" [kN/cm^2]		Force *P (kN)*				
Method		20.7	31.2	42.2	51.7	67.8
FEA	$\sigma_{,z}$	2.9	4.0	5.1	6.4	8.6
	$\sigma_{,x}$	0.4	0.7	0.8	1	1.4
	$\sigma_{,u}$	3.0	4.0	5.3	6.5	8.6
Testing	$\sigma_{,z}$	2.6	3.8	5.2	6.4	8.6
	$\sigma_{,x}$	1.7	2.2	2.8	3.3	4.3
	$\sigma_{,u}$	2.3	3.3	4.5	5.5	7.4
[6]	$\sigma_{,z}$	3.5	5.0	6.7	8.1	10.5
	$\sigma_{,x}$	0.6	0.9	1.1	1.4	1.8
	$\sigma_{,u}$	3.2	4.7	6.2	7.5	9.7
[2]	$\sigma_{,z}$	3.9	5.6	7.3	8.9	11.5
	$\sigma_{,x}$	2.1	2.9	3.8	4.6	5.8
	$\sigma_{,u}$	3.3	4.8	6.4	7.7	10.0
[8]	$\sigma_{,u}$	0	0	0	0	0
[7]	$\sigma_{,z}$	2.2	3.3	4.4	5.3	6.9
	$\sigma_{,x}$	0.5	0.7	0.9	1.0	1.3
	$\sigma_{,u}$	2.0	3.0	4.0	4.9	6.3
[4]	$\sigma_{,u}$	0	0	0	0	0
[9]	$\sigma_{,u}$	0	0	0	0	0

Table 2

Stress in "A" [kN/cm^2]		Force *P (kN)*				
Method		2070	3115	4220	5170	6775
FEA	$\sigma_{,z}$	1.2	1.7	2.2	2.6	3.4
	$\sigma_{,x}$	-1.5	-2.1	-2.7	-3.2	-4.2
	$\sigma_{,u}$	2.3	3.3	4.3	5.0	6.6
Testing	$\sigma_{,z}$	2.0	3.2	4.2	5.1	6.7
	$\sigma_{,x}$	1.2	1.9	2.4	2.9	3.8
	$\sigma_{,u}$	1.7	2.8	3.6	4.4	5.8
[6]	$\sigma_{,z}$	1.6	2.5	3.2	3.9	5.2
	$\sigma_{,x}$	-0.9	-1.3	-1.7	-2.0	-2.6
	$\sigma_{,u}$	2.2	3.3	4.3	5.2	6.9
[2]	$\sigma_{,z}$	1.9	3.0	3.8	4.6	6.2
	$\sigma_{,x}$	2.0	3.0	3.7	4.4	5.9
	$\sigma_{,u}$	2.0	3.0	3.8	4.5	6.1
[8]	$\sigma_{,z}$	1.8	2.8	3.6	4.4	5.9
	$\sigma_{,x}$	1.5	2.1	2.7	3.2	4.2
	$\sigma_{,u}$	1.7	2.5	3.2	3.9	5.2
[7]	$\sigma_{,z}$	1.5	2.4	3.1	3.8	5.1
	$\sigma_{,x}$	-0.5	-0.7	-0.8	-1.0	-1.3
	$\sigma_{,u}$	1.8	2.8	3.6	4.4	5.9
[4]	$\sigma_{,z}$	2.5	3.8	4.8	5.8	7.8
	$\sigma_{,x}$	1.1	1.6	2.0	2.4	3.2
	$\sigma_{,u}$	2.1	3.3	4.2	5.1	6.8
[9]	$\sigma_{,z}$	1.4	2.2	2.8	3.4	4
	$\sigma_{,x}$	2.4	3.5	4.4	5.3	7.0
	$\sigma_{,u}$	2.1	3.1	3.9	4.7	6.2

Table 3

Stress in "B" [kN/cm^2]		Force *P (kN)*				
Method		22.5	30.4	41.1	51.7	67.7
FEA	$\sigma_{,z}$	1.7	2.2	2.8	3.4	4.4
Testing	$\sigma_{,z}$	2.4	3.3	4.6	5.9	7.8
[6]	$\sigma_{,z}$	3.8	4.9	6.5	8.1	10.5
[2]	$\sigma_{,z}$	2.5	3.4	4.5	5.6	7.2
[8]	$\sigma_{,z}$	2.7	3.6	4.7	5.9	7.7
[7]	$\sigma_{,z}$	2.0	2.6	3.5	4.4	5.7
[4]	$\sigma_{,z}$	0	0	0	0	0
[9]	$\sigma_{,z}$	0	0	0	0	0

6. CONCLUSION

Results obtained in this paper can be of great importance at designing single girder bridge cranes but also monorail tracks at which the bottom flange is -"I" profile. Researches have shown the necessity of stress check in characteristic sections which are defined in literature, i.e. in sections "C","B"and "A".

Point "A", beneath the radius that connects web and flange, has the lowest stresses, so the stress analysis in it is of less importance.

Stresses on outer edge of flange under point "A" are higher and should be checked.

For stress determination in point"C", best results gives the methodology defined in [7], while for point "B" methodology defined in [2] and [8].

For stress determination in point "A", the best results are given by methodologies defined in [7] [2]and [9], but also the results obtained by methodologies [8] [4] and [6] do not have big deviations.

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REFERENCES

[1] Z. Petković, D. Ostrić, “Metal structures in machine-building,” Faculty of Mechanical Engineering Belgrade, 1996 (In Serbian).

[2] G. Mendel, “Berechnung der Tragerflansch-beansprung mit Hilfe der Plattentheorie,” Forden und Heben, vol. 14.

[3] G. Huber, F. Tshemmernegg, “Modelling of steel connections,” Journal of Constructional Steel Research, vol. 45, pp.199-316, 1998.

[4] B. Zarić, D. Buđevac, B. Stipanić, “Steel structures in costruction,” Faculty of Civil Engineering Belgrade, 2000 (In Serbian)

[5] S. Bošnjak, Z. Petković, P. Matejić, “ Analysis of tension state due to local belt and girder bending,” Transport in industry, Faculty of Mechanical Enginering Belgrade, pp.337-342, 1994.

[6] CEN-“European Committee for standardization Eurocode 3: Design of steel structures 1993-6, Crane supporting structures,” 2007.

[7] I.I. Abramovič, “Industrial hoisting machines,” Mašinstvo-Moskva, 1989 (in Russian).

[8] “Hoist-transport machines,” Visoka škola-Moskva, 2006 (in Russian).

[9] T.D. Ricker, “Steel interchange,” Modern Steel Construction, 1999.

[10] T.D. Ricker, “Tips for avoiding crane runway problems,” Engineering Journal, Vol 4. 1982.

[11] N. Zrnić, S. Bošnjak, V.Gašić, “Loading capaties curves for I-sections runway beams according to bottom flange bending and lateral buckling,” Machine design, pp.181-186, 2008.

[12] W.J. Lee, “Behavior of Connection with Beam Bearing on Bottom Flange of Girder,”Blacksburg, 2001.

[13] N.S. Trahair, “Steel cantilever strenght by inelastic lateral buckling,”School of civil engineering, Sidney, 2001.

[14] N.S. Trahair, “Lateral-Distortional buckling of Monorails,”School of civil engineering, Sidney, 2006.

[15] M. Ahnlen, “Lateral torsional buckling of I-beams,” Department of civil and environmental engineering, Geteborg, 2013.

[16] N.D. Lagaros, M. Papadrakakis, “Applied soft computing for optimum design of structures,” Struct. Multidisc.Optim., vol 45. pp.787-799, 2012.

[17] J.S. Park, D.Y Yoon, B. H. Choi, “Moment gradient Modifier of Continuously Braced Nonuniform Beams with Top Flange Loading,” KSCE Journal of Civil Engineering, vol 9.No2. pp.125-133, 2005.

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EVALUATION OF EFFICIENCY OF URBAN BUS LINES IN NIŠ

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Abstract

The efficiency of transport systems is determined by the ratio of the achieved results of the system and consumed resources (vehicles, living labor, energy, etc..) in the process of making transportation services. Besides an efficient UPPT system, citizens should be offered public transport an appropriate quality of transport services in order to retain existing and attract new customers. Quality of service must be measured, controlled and maintained on the basis of continuous user satisfaction research. The paper integrates Data Envelopment Analysis (DEA) for examination operational efficiency and the quality of the transport services of public urban transport system in Niš. Based on the calculated and compared values is obtained the overall efficiency of bus routes and given are some recommendations for the justification of the change bus routes after the UPPT Study conducted in Nis 2007th.

Keywords: *DEA, UPPT, Quality of the transport services.*

1. INTRODUCTION

Modern cities are faced with the problems posed by the growing number of individual vehicles, which require more traffic areas than what the city can offer, and getting worse the living conditions and quality of life. The increased number of passenger cars in cities has resulted in traffic congestion and inefficient public transport, as well as worsening of the environment due to exhaust emissions and noise. The only solution that can alleviate and overcome the traffic problems in cities is radically reform and modernization of Urban Public Passenger Transport (UPPT). Quality of UPPT should be raised to a level that meets the criteria of the modern citizen and who would thus become attractive for the part of citizens who mostly use their cars for transportation. In the 50 largest cities in the world in operational use is about 55,700 buses [1]. The growth of urban areas and their changes represent a challenge for regional development, particularly in connection with issues of sustainability. Public transport will no doubt continue to play a major role in the urban areas. There has been much research over the past ten years on aspects of service and efficiency of bus transport system. Common to all the studies of public transport is a necessity to assess transportation system which serve a population.

Public agencies for passanger transport are trying to operate more efficiently as the level of government funding declines, or as a result of changes in ownerships or regulations. Many agencies have also begun to focus more on service planning, attempting to analyze regional and local demographics in relation to transport services. This trend has stimulated much research interest in the evaluation of the performance of public transportation systems. The majority of existing research focuses on evaluating the performance of agencies for passanger transport from management perspectives [2].

The last ten years there has been major changes in Serbia, which led to changes in the systems of urban and suburban passenger transport. Considering the conditions in which are operated the 90s, the current domestic carriers have emerged from this period considerably weakened, with old vehicles, a large number of employees, low production and economic efficiency, and there are new companies that have the resources and knowledge are not enough trained for the challenges of the new trends in technology and management. New systems of UPPT in cities are becoming more complex and in structure (more carriers, more subsystems) and in operation (integration needs of carriers in the system in a functional, tariff and logical sense), and as a consequence and in organization and management.

Methodological, the paper integrates Data Envelopment Analysis (DEA) for examination operational efficiency and the quality of the transport services of public urban transport system in Niš. Efficiency in passenger transport, are achieved primarily by minimizing the spent resources, because the results are precisely defined by the user as far as space, time and quality of realization services. The quality of service means a general effect of service properties that determines the degree of satisfaction of the needs of the service user. From the viewpoint of transport users, the most important parameters of quality of transport services in passenger transport can be categorized into the following:

- the speed of transportation (ie travel time from point of departure to destination),
- transportation costs (direct expenditure which user has when performing travel),
- comfort (conditions under which transport is performed - approaching the vehicle, payment services, kindness services, etc.),
- safety (probability that travel are performed without accident ie without harmful consequences) and
- reliability (guaranteeing a certain time travel, which can be predicted in advance).

Because of the data lack for the new bus lines which established after study done, were been used data collected for the then existing bus lines from 2007. The aim is to identify the best, and insufficiently efficient or ineffective bus lines. Then are given analysis of the results and comments on the changes bus routes after conducting the Study.

2. REVIEW OF LITERATURE FROM THE FIELD OF DEA FOR EVALUATING PERFORMANCE PUBLIC TRANSPORT

There has been much research over the past 20 years on evaluating public transport performance with DEA. Chu, Fielding, and Lamar (1992) developed a single index for measuring service efficiency as well as service effectiveness of public agencies for passanger transport. Obeng (1994) addressed the influence of subsidies on the efficiencies of US public transportation systems. Nolan (1996) did a DEA study of 25 mid-sized bus agencies using USDOT section 15 data from 1989 to 1993. He also tried to identify the relationships between the efficiency scores and agency characteristics using Tobit regression. Viton (1997) and Viton (1998) examined the technical efficiency of US multimode bus transit and discussed technological challenges facing the industry [2].

Boilé (2001) evaluated 23 urban transportation systems and identified inefficiencies related to input and output variables in the DEA models as well as inefficiencies attributed to external factors. In the paper was developed four DEA models and are used to assess the performance of a group of bus transport systems in the United States [6]. The most efficient systems within the group were identified, while for the remaining systems the types and sources of inefficiency were determined. The types of inefficiencies that were considered are global and local technical inefficiencies and scale inefficiencies. Systems that operate locally inefficiently may improve their service by utilizing operation strategies, which will result in better use of resources to provide service. Systems that exhibit scale inefficiencies may be improved upon by identifying and dealing with external factors that create disadvantageous conditions for the systems. The methods demonstrated in this paper are more comprehensive compared to the single input/output ratios typically used as transit performance indicators. However, they are not intended to be used as the sole measure of transport efficiency. Results of these methods provide decision makers in transport organizations with additional useful information to determine the relative performance of their systems, identify sources of inefficiency, and assist them in allocating resources and making investment decisions [6].

De Borger et al. (2002) gave an extensive review and analysis of the literature on the production and cost frontiers for public transit operators. The paper summarized many critical issues insightfully, including technical versus scale versus allocative efficiencies, the selection of input and output measures, returns to scale and scope, and the impact of ownership and government subsidies [2].

Finally, Tsamboulas (2006) evaluated performance of 15 European transit systems operating under different regulatory regimes. Each of the transportation system included in the sample was chosen to cover different situations with regard to regulatory and organizational forms of European cities. These transit systems were, then, clustered into four groups, according to the area and population size of each city, in order to avoid misleading results as far as their performance assessment is concerned [7]. The final four clusters are "very large", "large", "medium" and "small" cities, whereas, the final data set created for this study refers to a 10-year period of time (1990–2000) and includes operating characteristics, such as number of vehicles used on a yearly basis by each transit system, number of employees operators, maintenance, and administrative personnel, vehicle kilometers traveled and number of passengers [7].

From the brief overview above it is clear that existing DEA literature has primarily been devoted to comparing and evaluating public transportation agencies at regional or national levels. These studies have provided rich and insightful information on DEA based assessment theory, methodology, and empirical findings for public transportation agencies. However, as Triantis (2004, p. 426) pointed out, "very little research has focused on the evaluation of performance at the transportation process level". Bus lines are only researched in the paper [2], which tries to fill this gap by evaluating performance of bus lines within a public transport agency.

3. USING DEA FOR EVALUATING PERFORMANCE OF BUS LINES IN THE CITY OF NIŠ

3.1. DEA model

DEA is a linear programming technique to measure relative efficiencies of a set of peer units called decision making units (DMU) [2]. The basic assumption is that each DMU requires certain resources (inputs) to produce its goods or services (outputs). A DEA model essentially establishes an empirical and piecewise linear production frontier to monitor the "conversion" of each DMU's inputs into outputs. A DMU's relative efficiency is calculated by comparing its production function with the estimated production frontier. Thus a DMU's performance is directly compared against the "best practice" of a peer or a combination of peers. DEA does not require an assumption of a functional form relating inputs to outputs. Further, inputs and outputs may have very different units. DEA has become a popular and powerful approach largely due to its ability to model multiple input and output relationships without a priori information about the trade-offs [2].

In this paper, each bus line is treated as a decision making unit (DMU). Adopted DEA model is the output-oriented BCC model (Banker et al., 1984), as the overall objective of a bus line is to serve as many passengers as possible [2]. Another reason why is chosen the BCC model is that it makes the variable returns to scale (VRS) assumption, which means that efficiency may increase or decrease with a change of size in input or output. The VRS assumption is more appropriate for bus lines with higher variability of productivity. Mathematically, VRS suggests that the estimated production frontier can pass anywhere relative to the origin in input–output space [2].

First it is necessary to define the model variables:

j: index of DMUs, $j = 1, \dots, n$,

i: index of input,, $i = 1, \dots, m$,

r: index of output, $r = 1, \dots, s$,

x_{ij}: the i-th input for DMU_j,

y_{rj}: the r-th output for DMU_j,

λ_j: the nonnegative scalars (weight) for DMU_j,

μ: the optimal output level.

Mathematically, the output-oriented BCC model (Banker et al., 1984) can be written as [2]:

$$Max\ \mu \tag{1}$$

$$s.t. \qquad x_{io} \geq \sum_{j=1}^{n} x_{ij}\lambda_j \quad i = 1,\ldots,m \tag{2}$$

$$y_{ro}\mu \leq \sum_{j=1}^{n} y_{rj}\lambda_j \quad r = 1,\ldots,s \tag{3}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{4}$$

$$\lambda_j \geq 0 \quad j = 1,\ldots,n \tag{5}$$

Since the model needs to be solved *n* times (once for every DMU), we use DMUo to represent one of the *n* DMUs under evaluation. x_{io} and y_{ro} are the i-th input and r-th output for DMUo, respectively. The DEA model essentially seeks to create the most efficient virtual DMU for a given DMUo, whose productivity is based on the linear combination of peer DMUs' input and output. The objective function (1) attempts to maximize the level of output for the virtual DMU. Constraint (2) sets the limit of input to no more than the observed amount of input. Constraint (3) specifies that the output level is at least as good as that of DMUo. Constraint (4) ensures that the DEA model's variable returns to scale (VRS) status. Constraint (5) imposes non-negativity restrictions for λ_j [2].
It may be noted that $\mu = 1.0$ is always a feasible solution to the DEA model. If it also turns out to be $\mu = 1.0$ the optimal solution, then DMU_o is technically efficient, since the model is unable to find a virtual DMU with a higher level of output without increasing the current level of input. If the optimal solution μ is greater than 1.0, then the DEA model has identified a virtual DMU that can perform better than DMU_o. This indicates that DMUo is not technically efficient. The higher the value of μ is, the less efficient the DMU_o is. The relative efficiency score of DMUo can be calculated as 1/ μ [2].

3.2. Impact of DEA model on operational efficiency

When is DEA model chosen, the next critical step is to select the input and output indicators for the DMUs. There are many variations in specifying input–output factors in DEA literature for assessing transportation agencies. Most commonly, labor, capital and energy are used as inputs; and vehicle-km, seat-km, or passenger-km are used as outputs (De Borger et al., 2002) [2].
By using the output-oriented BCC model (Banker et al., 1984.), in paper are taken into account the 15 urban bus routes in the city of Niš. Considering the values of inputs in terms of the Length of bus routes (L_{AB}+ L_{BA}), the number of bus stops (n_{AB}+n_{BA}), the average distance between bus stops (d_{sr}) and travel time (T_p) (Table 1) [3], the aim was to maximize the total number of passengers carried per day (P). The model is solved using the software MaxDEA [8].
The result of the DEA model is displayed in Table 1. Out of the 15 fixed routes, five bus lines are technically efficient (1/μ = 1.0); two bus lines are fairly efficient (1/μ > 0.6); and 8 bus lines are considered inefficient (1/μ<0.6). Why are there so many relatively inefficient bus routes? The most likely reason is that certain aspects of bus services, such as schedules, frequencies, or stop locations, are not adequate to meet the needs of users. As a result, only a very small portion of the target population is being served by buses. The second possibility is that part of the target population may not be interested in bus services as they are already well served by other means of transportation. Second, the presence of a very productive bus route, Line 1, has made many other bus lines appear very inefficient. First of all, most of these inefficient bus routes serving the area of Niš with a low population density. An example of this was Line 12. Line 38, length 15 of kilometers, representing a line in its characteristics and is not a typical city line. Line 34 was ineffective (1/μ=0.258187) because it was a circular line in one direction.

3.3. Impact of DEA model on quality of the transport services

As the basic unit for defining the characteristics of quality can be observed line of transportation that is an integral part of the overall UPPT system. Between quality of UPPT system and quality of transport service exists interdependence based on unifying the interests of service users, carriers and strategy development community, ie the overall transport system. Quality of public passenger transport is defined as the projected level of satisfaction of transport user needs, in which the system is designed on the basis of pre-defined quality characteristics.
By recording the departure times of all UPPT vehicles during the time of their functioning during the day in the UPPT system have been researched characteristics (indicators) of quality UPPT system. Quality indicators of UPPT (Table 2) which have been investigated by certain lines are as follows: F (veh/day) - Vehicles frequency, C (seats/day) - the Working capacity of the line, BTR_1 (veh.km/day) - Gross transport work, BTR_2 (seats.km/day) - Gross transport work and K_i-Coefficient of capacity line [3].
By using the output-oriented BCC model (Banker et al., 1984.), in paper are also taken into account the 15 urban bus routes in the city of Niš. Considering the values of inputs in terms of vehicles frequency, working capacity of lines, gross transport work and the coefficient of capacity lines (Table 2), the aim was to maximize the total number of passengers carried per day (P).
In Table 2 is displayed the result of the DEA model for quality of the transport services. It is interesting to note that 15 bus routes can be divided into two groups. 8 of them are technically efficient (1/μ = 1.0) while the remaining 7 lines fairly efficient (1/μ > 0.6). This indicates that the quality of the service provided was on high level and also that a large part of the services UPPT is not well understood by the local population.

3.4. Comparison of operational efficiency and quality of the transport services

The best way to obtain a comprehensive picture of bus line performance is to compare operational efficiency with quality of the transport services (Table 3). In other words, bus lines with high operational efficiency scores may or may not have high quality of the transport services scores, and vice versa. Therefore, were further examined the two performance scores for bus lines and search for implications

Table 1 Input, output indicators for the DEA model and calculated efficiency

Line No	Line name	$L_{AB}+L_{BA}$ (km)	$n_{AB}+n_{BA}$	d_{sr} (km)	T_p (min)	P (passengers/day)	Efficiency $1/\mu$
1	Niška Banja – Novo selo	17+17	26+28	0.654	62.2	41431	1
2	Bubanj – Donja Vrežina	7.1+7.1	18+15	0.394	53.0	16542	1
3	Mokranjčeva – N. R. Jović	6.7+6.7	15+15	0.447	46.7	5565	0.379373
5	Žel. stanica - Somborska	5.3+5.3	12+10	0.442	37.5	5632	0.668316
6	Žel. stanica - Duvanište	6.1+6.1	14+14	0.436	44.9	11259	0.867801
7	Trg Ka – Kalač brdo	3.2+3.2	9+9	0.356	21.2	477	1
8	Trg KA – Novo Groblje	6.1+6.1	9+9	0.678	36.4	2381	0.411592
9	Trg KA - Pribojska	4.5+4.5	11+11	0.409	34.1	3177	0.450144
9a	Trg KA – Donji Komren	5.2+5.2	11+11	0.473	36.1	2766	0.32805
10	Trg KA – Gabrovačka reka	5.1+5.1	14+14	0.364	34.8	1964	0.508926
11	Trg KA - Medoševac	3.5+3.3	7+6	0.500	28.4	834	1
12	Njegoševa – Tehnički fakulteti	4.55+4.0	12+8	0.379	37.5	163	0.038824
13	Trg KA – Ćele kula	4.4+4.4	11+11	0.400	37.3	7824	1
38	Mramor - Čalije	15+15	28+26	0.536	79.2	4534	0.150455
34	Aerodrom – Autobuska stanica – Žel. stanica - Aerodrom	20.88	45	0.464	71.5	6001	0.258187

Table 2 Input, output indicators for the DEA model and calculated efficiency

Line No.	Line name	F (veh/day)	C (seats/day)	BTR_1 (veh.km/day)	BTR_2 (seats.km/day)	K_i (-)	P (passengers/day)	Efficiency $1/\mu$
1	Niška Banja – Novo selo	193.0	33969.15	4299.80	756764.800	0.205	41431	1
2	Bubanj – Donja Vrežina	137.5	20660.57	1946.80	293380.11	0.155	16542	0.949449
3	Mokranjčeva – N. R. Jović	56.5	9351.49	757.5	125310.00	0.102	5565	0.775247
5	Žel. stanica - Somborska	71.3	9720.58	755.6	103038.10	0.12	5632	0.80187
6	Žel. stanica - Duvanište	114.5	11450.00	1396.90	139690.00	0.205	11259	1
7	Trg Ka – Kalač brdo	16.0	1600.00	102.4	10240.00	0.09	477	1
8	Trg KA – Novo Groblje	29.5	3097.50	359.9	37789.50	0.226	2381	0.967753
9	Trg KA - Pribojska	34.5	4455.00	310.5	40095.00	0.189	3177	1
9a	Trg KA – Donji Komren	30.0	4224.00	312	43929.60	0.155	2766	0.952799
10	Trg KA – Gabrovačka reka	33.0	3630.00	336.6	37026.00	0.16	1964	0.684834
11	Trg KA - Medoševac	20.0	2620.00	136	17816.00	0.112	834	0.913528
12	Njegoševa – Tehnički fakulteti	11.0	1100.00	94.6	9460.00	0.03	163	1
13	Trg KA – Ćele kula	84.0	11004.00	739.2	96835.20	0.168	7824	1
38	Mramor - Čalije	36.0	3912.33	1067.00	117370.00	0.172	4534	1
34	Aerodrom – Autobuska stanica – Žel. stanica - Aerodrom	63.0	5040.00	1348.20	107856.00	0.213	6001	1

Table 3 DEA results: Operational efficiency in relation to the quality of transport services

Line No.	Line name	Operational efficiency	Quality of transport services	Difference
1	Niška Banja – Novo selo	1	1	0
7	Trg KA – Kalač brdo	1	1	0
13	Trg KA – Ćele kula	1	1	0
2	Bubanj – Donja Vrežina	1	0.949449	0.050551
11	Trg KA – Medoševac	1	0.913528	0.086472
12	Njegoševa– Tehnički fakulteti	0.038824	1	-0.96118
38	Mramor – Čalije	0.150455	1	-0.84955
9	Trg KA – Pribojska	0.450144	1	-0.54986
6	Žel. stanica – Duvanište	0.867801	1	-0.1322
34	Aerodrom – Autobuska stanica – Žel. stanica – Aerodrom	0.258187	1	-0.74181
8	Trg KA – Novo Groblje	0.411592	0.967753	-0.55616
9a	Trg KA – Donji Komren	0.32805	0.952799	-0.62475
5	Žel. stanica – Somborska	0.668316	0.80187	-0.13355
10	Trg KA – Gabrovačka reka	0.508926	0.684834	-0.17591
3	Mokranjčeva – N. R. Jović	0.379373	0.775247	-0.39587

Table 4 Basic characteristics of the existing network of city lines

Line No.	Line name	L_{AB} (km)	n_{AB}	L_{BA} (km)	n_{BA}	d_{sr} (km)
1	Niška banja - Ledena stena	12.9	20	12.9	22	0.645
10	Ćele kula - Novo selo	9.7	17	9.7	19	0.571
2	Bubanj - Donja Vrežina	7.1	18	7.1	15	0.458
3	N.R. Jović - EI	9.1	17	9.1	16	0.587
4	Bubanj - Čalije	9.5	23	9.5	20	0.463
5	Železnička stanica - Somborska	5.3	12	5.3	10	0.530
6	Železnička stanica - Duvanište	6.1	14	6.1	14	0.469
7	Trg KA - Kalač brdo	3.2	9	3.2	9	0.400
8	Novo groblje - Gabrovačka reka	11.2	22	11.2	22	0.533
9	Trg KA - Pribojska	4.5	11	4.5	11	0.450
9a	Trg KA - Donji komren	5.2	11	5.2	11	0.520
11	Medoševac - Mokranjčeva	6.4	13	6.6	14	0.520
12	Donji Komren - Njegoševa	7.1	12	7.2	13	0.622
13	Trg KA - Ćele kula	4.4	11	4.4	11	0.440
34	Aerodrom - Autobuska stanica - Žel. stanica - Aerodrom	20.88	45	20.88	45	0.464

of their relationships.
The best-performing bus lines have very high scores in both operational efficiency and quality of the transport services. They are Lines 1, 7, 13, 2 and 11. Technically, these bus lines are located on or near the production frontier derived from the two DEA models. They provide benchmarks for performance evaluation. Specifically, Lines 1 and 13 are primary routes that serve major urban areas. Lines 7, 2 and 11 are routes which linking bigger settlements within the city of Niš.
Bus lines with very low operational efficiency and quality of the transport services scores are the worst performers that should be carefully re-planned or even eliminated. Seven bus lines belong to this category: Lines 12, 38, 9, 6, 34, 8 and 9a.
If are observed the resulting data carried DEA analysis (Table 3) and the current state of bus lines in Niš (Table 4) it can be observed some similarities:

- Lines 13, 7, 2, 6 and 5 have remained unchanged ($1/\mu > 0.6$).
- Lines 10 and 8 are modified in a single Line, Novo groblje - Gabrovačka reka.
- Introducing another direction on the Line 34 is justified because of the low value of the operational efficiency (0.258187).
- The quality of transport services is not influenced on the change lines, but only operational efficiency.

4. CONCLUSION

In this paper was used Data Envelopment Analysis (DEA) to examine operational efficiency and quality of transport services UPPT in Niš and analyzed the 15 urban bus lines. On the basis of the paper [2] and the data from listed Study [3], are formed the input and output indicators for DMUs. Each bus line is treated as a decision-making unit (DMU). DEA model used is output-oriented BCC model for the reason that the bus line service as many passengers as possible.
For operational efficiency has been taken: length of bus routes, the number of bus stops, the average distance between bus stops and travel time. In this paper was used real-time travelling as opposed to many other studies of public transport which used round distance as a measure of reasonable alternative real-time travel. For evaluating the quality of transport services as inputs were used: vehicles frequency, working capacity of the line, gross transport work, gross transport work and coefficient of capacity line. In both DEA model of operational efficiency and quality of transport services of UPPT in Niš, was adopted as the output indicator the total number of passengers carried per day and line.
The analysis shows that in the UPPT in Niš most efficient are bus lines 1, 7, 13, 2 and 11. Also, are given some recommendations related to the justification of changes in bus lines after conducting the Study. It can be concluded that the quality of transport services is not affected by the lines change.
It should be noted that this DEA models are based on a relatively small transit market. Therefore, the difference is not taken between the bus lines with different characteristics; otherwise the data set would be too small from the DEA modeling perspective. Performed research and the results in this paper, it should be noted, were obtained through two limitations. One is to treat each bus line independently and are not considered a transfer points between the bus lines. Current DEA model cannot easily account for the impact of interdependence within the transport system. Significant modification to the model may be needed to address this limitation in future research. The second limitation is in the form of lack data about the age structure of the users bus services relating to individual bus lines and therefore not carried out analysis of the impact of spatial effectiveness.

REFERENCES

[1] S. Filipović, S. Tica, P. Živanović, S. Bajčetić, "Izvodi iz izabranih predavanja iz predmeta Javni gradski transport putnika", Saobraćajni fakultet Beograd, 2009.

[2] Y. Lao, L. Liu, "Performance evaluation of bus lines with data envelopment analysis and geographic information systems", Computers, Environment and Urban Systems, 33, 2009, pp. 247–255.

[3] Filipović S., grupa autora, "Studija javnog gradskog i prigradskog prevoza putnika na teritoriji grada Niša", Naučno – istraživački projekat, Saobraćajni fakultet u Beogradu, 2007.

[4] G. Savić, M. Martić, S. Krčevinac, "Ograničavanje težina u DEA metodi", SYM-OP-IS '99, XXVI Jugoslovenski simpozijum o operacionim istraživanjima, Beograd, Zbornik radova, Beograd, 1999, pp. 15-18.

[5] M. Martić, S. Krčevinac, G. Savić, "Primena DEA metode za merenje efikasnosti i rangiranje bankarskih filijala", SYM-OP-IS '98, XXV Jugoslovenski simpozijum o operacionim istraživanjima, Zbornik radova, Herceg Novi, 1999, pp. 219- 222.

[6] M. P. Boilé, "Estimating technical and scale inefficiencies of public transit systems", Journal of Transportation Engineering, 127 (3), 2001, pp. 187–194.

[7] D. A. Tsamboulas, "Assessing performance under regulatory evolution: A European transit system perspective", Journal of Urban Planning and Development, 132 (4), 2006, pp. 226–234.

[8] http://www.maxdea.cn/

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MULTI-CRITERIA ANALYSIS OF ALTERNATIVE PROPULSION SYSTEMS FOR VEHICLES OF PUBLIC TRANSPORT PASSENGERS IN NIŠ

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Abstract

Environmentally cleaner system of public passengers transport is imperative for sustainable development of cities. Vehicles with conventional propulsion, in which includes most of the city bus transport of passengers, are one of the major causes of urban pollution and emissions in cities. Considering that is necessary to introduce alternative propulsion systems in public transport, and there are a number of limitations and uncertainties, it is a decision on the selection of appropriate alternatives are very complex. In paper, with TOPSIS method, according to the adopted criteria, is carried out multi-criteria ranking of alternative propulsion systems and fuels for buses and additional sub-urban public passenger transport with electric propulsion (trolleybus and tram).

***Keywords**: TOPSIS, Urban Public Passenger Transport, alternative fuels.*

1. INTRODUCTION

Key problems of humanity are lack of energy and environmental pollution. Increase mobility while reducing pollution, congestion and accidents are the challenges faced by most European cities. The European Commission is in the White Paper 2011th recommends that it is necessary to halve the use of "conventionally powered" cars in urban transport to the 2030th, remove them from the towns in 2050th, and introduce alternative propulsion systems and fuels in the fleet of city buses. Public passenger transport in the city is a significant energy consumer and polluter of the environment and therefore need to be improved. At the Faculty of Mechanical Engineering has conducted research of public passenger transport in the city of Niš, which is performed on the lines of a total length of 134 km, with 124 buses that annually exceed about 8.8 million km. Accordingly, this paper set the goal to perform multi-criteria analysis of alternative propulsion systems and fuels for buses, to be included in the analysis, and other forms of transport, trolleybus and tram, make ranking adopted alternatives and determine the best alternative that corresponds to the adopted criteria. Used alternatives and criteria are adopted based on the review of foreign scientific and technical literature and by expert estimates of authors.

2. URBAN PUBLIC PASSENGER TRANSPORT

Urban Public Passenger Transport (UPPT) provides transportation services available to all users by pre-defined and well-known operating conditions. The role of public transportation is important for all the cities, especially to solve the problem of traffic in the central city area.
Urban transport is responsible for about a quarter of carbon dioxide emissions in the transport [1]. Gradually removal of vehicles with conventional fuels from the urban areas is a major contribution to reducing the large oil dependence, greenhouse gas emissions, pollution and noise. To ensure this, it is necessary to introduce a new vehicle with appropriate alternative sources of energy. Considering that the vehicles of public transportation are major "polluters", the introduction of alternative energy sources is particularly effective in the fleet of city buses.

2.1. Bus subsystem of UPPT

Bus subsystem of UPPT is today the most widely used technology in passenger transport, with the basic characteristics of the autonomous movement of the vehicle, with the power unit as energy commonly used conventional fossil fuel (oil) or today the so-called alternative energy sources (natural gas, renewable biofuels (biodiesel, ethanol, biogas), hydrogen, etc.) [2].
Bus subsystem has a wide range of vehicles by capacity and performance (type of propulsion energy, engine, transmission, ergonomic elements, body, etc.), whose application depends on the transport requirements of the line, the morphological structure of the city (above all configuration of the terrain and street network), type of the route line, the desired quality of service, etc. [2].
Nowadays, increasingly, the buses are divide by type of propulsion energy which vehicle use, ie:

- *Bus with conventional diesel engine (oil).* Conventional diesel buses represent the solution that in Serbia used to transport passengers in over 99% of cases [3]. Represents a major source of environmental pollutants in urban conditions, especially particulate pollution and nitrogen oxide. Today, after the famous energy crisis in the world and the most harmful emissions buses with diesel engine, the more it comes to finding new technological solutions based on the application of new type of propulsion (alternative fuels), improving the combustion process, ie reduce emissions of pollutants.

• *Bus powered by Compressed Natural Gas-CNG or Liquid Natural Gas - LNG.* A technology vehicle with compressed natural gas is already commercialized around the world and there are about four million CNG vehicles in the world. Vehicle to compressed natural gas is widespread in countries with their own natural gas. This vehicle emits only small amounts of carbon dioxide, has a high-octane value and is suitable for use as a public transport vehicle. A large number of buses powered by compressed natural gas are present in EU cities: Rome (400) Madrid (381), Barcelona (300) Torino (222), Porto (255), Lille (167), and Paris (130) [3]. In Belgrade, the use of gas-powered buses carried only in research/experimental purposes, while is in Novi Sad from 2011th in the implementation six buses on compressed natural gas. Natural gas supply, distribution, and security are issues that require improvement [4]. In Japan, Italy and Canada as much as 7% of buses is powered by LNG and some European countries are planning to introduce LNG in vehicles to reduce pollution [5].

• *Bus powered by renewable biofuels (biodiesel, ethanol and biogas).* Biodiesel is a liquid form of renewable energy derived from biomass, ie oil obtained from the seeds of oil crops. Characteristics of biodiesel are similar to diesel fossil and improvement comes from the oxygen content in biodiesel, which provides better combustion process and improves lubrication, which partly compensates for the impact of lower energy content. Because biodiesel is technically perfect substitute for fossil diesel and no significant modification of the diesel engine are not needed.

• *Hybrid electric bus with diesel engine.* Hybrid propulsion of buses means the two power units that use different sources of energy. Propulsion system of hybrid vehicles consists of the internal combustion engine, electric generator, electric motor, power converters and battery. In addition, the combustion engine powered the alternator which supplies the electric motor power of 100 -150 kW. The excess of electricity is stored in batteries, allowing independent movement of vehicles on the route 5-10 km, and when driving downhill, braking and stopping, the engine further complements the battery [4]. In some cities, such as Berlin, Brislel, London and Paris began the use of buses with a combined (hybrid) diesel-electric drive.

• *Bus powered by hydrogen (H_2).* Fuel cells are electrochemical devices for the immediate conversion of chemical energy, contained in some chemical element or compound, in DC electricity [3]. As a fuel is commonly used hydrogen in the tanks located in the liquid or gaseous state. Application of hydrogen as drive fuel buses has not been widespread, despite the great potential that lies primarily in the zero emissions of pollutants. All the world's leading vehicle manufacturers have long been working on the development of fuel cell powered vehicles. Mercedes has 35 buses experimentally put into operation in different cities of the world, in order to test the application of fuel cells.

• *Bus powered by electricity.* Implies an autonomous vehicle that is powered by electricity, which is stored in the battery of the vehicle. Electric vehicles are extensively developed for large manufacturers in the world, and special emphasis is the development of highly capacitive battery. Bus with electric DC motor has very favorable operating characteristics due simple control of the drive torque. A key issue in the exploitation of this category bus is the restoration of electricity sources (battery). In principle, this solved in two ways: recharging discharged batteries or replacing discharged battery with charged [5]. Restoration of electricity sources is still a major disadvantage of this technology.

2.2. Trolleybus subsystem of UPPT

Trolleybus subsystem is the subsystem of UPPT very similar to the bus subsystem, which is characterized by a vehicle with electric powered on tires (rubber wheels), which is in constant conjunction with a two-wire air-contact line via trolley electricity.

Today trolleybus subsystem experienced an expansion in cities around the world, while in 86 cities of the EU appears as the main form of transportation [2]. In the Russian Federation, today there are 89 systems with 14,110 vehicles, with the Moscow trolleybus subsystem as the largest in the world, with 2,032 vehicles. Beside him in EU the most developed trolleybus subsystem is in Athens with 315 vehicles. In Italy and Switzerland, there are a 15 and 14 trolleybus companies with cutting-edge technology, and these two countries are leading in developing trolleybus technology, while in many other countries, this form of transport again introduced or plans to introduce it [2].

Some of the major advantages of trolleybus subsystem of UPPT over conventional bus are [2]: 1. Environmentally friendly, without harmful emissions and the lowest noise level in comparison to other forms of public transport, 2. Economic (cost) more effective than conventional bus, because it uses renewable energy sources, 3. Cost effective due to increase the average life expectancy of exploitation trolley (about 15 years) compared to buses, etc.

Disadvantages of trolleybus subsystem of UPPT compared to traditional bus are: 1. Higher level of investment costs in relation to bus subsystem for about 10%, 2. Power supply network requires maintenance, 3. Less flexible compared to the bus subsystem, and so on.

2.3. Tram subsystem of UPPT

Today, electricity is the dominant form of propulsion power in the rail sub-UPPT. This type of propulsion energy gives excellent dynamic performance of the vehicle. Engines are very clean and suitable for maintenance. Environmentally is friendly and provides absolutely the possibility of energy recovery during braking.

Tram subsystem represents this form of rail subsystems UPPT, within which work vehicles-trams along a fixed routes according to the timetable. Trams as propulsion power use electrical energy obtained through constant contact electric trolley (pantograph) and air contact line [2].

3. MULTI-CRITERIA DECISION METHODS

From the sixties until today, is developed a large number of methods, which can be more or less successfully to solve most real problems of multi-criteria analysis. According to the type of information, all methods are divided into two groups [6]. The first group are the methods without information about the criteria: method of domination, MAXIMIN method, MAXIMAX method. The second group are the methods that require certain information about the criteria: Conjunctive, Disjunctive, ELECTRE, TOPSIS, PROMETHEE, and so on.

In order to take a good decision, it is necessary to specify the alternatives by defining of appropriate criteria. It is also necessary to define the weight coefficients of each criterion, ie the importance of each criterion relative to the other. The weight coefficients are numbers that can be obtained by any of the following methods: Eigenvector, Minimum weighted squares method, Entropy method, etc.
In addition, for each criterion is determined whether it is necessary choose an alternative so that criterion be minimum or maximum, ie what is the nature of this criteria. Thereafter, by each criterion are especially evaluated alternatives on the basis exactly determined of parameters or subjective evaluation. The way in which are presented those evaluations depends on the chosen method which is used for solving problems.
In this paper will be used the entropy method, which is explained in detail in [7], to determine the weight coefficients and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method for ranking the alternatives which is described in [8].

4. MULTI-CRITERIA ANALYSIS OF ALTERNATIVE PROPULSION SYSTEMS AND FUELS FOR PUBLIC TRANSPORT PASSENGERS IN NIŠ

The aim is to perform multi-criteria analysis of alternative propulsion systems and fuels for buses in the city of Niš, as well as that are in the analysis includes additional subsystems UPPT with electric propulsion, trolleybus and tram, make a ranking of the adopted alternatives and determine the best alternative that corresponds to the adopted criteria.
Alternative solutions considered in this paper are:

a_1 - Bus with conventional diesel engine (oil);
a_2 - Bus powered by Compressed Natural Gas-CNG or Liquid Natural Gas - LNG;
a_3 - Bus powered by renewable biofuels (biodiesel);
a_4 - Hybrid electric bus with diesel engine;
a_5 - Bus powered by electricity;
a_6 - Bus powered by hydrogen (H_2);
a_7 - Trolleybus like subsystem of UPPT with electric propulsion;
a_8 - Tram like subsystem of UPPT with electric propulsion.

The criteria that are taken for evaluation of alternative propulsion systems and modes of transport for the public transport of passengers in Niš:

f_1 - Energy supply;
f_2 - Energy efficiency;
f_3 - Air pollution; (PM, NO_x, HC, CO, CO_2) - respectively (f_3, f_4, f_5, f_6, f_7) - variant I
f_4 - Noise;
f_5 - Technical characteristics of the vehicle (Vehicle capacity, power, acceleration, braking, comfort, average speed);
f_6 - Investment costs (price of the vehicle);
f_7 - Maintenance costs;
f_8 - Inclusion the domestic industry.

Considering that air pollution is treated as the most important criterion, that the analysis is performed in two ways, primarily with 12 criterion (variant I) where are individually considered PM, NO_x, HC, CO and CO_2, respectively as criteria f_3, f_4, f_5, f_6 and f_7 (Table 1), and the second (variant II) in which is used as a criterion of air pollution f_3 only CO_2 (Table 2).
During the formation of the matrix of decision making, it is often the case that the criteria values for each alternative by certain criteria represent as qualitative value. There is the problem how to perform comparison qualitative with quantitative criteria values. For overcoming the above mentioned problem, is done so called quantification of qualitative criteria, ie translating qualitative criteria in a quantitative. There are various ways of translating qualitative attribute values in quantitative: ordinal scale, interval scale and ratio scale.
As the usually applies interval scale, this method is used and in this paper to translate qualitative values to quantitative. The range of the scale is in the interval from 1 to 9. Values 0 and 10, are not included because are do not know the explicit extreme values of the observed criterion.
Criterion f_1 - Energy supply. Evaluation of this criterion (min-1, max-9) is based on the possibility of providing energy, the cost of providing energy resources, developed infrastructure, supplies, etc. Evaluation performed by the information from [5] and the personal evaluation for trolleybuses and trams.
Criterion f_2 - Energy efficiency. Evaluation made based on information from [5] and [9]; for trolleybuses and trams used the relation: *1 liter of diesel fuel = 3.67 kWh*.
Criterion f_3 - Air pollution. Evaluation carried out on the basis of data on maximum measurements of gas emissions given in the literature [5] and [4]. (*Note - values * were adopted 50% less than the alternative A_1).*
Criterion f_4 - Noise [dB]. Evaluation made based on information from [5] and personal evaluation for trolleybus and tram.
Criterion f_5 - Technical characteristics of the vehicle (Vehicle capacity, power, acceleration, braking, comfort, average speed). Evaluation carried out on the basis of [5] and personal evaluation for trolleybus and tram, where it was taken into account that the capacity the tram is greater than bus.
Criterion f_6 - Investment costs (price of the vehicle). Information from the [5], [9] and [10].
Criterion f_7 - Maintenance costs [$]. Evaluation made based on information from [5] and personal evaluation for trolleybus and tram.
Criterion f_8 - Inclusion the domestic industry. Evaluation carried out on the basis of personal evaluation.
On the basis of the adopted alternatives and criteria are established quantified decision matrixes for I and II variant, by using which to determine weight coefficients of individual criteria influence at the adopted alternatives and conduct multi-criteria decision making procedure.
Assign the appropriate set of weight coefficients is the way of transformation that is used in cases where multi-criteria decision making problems require information about the relative importance of individual criteria. Weighting coefficients for both variants are calculated using entropy method.
As input data is used quantified decision matrix which is normalized, ie its members are reduced to the interval from zero to one. Then, such a normalized matrix is multiplied by the weighting coefficients, calculated relative closeness which represents the compromise between proximity ideal and negative ideal point for each alternative separately and formed rank alternatives.

Table 1 Analysis with the 12 criteria (variant I) where are individually considered PM, NO_x, HC, CO i CO_2 respectively

	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12	TOPSIS (S_i)	Ranking
	max	max	min	min	min	min	min	max	max	min	min	max		
Weight coefficient	0.0195	0.0896	0.2294	0.1275	0.1874	0.1048	0.1147	0.0009	0.0032	0.0915	0.0118	0.0199		
A1	7	1.0	1.26	15.66	1.30	10.23	1700	0.42	0.79	100000	11400	7	**0.387991461**	**8**
A2	5	0.8	0.02	7.25	9.87	0.73	1400	0.55	0.73	300000	10410	6	**0.53598002**	**7**
A3	2	0.8	0.07	4.28	1.31	5.25	1.8	0.58	0.52	120000	14700	6	**0.757568759**	**4**
A4	5	1.5	0.23	8.64	0.65	5.12	1.1	0.58	0.67	360000	22200	5	**0.721169**	**6**
A5	5	10.9	0.00	0.00	0.00	0.00	300	0.59	0.47	300000	18495	2	**0.948299654**	**1**
A6	1	1.9	0.00	0.03	0.32	6.23	200	0.58	0.56	600000	30720	1	**0.784973559**	**3**
A7	3	1.1	0.00	0.00	0.00	0.00	300	0.58	0.50	300000	10000	3	**0.808275333**	**2**
A8	3	1.5	0.00	0.00	0.00	0.00	100	0.50	0.80	2500000	15000	4	**0.746367995**	**5**

Table 2 Analysis with the 8 criteria (variant II) where is considered only CO_2

	f1	f2	f3	f4	f5	f6	f7	f8	TOPSIS (S_i)	Ranking
	max	max	min	max	max	min	min	max		
Weight coefficient	0.0555	0.2552	0.3268	0.0025	0.0091	0.2607	0.0335	0.0567		
A1	7	1.0	1700	0.42	0.79	100000	11400	7	**0.419507073**	**8**
A2	5	0.8	1400	0.55	0.73	300000	10410	6	**0.422704073**	**7**
A3	2	0.8	1.8	0.58	0.52	120000	14700	6	**0.600073734**	**3**
A4	5	1.5	1.1	0.58	0.67	360000	22200	5	**0.605292742**	**2**
A5	5	10.9	300	0.59	0.47	300000	18495	2	**0.875076042**	**1**
A6	1	1.9	200	0.58	0.56	600000	30720	1	**0.574804237**	**4**
A7	3	1.1	300	0.58	0.50	300000	10000	3	**0.568616091**	**5**
A8	3	1.5	100	0.50	0.80	2500000	15000	4	**0.423927569**	**6**

Topsis method was found, in both variants of criteria decision making, it is the best alternative A_5 (Bus powered by electricity). Also in both variants is the worst evaluated bus with conventional diesel engine (oil). Alternative solutions, A_3-Bus powered by renewable biofuels (biodiesel), A_4-Hybrid electric bus with diesel engine, A_6-Bus powered by hydrogen (H_2) and A_7-Trolleybus like subsystem of UPPT with electric propulsion, are evaluated as good solutions.

5. CONCLUSION

Within the paper was performed multi-criteria analysis of various subsystems UPPT, buses with conventional diesel engines and with alternative propulsion as well as the subsystem trolleybuses and trams. From alternative propulsion of bus, were considered propulsion at natural gas and biofuels, then diesel-electric ie hybrid, electric and hydrogen. The criteria according which the alternatives are evaluated were: Energy supply, Energy efficiency, Noise, Technical characteristics of the vehicle, Investment costs, Maintenance costs, Inclusion the domestic industry and as the most important criterion air pollution. TOPSIS method was found that is the best alternative - bus powered by electricity. However, bus powered by electricity is not yet technically developed for mass use because of unresolved issues needs for frequent recharging. That is why alternative solutions, such as bus at bio-diesel and hybrid propulsion, have exceptional significance for short term/immediate solutions. Propulsion on hydrogen is propulsion of future, but it is still in the development phase. The complexity of transport in cities is often poorly understood, and the impact of transport in urban areas is often underestimated. The goal of transportation planning should be not only efficient transport system, already and creation of modern cities with good and quality life, which implies a high level of mobility but also and clean air.

REFERENCES

[1] V. Stamenković, “Održivi razvoj transporta putnika u gradovima”, master rad, Mašinski fakultet u Nišu, 2012.

[2] S. Filipović, S. Tica, P. Živanović, S. Bajčetić, “Izvodi iz izabranih predavanja iz predmeta Javni gradski transport putnika”, Saobraćajni fakultet Beograd, 2009.

[3] I. S. Ivković, “Istraživanje performansi autobusa sa pogonom na komprimovani prirodni gas sa stanovišta bezbednosti i uticaja na životnu sredinu”, doktorska disertacija, Saobraćajni fakultet Beograd, 2012.

[4] S. Mišanović, “Strategije korišćenja ekološki čistih i energetski efikasnih autobusa za JGP u gradovima EU, sa osvrtom na iskustva GSP"Beograd”, UITP-Bus Committe, Brussels-Belgium, HCV - FP7 EC, Hybrid User Forum 2011-2013.

[5] Gwo-Hshiung Tzenga, Cheng-Wei Lina, S. Opricovic, "Multi - criteria analysis of alternative-fuel buses for public transportation", ELSEVIER, Energy Policy 33, 2005, pp. 1373-1383.

[6] S.J. Chen, C.L. Hwang, “Fuzzy Multiple Attribute Decision Making: Methods and Applications”, Lecture Notes in Economics and Mathematical Systems, No. 375, Sringer-Verlag, Berlin, Germany, 1991.

[7] M. Milićević, G. Županac, “Objektivni pristup određivanju težina kriterijuma”, Vojnotehnički glasnik/military technical courier, Vol. LX, No.1, 2012.

[8] M. Zeleny, “Multiple Criteria Decision Making”, McGraw-Hill, New York, 1982.

[9] M. Ristić, “Mogućnost uvođenja trolejbusa u javni gradski prevoz putnika u Nišu”, diplomski rad, Mašinski fakultet u Nišu, 2011.

[10] V. Vučić, “Javni gradski prevoz - sistemi i tehnika”, Naučna knjiga, Beograd, 1987.

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SCENARIOS ACCIDENTS AND RISK ASSESSMENT MODEL IN THE TRANSPORT OF DANGEROUS GOODS BY RAIL

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Abstract

In this paper attention is focused on the problem of transport of dangerous goods by rail. The subject of the research is to make decisions in an accident when not all the parameters known on the basis of which decisions are made, or when they have to predict future events while not known probability events. The basic hypothesis of which is based on the analysis of the risk that the emergence and development of the accidents are conditioned to sudden, unforeseen and unexpected circumstances of high risk, and is often therefore can not be analyzed and solved on the basis of past experience. The aim of this study is that using risk analysis techniques provide support for evaluations, and the uncertainty embedded in the problems of transport of hazardous materials treated with fuzzy logic.

***Keywords**: Rail transport, hazardous materials, risk management, fuzzy approach, scenarios accident*

1. INTRODUCTION

This paper considers the scenario of an accident during the transport of dangerous goods between loading and unloading, and the proposed method estimates the accident scenarios. Presented is the application of fuzzy logic model for risk assessment, the application of which is possible in real time and can be used to support the dispatcher in making decisions. Using fuzzy logic, the risk is determined based on the probability of an accident, damage from accidents and population density. Also, three different routes of transportation of sulfuric acid, between Novi Sad and Sombor, for the factory in Sombor, was performed a risk assessment and presented the advantages and disadvantages of the present solutions. Risk assessment in this case was made on the basis of the length of the transportation route, the quality of lines, types of transport vessel, the area of chemical exposure and population density.

2. SCENARIOS FOR ACCIDENTS IN RELATION LOADING AND UNLOADING OF DANGEROUS GOODS

The problem of managing environmental risk in the production, use and transportation of hazardous materials is a topical issue in the world and in Serbia. We have a large number of plants in which within the ordinary activities of products and apply hazardous materials, perform transport, storing and saving, so there is a constant potential danger of uncontrolled product to reach in the environment. A particular problem is the fact that you can not predict when it will occur and the location where the accident occur.

In the process of transport of dangerous goods there are several places where accidents can occur. On the way from the loading to the unloading of hazardous materials, we can define the following "critical point":

-the place of loading, the industry,
-shunting movement,
-the first technical station,
-transport to the next technical station,
-the second technical station,
-the place of unloading, the industry.

For each specified critical point, routing of dangerous goods, can be determined the activities that can cause an accident as well as possible consequences. Thus, at the loading terminal, the critical activities are:

-loading, and
-formation shunting composition.

When loading, an accident can cause damaged device for loading, transport vessel that is damaged, damaged packaging as well as the failure of workers. In the case of damaged packaging can occur spills of hazardous materials (with or without evaporation), fire (with or without evaporation), but there is a possibility that damaged packaging will not cause either one, depending on the characteristics of hazardous substances.

Freight trains can be in transit some technical stations (no re-forming). In this case, performed only the reception, processing and dispatch which is significantly different from re-forming of the train that includes: combining, collection , forming a train and provision on departure track.

3. ESTIMATES OF SCENARIO ACCIDENT

Given the complexity of the issues under consideration and the lack of a database on the Serbian Railways, estimates of accident scenarios can be achieved based on fuzzy logic.

3.1 Application of fuzzy logic for assessing scenarios of accidents

Fuzzy logic provides a different approach to control and classification problems. This method focuses on what the system should do, not modeled mode. Also, fuzzy logic can concentrate on solving the problem rather than the mathematical modeling of the system, even when it is possible. On the other hand, fuzzy approach requires expert knowledge for the formulation of the rule base, a combination of fuzzy sets and defuzzification. Generally, the use of fuzzy logic can be useful for very complex

process, when we do not have a simple mathematical model (eg. risk assessment in the transport of dangerous goods), for a non-linear process or if you need to be committed processing (linguistic formulation) of expert knowledge.
The basic element of fuzzy logic is fazzy set which can present each activity during transport of hazardous materials (Scheme 1). Display characteristic features fazzy set is given in Figure 1.

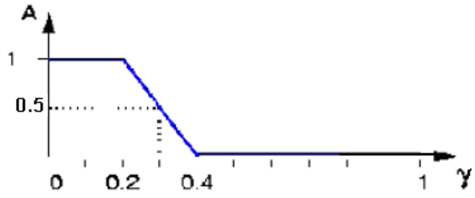

Fig. 1 The characteristic function of fuzzy sets

3.1.2 Application of fuzzy logic for assessing risk

Risk assessment with fuzzy logic does not require a large sample, and the results obtained thereby are applicable in real-time. Therefore, the fuzzy logic is suitable for Serbian Railways, because does not have an adequate database on accidents.
The Scheme 1 shows the factors affecting the risk when transporting hazardous materials. As the train can be considered a robot operated by a man, we have a surface for modify of the scheme, and so we get the base variables of fuzzy model.

RISK	**Traffic**	- Railway (substructure and superstructure, signalling) - Vehicle (stability, maintenance) - Organization (management, technical support) - Availability of infrastructure
	Vehicle	- Tank container - Tank wagon - Freight flat car (series S and R) - Box car (series G and H)
	Transhipment place	- Industry track (test and maintenance) - Equipment (fire extinguishers, systems for detection and fire fighting, hydrant network) - Inspection and testing equipment
	Transfer of information	- SNCF signalling device - Remote control - Remote control of fixed installations - Integrated systems
	The human factor	- Competence - Education - Motivation
	Physical barriers	- Mountains - Tress - Buildings - High voltage power lines
	Weather conditions	- Temperature (cold, hot, ice) - Rainfall (rain, snow, sleet, fog) - Turbulence (wind, air currents)
	Terrorism	- Army - Police - Civilians

Scheme 1. Factors affecting the risk when transporting hazardous materials

In the process of risk assessment, the risk of an accident is usually determined by *the probability of accidents* and *the possible consequences* for the life and health of people and the environment (Fig. 2 and 3).
As a third input variable is taken *population density* (Fig. 4).

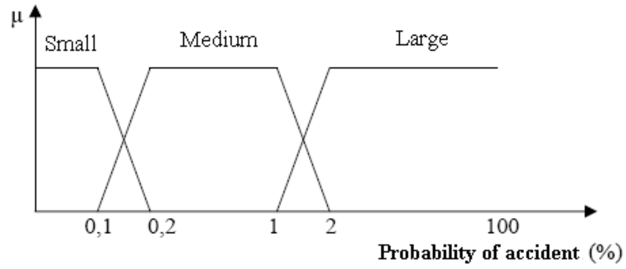

Fig. 2 Membership functions of fuzzy sets "Small", "Medium" i "High" probability of an accident

Possible consequences of the accident, which are expressed over damage from accidents, combines the death toll, the number of injured, dead domestic animals, dead wild animals, dead fish and surface contamination, as well as costs for their rehabilitation and payment of compensation. Possible consequences may be insignificant, significant and big.

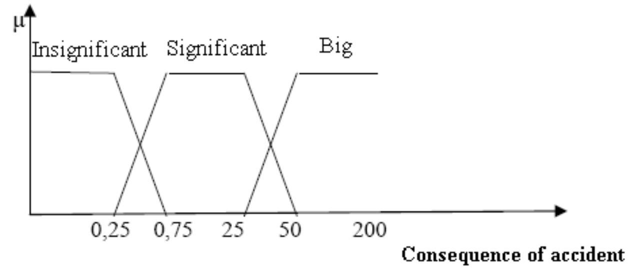

Fig. 3 Membership functions of fuzzy sets "Insignificant", "Significant" and "Big" consequences of accident

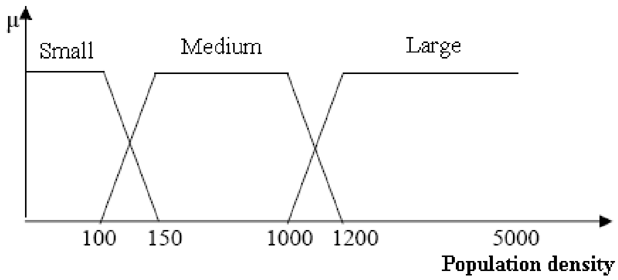

Fig. 4 Membership functions of fuzzy sets "Small", „Medium " and "Large" population density

For these input variables (probability of an accident, the possible consequences of accidents and population density) output variable is the *risk of accidents* that can be insignificant, small, medium, large and very large (Fig. 5).

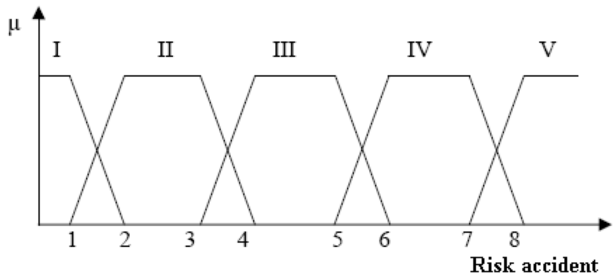

Fig. 5 Membership functions of fuzzy sets "Insignificant", "Small", "Medium", "High" and "Very high" risk accident

To solve this problem for fuzzy risk assessment in the transport of hazardous materials has been used UnFuzzy software which is based on fuzzy logic systems.

The values of the risk of accidents for different values of the probability of an accident, the potential consequences of accidents and population density are shown in Table 1.

Table 1. The values of the risk of accidents for different values of the probability of an accident, the potential consequences of accidents and population density

Probability of accident	Possible consequences of the accident	Population density	Risk of accident	Fuzzy risk value
0,01	24	250	4,500090	Medium
0,056	0,24	25	0,759160	Insignificant
0,9	100	1500	8,751930	Very large
1,5	0,38	50	5,063097	Medium
2	39	50	7,769886	Very large
0,01	5	68	2,499990	Small
0,121	0,12	0	1,313116	Insignificant
0,121	20	0	2,964181	Small
28	15	100	6,500026	Large

For different values of the input variables we get different values of output variables. Risk values obtained by using fuzzy logic is a measure the degree of an accident, and does not give us the answer to the question of whether the accident to come or not, but can help in taking measures of prevention, preparedness and response to accidents. This model can be used to support the dispatcher in making decisions.

4. RISK ASSESSMENT MODEL FOR THE DIFFERENT TRANSPORTATION ROUTES

Under current conditions 35-40% of transported consignments of goods from Serbia are the categories of dangerous goods (according to RID). It is real to expect an increase in the quantity of hazardous materials in transportation, and thereby increasing the risk of accidents. This increase is related to the transport of both domestic and international traffic. Therefore, it is very important to risk assessment for the route carrying hazardous materials because the only way we can establish guidelines for future action, to preserve the health and life of humans and the environment.

In this part of the work was carried out risk assessments for three railway routes to transport sulfuric acid from Novi Sad to Sombor, for the factory in Sombor. The main variables that are considered as:

-the length of the transportation route,
-the quality of lines,
-type of transport vessel,
-the area of chemical exposure and
-population density.

4.1 Risk analysis model

A formal definition of risk is the multiplication of the probability of an event by the consequence of that event. In the context of railroad hazardous materials transportation, risk (*R*) is defined as followed:

$$R = P_R \cdot P_C \cdot C \tag{1}$$

where:

P_R - probability that a tank car is involved in a release accident
P_C - probability of a particular release scenario occurring
C - consequence level (defined here as the number of people affected)

Each element in the risk calculation will be discussed in the following sections. In Section 4.5, the expected risk is calculated by considering all possible scenarios as follows:

$$R = \sum_{ijk} P_R \cdot P_{C_{ijk}} \cdot C_{ijk} \tag{2}$$

where:

i - small or large spill size
j - atmospheric condition (day or night)
k - population density classes

4.2 Tank car design features for transport of sulfuric acid

Sulfuric acid is transported by tankers Zas. These are Z quad car capable of transportation of hazardous materials at a maximum speed of 100 km/h. Their capacity is 60m^3 and the weight of 24.3 t.

4.3 Rail route features

Route-specific variables considered in this analysis include the track classes by length, total length and population density distribution. Transport of sulfuric acid from Novi Sad and Sombor can be achieved through Vrbas, Odžaci and Bogojevo. In the following will be assumed certain data in order to indicate the influence of parameters at risk during the transport of dangerous goods. For purposes of analysis it is assumed that the transport route across the Vrbas in good condition and passes through urban areas. Transport route across the Odžaci is of poor quality of the road over Bogojeva. Both go through the suburban and rural areas. Length of the first route is 96 km, second 110 km and third 125 km.

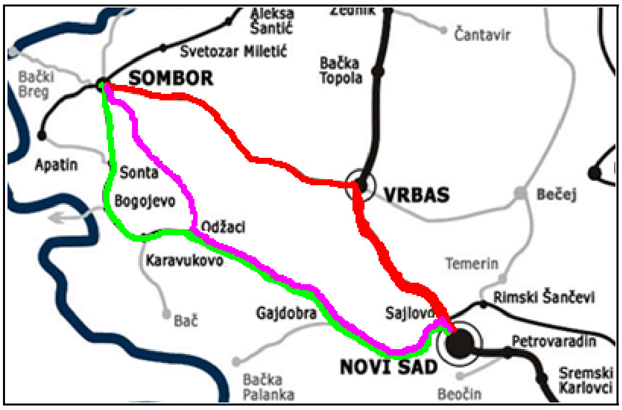

Fig. 6 Route Map

4.4 Accident caused release

The estimated rate of release for a tank car (P_R) is a product of the conditional probability of release given the car ($P_{R/A}$) and the accident rate (Z), defined as follows:

$$P_R = P_{R/A} \cdot Z \qquad (3)$$

$$Z = P_A \cdot M$$

where:

P_A - tank car derailment rate per kilometer
M - number of vehicle kilometre

$$M = S \cdot L$$

where:

S - number of shipments
L - route specific distance per shipment

4.4.1 Conditional probability of release, $P_{R/A}$

The conditional probability of release tank cars ($P_{R/A}$) serial number Zas is assumed to be 0,05 and it is determined by analyzing the statistical data, which unfortunately are not available.

4.4.2 Number of vehicle kilometre, M

If it is assumed that the delivery of sulfuric acid from Novi Sad to Sombor daily basis, then the number of shipment monthly 30. Number of vehicle kilometre is obtained by multiplying the number of shipments with route length:

-first route - 30 · 96 = 2880 vehicle kilometre
-second route - 30 · 110 = 3300 vehicle kilometre
-third route - 30 · 125 = 3750 vehicle kilometre

4.4.3 Tank car accident rate, P_A

Anderson & Barkan analyzed accident data for use in hazardous materials transportation risk analysis. Their work updated and extended previous work by Nayak and Treichel & Barkan that found that derailment rate was inversely correlated with track class.

The accident rate for tank car per kilometer (P_A) is determined in this analysis for each specific route as follows:

$$P_A = \sum_f P_{Af} \cdot \frac{L_f}{\sum_f L_f} \qquad (4)$$

where:

P_{Af} - accident rate for a tank car on track class f
L_f - total length of track class f

In this work accident rate for tank car serial number Zas on first route is $19 \cdot 10^{-6}$ vehicle kilometre, on second $47 \cdot 10^{-6}$ vehicle kilometre and on third $35 \cdot 10^{-6}$ vehicle kilometre.

4.4.4 Probability of release, P_R

Conditional probabilities of release ($P_{R/A}$) are multiplied by the number of vehicle kilometre (M) and the tank car accident rate (P_A) (Table 1.) to estimate the probabilities of release (P_R), were used for the risk estimation.

Table 2. Probability of release, P_R

Route	Tank car	$P_{R/A}$	P_A	M	P_R
First route	Zas	0,05	$19 \cdot 10^{-6}$	2880	0,002736
Second route	Zas	0,05	$47 \cdot 10^{-6}$	3300	0,007755
Third route	Zas	0,05	$35 \cdot 10^{-6}$	3750	0,006562

4.5 Release consequences

Possible levels of consequences are determined by multiplying the hazard exposure area for all of the scenarios considered in the following section with population densities as described in Section 4.5.2.

4.5.1 Hazard exposure model

The Department of Transportation Emergency Guide Response Guidebook (ERG)'s hazard exposure model was used in this analysis [3]. The affected area is defined as the area in which population must be evacuated and/or sheltered in-place. Thus the risk metric used in this analysis is the number of people likely to be affected. The area is calculated for four different scenarios as specified by the ERG (Table 3.).

Table 3. Exposure Areas for sulfuric acid

Atmospheric condition	Spill size (km^2)	
	Small	**Large**
Dan	0,041	2,286
Noć	0,641	21,196

It is assumed that sulfuric acid in the area is equally likely to occur during the day or night and thus, a 0.5 probability was assigned to these two atmospheric conditions. The proportion of "large" vs. "small" releases was determined using the quantity lost distribution for pressure tank cars in mainline accidents. We classified releases of 5% or less of a car's capacity as small spills, and releases of more than 5% as large spills.

4.5.2 Population exposure

As mentioned above, it is assumed that the first version of the route has the highest proportion of trackage trought urban areas, while the second and third variant routes have the highest proportion of trackage through suburban and rural areas. We assume that the population density for first version is 2000 people/km^2, for the second 400 people/km^2 and for the third 700 people/km^2.

4.5.3 Possible release consequences

The set of release consequences was determined by multiplying the exposure areas (Table 3.) by different average population densities:

$$C_{ijk} = P_{op} D_{en_k} MaxArea_{ijk} \tag{5}$$

where:

$P_{op} D_{en_k}$ - average population density of class k along a route

$MaxArea_{ijk}$ - exposure area per chemical specific guidelines

4.6 Risk analysis

Equation 2 was used to calculate the annual expected risk, R, defined as the expected number of people that would be evacuated and/or sheltered in place annually. The following table shows the R's for three variations of the transport of sulfuric acid.

Table 4. Risk for example sulfuric acid transportation analysis

Route	R
First route	25,1712
Second route	15,939
Third route	21,12964

Based on these results, we can conclude that it is necessary to avoid areas of high population density, which would reduce exposure to large numbers of people at risk in the transport of sulfuric acid. However, avoiding the area of increased density leads to increased transport times sulfuric acid due to the circular tracks.

The combination of longer and lower quality tracks increases the probability of spills of sulfuric acid in the accident.

The resulting combination of outcomes achieved kilometers, accident rates, population density and chemical hazards spill of sulfuric acid. A combination of other factors would have a different effect for each situation and unique approach to the effect of any potential should be considered in relation to each other.

5. CONCLUSION

In accordance with the prescribed standards, the risk in the transportation of hazardous materials must be reduced to a minimum at an acceptable price. The most common reasons for the occurrence of accidents stem from the lack of attention of participants in the transportation, the poor condition of the railway infrastructure, outdated vehicle but also as a consequence of a wrong decision because no dispose of reliable information.

As an increasing number of accidents in the country and the region, and the possible consequences of such accidents on the environment and the health and lives of people significant, risk analysis and modeling uncertainties in the transport of hazardous materials are gaining increasing importance.

In the paper presented a model for the application of fuzzy logic for risk assessment, as well as a different approach to modeling uncertainty, whose application is available in real time and can be used to support the dispatcher in making decisions.

For an effective response to the accident, is needed of modernization funds and equipment and adequate training of staff who will be able to respond effectively to the new situation, at any time, and in the whole area.

REFERENCES

[1] D. Dubois, H. Prade, "Possibility theory, probability theory and multiple – valued logics: A clarification", Annals of Mathematics and Artificial Intelligence, Netherlands, 2001, pp. 35-66.

[2] Guideline for risk assessment, Working Party on the Transport of Dangerous Goods, Eighty - first session, Geneva, 2006.

[3] Emergency Response Guidebook. Pipeline and Hazardous Materials Safety Administration, U.S. Department of Transportation, 2006.

[4] K.D. Jamison, "Modeling uncertainty using probabilistic based possibility theory with applications to optimization", Doctoral thesis, University of Colorado at Denver, 1998.

[5] M.R. Saat, C.P.L. Barkan, "The Effect of Rerouting and Tank Car Safety Design on the Risk of Rail Transport of Hazardous Materials", Proceedings of the 7th World Congress on Railway Research, Montreal, 2006.

[6] Risk management framework for hazardous materials transportation, U.S. Department of Transportation Research and Special Programs Administration, Washington, 2000.

[7] P.R. Nayak, D.B. Rosenfield, J.H. Hagopian. "Event Probabilities and Impact Zones for Hazardous Materials Accidents on Railroads", Report DOT/FRA/ORD-83/20, FRA, U.S. Department of Transportation, 1983.

[8] R.T. Anderson, C.P.L. Barkan. "Railroad Accident Rates for Use in Transportation Risk Analysis", Transportation Research Record, No. 1863, 2004, pp. 88-98.

[9] T.T. Treichel, C.P.L. Barkan, "Working Paper on Mainline Freight Train Accident Rates", Unpublished Report, Association of American Railroads, (1993).

[10] T.T. Treichel, J.P. Hughes, C.P.L. Barkan, R.D. Sims, E.A. Phillips, M.R. Saat. "Safety Performance of Tank Cars in Accidents: Probability of Lading Loss". Report RA-05-02, RSI-AAR Railroad Tank Car Safety Research and Test Project, Washington, D.C., 2006.

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AN OPTIMIZATION APPROACH TO THE LOCOMOTIVE CHEDULING PROBLEM

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Abstract

The locomotive cheduling problemis a particular challenge for transportation planners, as well as a motive for addressing problems related to transport efficiency. This paper has placed an accent on the application of a model, created on the premise that reducing to a minimum the time traction devices are spending in the traction home cell can reduce the number of locomotives necessary to achieve transportation targets in a period of time.The example shows that train traction transport efficiency constitutes an important segment of the overall efficiency of the railways system, a continuous increase of which can be achieved based on a systemic approach to this issue and a number of appropriate strategic, tactical and operative measures and activities within the Serbian Railways.

Keywords*: trsnsport efficiency management, railway, locomotive optimization model*

1. INTRODUCTION

For the majority of railway management systems the optimal use of train traction vehicles is one of the most serious challenges, in view of securing an appropriate train traction vehicle fleet on time, for the train schedule to be fully materialised.

There are three ways of planning train traction operations [2] – strategic, tactical and operative. The most difficult challenge for transport planners is the operative planning, that is, real-time planning, since delays in a train schedule, which might be very frequent, require a series of decisions in a fairly short period of time. What's worse, it is only when problems arise that it turns out the decisions were wrong and not only failed to contribute to the efficiency of the system, but increased the transport exploitation costs, too. [1,2].

Figure 1 displays a locomotive planning system used by a large number of railway managements. The locomotive planning system shows how an optimum-power locomotive is assigned to each train to minimise the total traction cost. The planning covers a period of one week, based on realistic needs and circumstances surrounding the train traction system at that point [3,4]. Regardless of a planning level, transport planners are challenged with complex optimisation problems, even if equipped with modern software solutions, offering strong support in various decision-making processes.

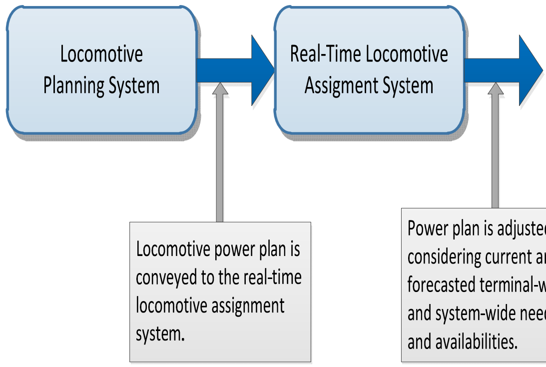

Fig. 1 Role of locomotive planning in real-time locomotive assigment

2. LOCOMOTIVE OPTIMIZATION MODEL

Assigning locomotives along traction lines to improve energy efficiency, requires an optimisation model, supposed to confirm the basic hypothesis of the paper. The creation of the optimisation model involves five stages, interlinked as shown in Figure 2.

2.1 Problem Formulation

The basic hypothesis for this work is the argument that the rationalisation of locomotive use can result in considerable fuel savings and, consequently, contribute to more energy efficient railway operations. The way it will be used depends on the established organisation of transport, train traction organisation, the way shifts are designed and traction devices linked. The existing analyses have shown that there are reserves in the use of traction devices; they are idle for too long while operative, which disrupts the transport organisation and train traction operation. Delays are increasingly frequent, regular trains are cancelled and disbanded until available locomotives are found. The primary objective of creating the model is to outline a procedure to define the required number of traction vehicles for a planned scope of operation, that is, the number of trains operating by direction, along specific train lines. This should be a universal model, applicable to all traction vehicle categories and engine sets involved in transport and train traction organisation, on both electrified and other rails within the Serbian Railways network.

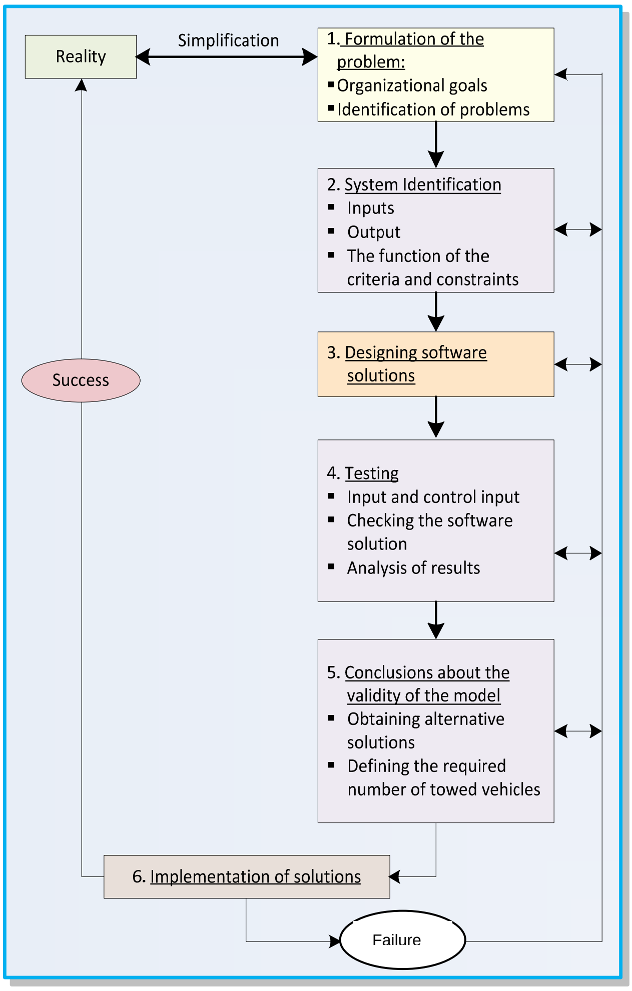

Fig. 2 Process of model creating

2.2 System identification

The system shown in Figure 3 includes a set of elements related to directions for which trains are predefined, relations (pulling sections), stations for each direction and appropriate number of trains which use defined directions and relations.

Entry data – these data are essential for the model since their selection impacts on the entire model functionality and possibility of gaining of appropriate output data. Creation of entry data defined basic postulates for functioning of hauling of trains. According to them, the organization of trains hauling is created individually for each kind of hauling vechicle, due to their technical and exploitation features, while the organization of passenger and goods transport is also separately observed.

Such approach provides obtaining of needed number of hauling vechicles for passenger transport in international, regional and local traffic (electric and diesel locomotives). For the local traffic, there is a plan to use only electric and diesel vechicles. This principle can be used for trains for transport of goods.

Output data – They can be obtained using the model which provides following data:

- Review of locomotives with appropriate ID number according to relations and direction of driving for each train, station of departure/arrival and time of arrival/departure,

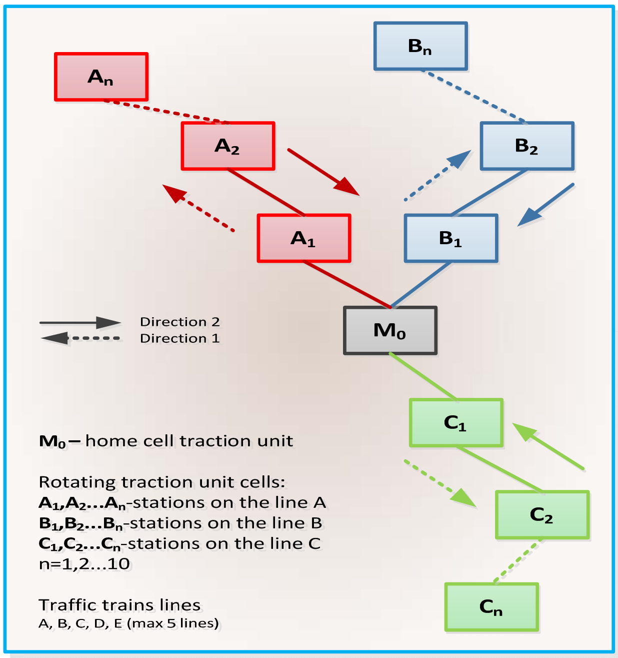

Fig. 3 Graphic review of enter data for the model

- Review of locomotives according to directions and stations including time which electromotive spend from the moment of entering the station with train „Train 1“ to moment when it take over the new train „Train 2“,
- Review of obtained train connections, in other words, the way of their connection according to defined criteria.

The advance of such way of presenting of output data is important because it provides relatively simple analysis of results, defining of deficiencies of the organization of traffic and trains hauling and obtaining of numerous variances.

Function of criteria and limitations – it is chosen according to the fact that the optimisation of turnaround of hauling vechicles belongs to a special kind of transport tasks, known as taks about assignation, selection or scheduling of executors for the certain number of activities, which can be generally presented in a following way:

$$\text{Minimize} \quad F(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \qquad (1)$$

subject to

$$\sum_{j=1}^{n} x_{ij} = a_i \ \text{ for } i = 1,2,\dots,m, \quad \sum_{i=1}^{m} x_{ij} = b_j \ \text{ for } j = 1,2,\dots,n, \qquad (2)$$

and $x_{ij} \geq 0$, for all i and j.

Where:

a_i - number of employees i^{th} categories i = 1,2,...m

b_j - needs of the groups activities j^{th} species j = 1,2,...n

x_{ij} - number of employees i^{th} categories to be allocated to activities j^{th} species i = 1,2,...m; j = 1,2,...n

c_{ij} - analyzed the efficiency of employees i^{th} categories on j^{th} group activities i = 1,2,...m; j = 1,2,...n

In case when the condition $a_i = b_j = 1$ is fulfilled, tasks of individual scheduling of executors for activities can be made. However, it is important to keep the closed model. In other words, the number of executors should be equal to the number of activities n = m.

Set of limitations (2) and (3) become:

$$\sum_{j=1}^{n} x_{ij} = a_i \text{ for i = 1,2,...,n, } \sum_{i=1}^{m} x_{ij} = b_j \text{ for j = 1,2,...n,} \quad (3)$$

$$x_{ij} = \begin{cases} 1 & \text{i}^{\text{th}} \text{ train assigned locomotive of j}^{\text{th}} \text{ train} \\ 0 & \text{j}^{\text{th}} \text{ train assigned locomotive of i}^{\text{th}} \text{ train} \end{cases} \quad (4)$$

This model is shown as very favorable for solving of locomotives work optimization. In order to obtain optimal solution, where the total time of work of hauling vechicles in matrix units is minimal, each hauling section gets the matrix which includes time of locomotives work from each i to each j train. The selection of minimum values using the assignation method can be made by chosing the only one time for which $x_{ij} = 1$ and for others $x_{ij} = 0$. The time can be chosen from the one row and one column.

There is a large number of standard programs for solving tasks using this method. Since the organization of hauling of trains is a complex system the original program was used for this work. This program is entirely adapted to functioning of the system of hauling of trains for Serbia Railways.

Basic limitations used for this model are made for two scenarios:

Scenario 1 – minimum time of work in hauling matrix unit is $\mathbf{t}_{hom}$ = 120 minutes, and in turnaround unit it has a value $\mathbf{t}_{wor}$ = 50 minutes,

Scenario 2 – presents the projection of technological norms of keeping locomotives in order to prepare for conditions when Serbia Railways will be able to replace old vechicles with contemporary hauling vechicles with more progressive performances. Minimum time of work in hauling matrix unit can be $\mathbf{t}_{hom}$ = 90 minutes and in turnaround unit it can be $\mathbf{t}_{wor}$ =30 minutes.

The criterion that the driving time in direction 1(t_{dr1}) with time of work in hauling turnaround unit ($\mathbf{t}_{wor}$) and return in direction 2 (t_{dr1}) is less than 22 hours is important for both scenarios.

$$\mathbf{t}_{dr1} + \mathbf{t}_{wor} + \mathbf{t}_{dr2} < 22 \text{ hours} \quad (5)$$

The one electro-locomotive is needed for the realization of turnaround. In case when the realization of turnaround includes more than 22 hours, the needed number of locomotives can be defined according to locomotives turnaround $\boldsymbol{\theta}$, where:

$$\boldsymbol{\theta} = \mathbf{t}_{dr1} + \mathbf{t}_{wor} + \mathbf{t}_{dr2} + \mathbf{t}_{hom} \quad (6)$$

in that case, when:

$\boldsymbol{\theta} < 24$ - the one hauling vechicle is needed;
$24 < \boldsymbol{\theta} < 48$ - two hauling vechicles are needed and
$48 < \boldsymbol{\theta} < 72$ - three hauling vechicles are needed, etc. (7)

Beside the limitations regarded to function of hauling of vechicles, there are limitations about the total number of directions, relations and number of trains for each direction, which can be processed by the program, so it would be good if the maximum number of observed directions is 5, while the maximum number of stations for each direction is 10, and the total number of trains for each direction can be 100. These are chosen values since they cannot be overrated in practice.

2.3 Projection of software solution

This step includes the selection of appropriate approach to modelling which should provide software solution of the problem. Object-oriented approach to programming is chosen. This approach is very interesting and useful tool in solving of certain problems, because it connects operations and data into unique object. Objects include following equation:

$$\textbf{Object = Operations + Data} \quad (8)$$

The solution for problem can be obtained by the communication in network of mutually connected objects [16,17]. Such approach to programming provides to embrace complex problems in flexible way, so it is the main reason for emphasizing the object-oriented technics for solving of engineering problems [19]. Software solution of problem of obtaining of needed number of hauling vechicles using object-oriented program and program language C++ treats stations, directions, train routes as objects while connecting of routes is possible in two ways: connecting trains in turnaround for each direction separately and connection of trains in turnaround on a level of all relations at once. In both cases, software provides the application of limitating criteria related to minimalization of time for hauling vechicles in hauling matrix.

2.4 Testing

Testing is the most important phase in development of locomotive optimization model. After import and control of entry data, checking and analysis of results, this should provide enough information about validity of software solution for traffic planners.

Import and control of entry data – this is possible in two ways:

1. Direct import into the program, train by train – it takes a lot of time when larger number of trains is involved. There is a greater chance to make mistake during the importing of data.
2. Loading from the file in .txt format – it is faster way because of smaller number of mistakes. Software includes the control of entry data, which prevents results in case of inadequate or incorrect data.

Check of software solution – it is necessary after the projecting of software solution. It is assumed that the validity of software is easy to prove if the departure schedule is used as an import data. This present the organization of traffic, where all routes are connected and the exact number of needed vechicles is known. If the result implies that the organization is the same with the same or smaller number of hauling vechicles regarding those from import data, the software should be considered as checked and ready for application.

Results analysis – it is important step which can imply to significant deficiencies in projecting of software solution and possibilities for overcoming them. It seems to be a difficult task. However, considering this kind of analysis, after the first analysis of results, deficiencies can be observed. Their kind implies to imprecision in reasoning and problem set during the design software solution that can then be corrected.

2.5 Conclusions about validity of the model

Conclusions about validity of the model presents the final phase in model creating process. They are defined according to results of testing and analysis of results.

Obtaining of alternative solutions for problems – it presents expected aim in model creating in order to define needed number of hauling vechicles, while the focus is placed on turnarounds of locomotives for each prepared scenario.

Defining of needed number of hauling vechicles according to type – it is used for new organization of traffic, presented through turnarounds of hauling vechicles. The total number of hauling vechicles needed for certain traffic organization for transport of passengers and goods is defined:

$$\mathbf{M} = \mathbf{M}_P + \mathbf{M}_G \quad [\text{loc/day}] \tag{9}$$

M [loc/day] – total needed number of hauling vechicles for traffic organization during the day.

$\mathbf{M_P}$ [loc/day] – total needed number of hauling vechicles for traffic organization for passengers transport.

$\mathbf{M}_G$[loc/day] – total needed number of hauling vechicles for traffic organization for transport of goods.

The final result of application of the model is the table review of indicators of work of existing and rationalized organization of trains hauling. Their comparison can be used for conclusions about observed organization.

2.6 Model implementation

Creation of optimization model is creative task which also includes expert knowledge in area of trains hauling. Such aspect is shown as very important in model implementation process. It can be used for finding mistakes in programming. These mistakes lead to illogical connecting of locomotives. In order to observe mistakes, it is needed to go back to start, eventually simplify the problem and repeat all six steps in modeling process, presented in figure 2.

From the set of possible hauling relations on which electric locomotives operate, table 1 present hauling relations and their length. They are used for analyzing of organization of trains traffic which includes 44 trains for passengers transport and 36 trains for transport of goods with parametres for organization according to relations, presented in table 2.

Table 3 presents the review of turnarounds of locomotives according to relations for existing organization of traffic, which are defined by scenarios 1 and 2.

Beside obtained turnarounds for locomotives, times of work of locomotives in matrix and turnaround hauling units are results for each observed scenario. Concrete result of the implementation of the implementation of model for optimization of the use of locomotives is following:

- Total time of work of hauling vechicles in matrix hauling unit is decreased for 46% while the total number of needed locomotives is less for 6. In other words, the number of needed locomotives is less for 16% for Scenario 1 regarding the observed organization of traffic.
- Total time of work of hauling vechicles in matrix hauling unit is decreased for 56% for Scenario 2 while the total number of needed locomotives is less for 7. In other words, it is nearly 19% less number of locomotives for Scenario 2 regarding the observed traffic organization.

Table 1. Summary of traction relations and their length

Traction relations	Length (km)
Beograd - Niš	243,5
Niš - Skoplje	221,0
Beograd - Subotica	175,4
Beograd R. – N. Sad	84,7
Bgd. Ranžirna - Ruma	73,9
Bgd Ranžirna - Subotica	185,5

Table 2. Overview of parameters for relations

	Relations from the table 1				
Relations	1+2	3	4	5	6
Line lenght (km)	243+221	69	175	85	182
Vehicle kilometers (train km)	70350	830	3859	508	3267
Vehicle hours (train hour)	115	16	59	14	89
Commercial speed (km / h)	61	53	66	35	37

Using the analysis of results it can be assumed that more rational use of hauling vechicles can make significant impact on efficient use of energy sources. Using modern informational and computing technologies and innovating of technological norms for keeping of locomotives in matrix and turnaround hauling units can contribute to more energy efficient functioning of trains hauling in Serbia Railways.

3. CONCLUSION

The implementation of the system for monitoring and improving of transport efficiency becomes important part of business of transport organizations. World trends slowly but firmly gets to Serbia so there is need to align business of domestic transport organizations with organizations from Europe. European organizations support principles of sustainable development.

Increased number of demands related to efficiency of transport system present a problem for most of transport organizations, especially for railways, which are known as a large, complex and inert system which is difficult to tolerate any kind of changes. However, changes are inevitable and significant for survival of railway which is in great losts in business. Any kind of the research is welcome.

Using the created model for locomotives scheduling, the hypothesis is proved and it is observed that locomotives at Serbia Railways are irrationally used due to increased and unnecessary delay in matrix hauling units. It is important to highlight that implementation of innovations related to all levels of organization functioning including trains hauling is important for competitive advantage and inclusion of Serbia Railways in European transport market. This work showed that technological norms of delaying of hauling vechicles in hauling units can contribute to more rational use of locomotives and increasing of transport efficiency of trains hauling and Serbia Railways in whole.

Table 3 Review of cycles of existing locomotives and rationalized of the train traction at relations

	Cycles locomotive observed organization	Scenario 1 - cycles locomotive rationalized organization for T_{hom}= 120; T_{wor}= 50	Scenario 1 - cycles locomotive rationalized organization for T_{hom}= 90; T_{wor}= 30
Total of locomotives	37	31	30

Table 4 Comparative review of time dealing with of locomotives in home and working units snapped in relations

Relation	Type of train	Home unit			Working unit		
		*	**	***	*	**	***
Beograd-Niš-Skopje	Passenger	67:21	60:02	60:02	58:42	57:43	57:43
Beograd - Subotica	Passenger	132:40	80:43	83:13	72:58	76:38	74:08
Beograd R.- Ruma-N.Sad-Subotica	Freight	254:25	102:22	56:46	68:25	92:04	89:43
	Ukupno	**454:25**	**243:07**	**200:01**	**200:05**	**226:25**	**221:34**

* - Existing organization
** - Scenario 1 – rationalized organization for T_{mat}=120 t_{ob}=50
*** - Scenario 2 – rationalized organization for T_{mat}=90 t_{ob}=30

REFERENCES

[1] U. Henning, M. Bergendorff, C. Spalvieri, L. Nicod, C. Struve, "Innovative Integrated Energy Efficiency Solutions for Railway Rolling Stock", Infrastructure and Operation, http://www.uic.org/cdrom/2008/11_wcrr2008/pdf/R.3.4.3.1.pdf

[2] B..W. Powell, "Strategic, Tactical and Real-Time Planning of Locomotives at Norfolk Southern Using Approximate Dynamic Programming", Department of Operations Research and Financial Engineering, Princeton University, 2012, http://www.castlelab.princeton.edu/Papers/Powell-and Locomotive Optimization _long.pdf

[3] A. Nahapetyanl, K. R. Ahuja, F. Z. Sargut, "Simulation/Optimization Framework for Locomotive Planning", 7th Workshop on Algorithmic Approaches for Transportation Modeling, Optimization and Systems ATMOS, 2007, pp.259-276.

[4] R. Ahuja, K. Liu, B. Orlin, D. Sharma, L. A. Shughart, "Solving real-life locomo- tive scheduling problems", Transportation Science 39, 2005, pp. 503–517.

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LOGISTIC CENTERS: LITERATURE REVIEW AND PAPERS CLASSIFICATION

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Abstract

Today, logistic centers are one of the most important nods in logistic network. They can be viewed as places were transformation of freight flows is carried out. In contemporary literature there is wide range of different terminology and definitions regarding logistics centers, and it is noticeable a lack of unified and widely accepted definition of logistic centers. Idea of logistics centers exists for a number of years. Functions, structure and development objectives of the logistic centers changed during the time and received different forms. So today there are many different terminology views about the concept of logistic centers. Accordingly, during their development, depending on the location, purpose and technological sense, logistics centers gained different names. In the literature we can often find names like: freight terminals, freight distribution terminal, intermodal terminals, city logistic terminal, dry port, container terminal, etc. What is common to all mentioned "types" of logistics centers is that they are often located near large industrial centers, major transportation hubs, traffic corridors, seaports, important marshalling yards, and so on. In accordance with long-standing development of logistics centers, different authors have dealt with various research problems related to logistics centers (technological, organizational, locational, dimensional, etc.). In this paper we created a literature review and classification of papers related with topic of logistic centers, with aim of providing the insight in current development of this research area. Main focus of presented paper is clarifying the terminology and definitions of logistics centers. Classification of research papers is carried out by different research topics, with focus on the most important and currently actual research topics.

***Keywords**: logistics centers, supply chain, intermodal transportation, logistic network.*

1. INTRODUCTION

Intensive development of logistics in the economic system began in the second half of the 20th century. The real boom in the logistics development come with globalization and decentralization of production and with the revolutionary development of information and communication technologies. Today, under the conditions of globalized markets, economic success is impossible without effective and efficient logistics.

Logistics is the part of the of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point of the origin to the point of consumption in order to meet customers [1], and as such, it is an important part of the economic system. With the increase of trade, importance of logistics is also growing, and following trends are noted:

- In the last decade, despite the economic crisis, the value of merchandise trade in the world has increased by over 50% [2].
- For the indicator od development of international merchandise trade and hence for activity of the global economy RWI/ISL Container Throughput Index could be used. RWI/ISL index is based on data of 75 world container ports covering approximately 60% of worldwide container handling. Increase the manipulation of these ports in the period of 2009-2013 was approximately 20% and it is a good indicator of the movement of world merchandise trade [3].

Worldwide globalization of industry and trade made a significant impact on practice and theory of logistics and supply chain management. Supply chains are the backbone of international trade and commerce. Their logistics encompasses freight transportation, warehousing, border clearance, payment systems, and increasingly many other functions outsourced by producers and merchants to dedicated service providers [4]. Supply chains are only as good as their weakest link, and sustainable improvements require complex changes in a range of policy dimensions in areas including infrastructure, trade facilitation and services. An important component of logistics infrastructure and technological hub in the logistics network are logistics centers. Increase in cargo flows, increased the importance of these nodes and therefore the interest of science in different issues related to their work. The aim of this study is to is clarify the terminology and definitions of logistics centers as well as to extract the most frequently studied problems in this area, according to available literature.

2. LOGISTICS CENTERS

The concept of logistics centers in Europe began to develop around the 1970 [5]. Nevertheless, there are still some concerns about how to terminologically to define areas where there is concentration and implementation of various logistics activities, and what are the activities and conditions that some center must fulfill, to be considered as logistic center. The reasons for the differences in the terminology and the conceptions of logistics centers, are primarily in the following facts:

- linguistic and national differences influenced to such centers in different countries are defined by different names such as:logistics centers, güterverkehrzentrum, distribution centre, freight/transport terminal, transport node, logistics platform, freight village, Interporto, logistics depot, etc.
- due to differences in geographic and traffic characteristics of the region and the characteristics of logistics flows, logistics centers are associated with smaller or larger number of functions;
- with the development of logistics and supply chain management, role and functions of logistics centers also evolved.

In order to the terminologically and functionally understand of the concept of a logistics center and its related terms, in the following text we will list some of the interpretations, of the concept of logistics centers, that may be encountered in the literature. Zečević [5] find that each center that performs some of the logistics activities is logistics center. In this way, all freight terminals that perform logistics activities are considered as logistics centers. However, Zečević [5] later in the book, presents a description of VAL services (value added logistics services), that shows the difference between traditional freight terminals (which implement the basic functions: receiving shipments, storage, preparation for shipment, distribution) and „highly productive“ logistics centers (which are performing some additional activities, eg. labeling /marking of goods, merging, packing and repacking, sterilization, filling, painting, installation, etc.). Providing additional services to users, logistics centers are becoming centers of competence [6].
For a better understanding of the concept of logistics centers, Meidute [7] proposes an analysis of the two approaches (Fig. 1) and notes that in the different regions there is a trend of favoring one of the approaches (logistics center: in Europe and Central Asia there is a approach that logistic centers are a part of the transportation infrastructure, while in US and rest of the Asia, there is a aprroach thet logistic centers are generator of business). As a conclusion Meidute [7] states that there is no clear definition of a logistics center.

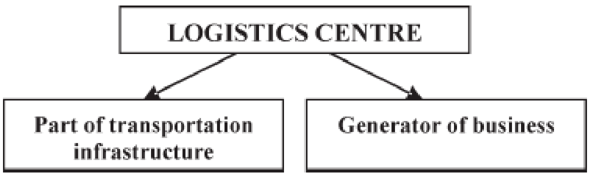

Fig. 1 An approach to the concept of logistics centers [7]

Logistics centers is a village planned and built to best manage all the activities involved in freight movement. Logistics centers are seen as promoters of local consolidation, intermodal transportation, and regional economic activity [8]. A logistics centre is the hub of a specific area where all the activities relating to transport, logistics and goods distribution – both for national and international transit – are carried out, on a commercial basis, by various operators [9]. A freight village is an area of land that is devoted to a number of transport and logistics facilities, activities and services, which are not just co-located but also coordinated to encourage maximum synergy and efficiency. Central to a freight village is an intermodal terminal that is connected to major freight corridors and a nearby seaport [10].

3. DISCUSSION

Different authors dealt with this problem of defining the concept of logistics centers. The most noticed and discussed papers are [8, 11, 12]. Mentioned papers cover in details problem of the logistics centers, but have different views about terminology of logistics centers and there is no consensus about typology and hierarchy levels of the logistic centers. Higgins, et al. [13] propose a hierarchy of intermodal logistics centres according to each facility's size, influence, and function in regional freight and logistics and value added activities. Also in the same paper, they propose a unified and standardized typology anddivided hierarchy in 3 levels of logistics centers based on the merging papers of [8, 11, 12]. For the "1st" hierarchy level of logistic centers (warehousing and distribution cluster) Higgins, et al. [13] defined following fright terminals: Industrial park, Distribution center, Distribution terminal, Distribution center, Urban distribution center, Urban consolidation center Distribution center, Inland container depot, Inland container depot, Warehouse, Container yard. In "2ed" hierarchy level (freight transportation and distribution cluster) Higgins, et al. [13] classified: Nodal centers for goods, Freight village, Logistics center, Logistics center, Logistics center, Trade and transportation center inland port, Load center, Inland port, Dry port, Inland port, Maritime feeder inland port, Hinterland terminal, Satellite terminal, Inland waterway port, Barge terminal, Transport terminal, Intermodal and multimodal industrial park, Intermodal railroad terminal, Intermodal freight center, Transfer terminal, Transmodal terminal, Intermodal terminal. The last and most important hierarchy level of logistic centers, "3rd" level (gateway cluster) includes: Gateway, Logistics node, Seaport, Air cargo port, Bulk terminal.
Following the consolidated logistics center classification and scope of activities given by [13], we tried to look at the trends that exist in development of centers that fall under the concept of logistics centers, in the past 10 years. For this purpose, we have selected and studied 64 papers from the literature and perform classification under previously adopted typology and hierarchy. Beside typology and hierarchy classification, we have also classify papers by the research topics which were dominant in present papers (framework developments and future strategies, internal organization and process optimization, location problems and case studies), Table 1.

Table 1. Papers classification of logistics centers based on hierarchy and research topics in period (2004-2014)

Author		Logistics center hierarchy (levels)			Terminology, typology and hierarchy classification	Framework development and future strategies (analyses of current conditions, literature reviews, etc.)	The internal organization and proce optimization (modelling of freight flow optimization of handling equipmen quality aspects, simulations, etc.)	Location problem	Case study
		1st	2nd	3rd					
1	[14]		X				X		
2	[15]		X	X		X			
3	[16]			X			X		
4	[17]					X			
5	[18]			X			X		
6	[19]		X				X		
7	[20]	X					X		
8	[21]	X					X		
9	[7]				X				
10	[22]	X						X	X
11	[23]			X			X		
12	[24]		X			X			X
13	[25]	X						X	
14	[26]		X				X		
15	[27]		X				X		
16	[28]			X			X		
17	[29]			X			X		
18	[30]			X			X		
19	[31]		X			X			
20	[32]			X			X		
21	[33]		X				X		
22	[34]				X	X			
23	[35]		X		X				
24	[36]					X			
25	[37]		X			X			X
26	[38]					X			
27	[8]				X				
28	[39]		X			X			
29	[40]		X				X		X
30	[41]			X			X		
31	[42]			X			X		
32	[43]			X			X		
33	[12]		X		X				
34	[44]			X		X	X		
35	[45]		X				X		
36	[46]	X				X			X
37	[47]	X						X	
38	[48]								
39	[48]	X				X			
40	[49]	X				X	X		
41	[50]		X		X	X			
42	[51]		X					X	
43	[52]							X	X
44	[53]			X			X		
45	[54]		X			X			
46	[55]			X			X		X
47	[56]			X			X		X
48	[57]							X	
49	[10]		X		X	X			X
50	[58]		X				X		X
51	[59]		X		X	X			
52	[13]				X	X			
53	[60]					X		X	X
54	[61]			X			X		
55	[62]			X			X		
56	[63]		X	X	X				
57	[64]			X			X		
58	[65]			X			X		
59	[66]			X			X		
60	[67]				X			X	X
61	[68]				X			X	X
62	[69]		X				X		X
63	[70]		X				X		
64	[71]					X			

Summarizing the Table 1, on Fig. 2, we can see the distribution of research topics that were occupying the researchers in past 10 years. From the graph we can see that centers that are clasified in “2ed”, and “3rd” level of logistic centers, are more interesting for researchers than centers in “1st” hierarchy level. Also “The internal organization and process optimization” and “Framework development and future strategies”, are the topics that occupied the most research papers in observed period, within group of 64 selected papers. As it was mentioned in earlier, logistic centers terminology is still not unified and cleared out, which can be also be see form graph, were “Terminology” question is concerned only in 12 papers from total group of 64. Location problem was also less in focus of researches, mainly because location problems of centers in “2ed” and “3rd” level is something that is planning for a long period of time, and today locations of freight terminals in “2ed” and “3rd” level are mainly inherited from the previous periods.

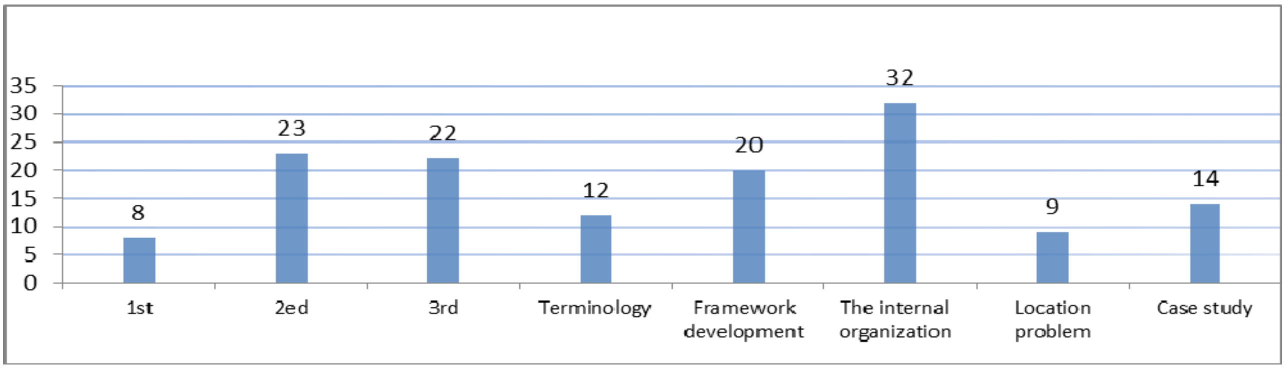

Fig.2. Distribution of research topics related to the research area of logistic centers

4. CONCLUSION

Despite the undefined terminology and non unified definitions of logistics centers, most researchers agree that logistic centers are one of the most important drivers of local and regional economies. Importance of logistic centers is also seen through logistic performance index (LPI), were development of logistic centers are one of the parameters that influence on LPI rating of some particular country. As we previously indicate despite of the different terminology and different views which are the activities that need to be carried out in some freight terminal, in order to thet terminal could be considered as logistic center, a common features of logistics centers can be distinguished: intermodality, public openness, multi-functionality, storage and handling of various cargo, electronic exchange of information interconnectedness of different business sectors and entities, striving for lower total costs and additional services.

Basically logistics centers could be understood as freight terminals which depending on the how much logistic activities some freight terminal is offering to the users, depends on what level of integration into logistic center will that particular terminal will be. So according to Higgins, et al. [13] there are three hierarchy levels of freight terminals, classified by the scope of their activities and services. In presented paper, regardless of the non unified terminogly, we tried to see what are the topics that have the biggest interest among the researches, related to the topic of logistic centers. We select 64 papers from period of last 10 years, and classify them by different research topics. As most interesting, topic of internal organizatin emarged. Based on this we can see that researchers are trying to find now solutions and ways how to make these centers more efficient and optimized, despite the fact that terminology questions regarding to these centers aren't solved yet.

5. REFERENCES

[1] Brewer, A., K. Button, and D. Hensher, *Handbook of Logistics and Supply-Chain Management*. 2001: Pergamon.

[2] Eurostat, *External and intra-EU trade*. 2011.

[3] ISL. *Institute of Shipping Economics and Logistics*. 2014 [cited 2014 27.03.]; Available from: http://www.isl.org/en/home.

[4] World-bank, *Trade Logistics in the Global Economy* The Logistics Performance Index and Its Indicators. 2014.

[5] Zečević, S., *Robni terminali i robno-transportni centri*. 2009, University of Belgrade: Faculty of Transport and Traffic Engineering.

[6] Milosav, G., B. Sanja, and B. Vladimir, *Logistics as economical potencial*, in *CESS magazine*. 2011. p. 4-11.

[7] Meidute, I., *Comparative analysis of the definitions of logistics centres*. Transport, 2005. **XX**(3): p. 106-110.

[8] Rimienė, K. and D. Grundey, *Logistics Centre Concept through Evolution and Definition*. ENGINEERING ECONOMICS, 2007. **54**(4): p. 87-95.

[9] Europlatforms, *Logistics centres - directions for use*. 2004, EEIG.

[10] Higgins, C.D. and M.R. Ferguson, *An Exploration of the Freight Village Concept and its Applicability to Ontario*. 2011, McMaster Institute of Transportation and Logistics Hamilton, Ontario. p. 202.

[11] Wiegmans, B.W., E. Masurel, and P. Nijkamp, *Intermodal Freight Terminals: an Analysis of the Terminal Market*. Transportation Planning and Technology 1999. **23**(2): p. 105-128.

[12] Notteboom, T. and J.-P. Rodrigue, *INLAND TERMINALS WITHIN NORTH AMERICAN AND EUROPEAN SUPPLY CHAINS*, in *In Transport and Communications Bulletin for Asia and the Pacific No. 78: Development of Dry Ports, Economic and Social Commission for Asia and the Pacific*. 2009, United Nations: New York.

[13] Higgins, C.D., M. Ferguson, and P.S. Kanaroglou, *Varieties of Logistics Centers Developing Standardized Typology and Hierarchy*. Journal of the Transportation Research Board 2288, 2012. **1**: p. 9-18.

[14] Baublys, A., *Modelling of freight flows distribution at the transport terminal*. Transport, 2004. **XIX**(2): p. 86-91.

[15] Steenken, D., S. Voß, and R. Stahlbock, *Container terminal operation and operations research – a classification and literature review*. OR Spectrum 2004. **26**: p. 3–49.

[16] Wiegmans, B.W., P. Rietveld, and P. Nijkamp, *Container terminal handling quality*. European Transport \ Trasporti Europei, 2004(25-26): p. 61-80.

[17] Palšaitis, R. and D. Bazaras, *Analysis of the prospectives of intermodal transport and logistics centres in Lithuania*. Transport, 2004. **XIX**(3): p. 119-123.

[18] Chu, C.Y. and W.C. Huang, *Determining container terminal capacity on the basis of an adopted yard handling system*. Transport Reviews, 2005. **25**(2): p. 181-199.

[19] Ballis, A., *Freight villages: Warehouse design and rail link aspects*, in *85th Annual Meeting of Transportation Research Board*. 2005.

[20] Chena, M.-C., et al., *Aggregation of orders in distribution centers using data mining.* Expert Systems with Applications, 2005. **28**.

[21] Eskigun, E., et al., *Outbound supply chain network design with mode selection, lead times and capacitated vehicle distribution centers.* European Journal of Operational Research, 2005. **165**: p. 182-206.

[22] Thai, V.V. and D. Grewal, *Selecting the location of distribution centre in logistics operations : a conceptual framework and case study.* Asia Pacific Journal of Marketing and Logistics, 2005. **17**(3): p. 3-24.

[23] Assumma, V. and A. Vitetta, *Microsimulation models in a RO-RO high speed services intermodal container terminal: ordinary and perturbed conditions*, in *European Transport Conference '06*. 2006: Strasbourg, France. p. 1-20.

[24] Evangelos, K. and A. Maria, *The role of freight villages to the development of the Balkan region. The case of Promachon Freight Village (Greek Bulgarian borders)*, in *46th Congress of the European Regional Science Association (ERSA)*. 2006: Volos, Greece.

[25] Klapita, V. and Z. Švecová, *Logistics centers location.* TRANSPORT, 2006. **XXI**(1): p. 48-52.

[26] Soriguera, F., et al., *Optimization of handling equipment in the container terminal of the port of Barcelona, Spain.* Inland Waterways, Ports, and Shipping, 2006(1963): p. 44-51.

[27] Park, B.J., et al., *Simulation analysis on effective operation of handling equipments in automated container terminal.* AI 2006: Advances in Artificial Intelligence, Proceedings, 2006. **4304**: p. 1231-1238.

[28] Zhou, P.F., H.G. Kang, and L. Lin, *A fuzzy model for scheduling equipments handling outbound container in terminal.* WCICA 2006: Sixth World Congress on Intelligent Control and Automation, Vols 1-12, Conference Proceedings, 2006: p. 7267-7271.

[29] Chen, L., et al., *A tabu search algorithm for the integrated scheduling problem of container handling systems in a maritime terminal.* European Journal of Operational Research, 2007. **181**(1): p. 40-58.

[30] Ha, B.H., E.J. Park, and C.H. Lee, *A simulation model with a low level of detail for container terminals and its applications.* Proceedings of the 2007 Winter Simulation Conference, Vols 1-5, 2007: p. 1982-1990.

[31] Iannone, F., S.A. Thore, and E. Forte. *Inland Container Logistics and Interports. Goals and Features of an Ongoing Applied Research*. in *Ninth Scientific Meeting of the Italian Society of Transport Economists*. 2007. Naples, Italy

[32] Xue, S.L., *Research of a monitoring system for the intelligent and efficient automated handling container terminal.* Icemi 2007: Proceedings of 2007 8th International Conference on Electronic Measurement & Instruments, Vol Iii, 2007: p. 518-521.

[33] Ballis, A. and G. Mavrotas, *Freight village design using the multicriteria method PROMETHEE.* Operational Research. An International Journal, 2007. **7**(2): p. 213-232.

[34] Jaržemskis, A., *Research on public logistics centre as tool for cooperation.* TRANSPORT, 2007. **XXII**(1): p. 50-54.

[35] Jaržemskis, A. and A.V. Vasiliauskas, *Research on dry port concept as intermodal node.* TRANSPORT, 2007. **XXII**(3): p. 207-213.

[36] Kabashkin, I., *Logistics centres development in Latvia.* TRANSPORT, 2007. **XXII**(4): p. 241-246.

[37] Labanauskas, G. and R. Palšaitis, *Study of possibilities to establish regional transport terminal in Kaunas.* TRANSPORT, 2007. **XXII**(2): p. 118-121.

[38] Meidute, I., *Economical evaluation of logistics centres establishment.* TRANSPORT, 2007. **XXII**(2): p. 111-117.

[39] Roso, V., *Evaluation of the dry port concept from an environmental perspective: A note.* Transportation Research Part D, 2007. **12**: p. 523–527.

[40] Afandizadeh, S. and R. Moayedfar, *The feasibility study on creation of freight village in hormozgan province.* TRANSPORT, 2008. **23**(2): p. 167–171.

[41] Huang, S.Y., et al., *Capacity analysis of container terminals using simulation techniques.* Int. J. Computer Applications in Technology, 2008: p. 246-253.

[42] Hoshino, S., et al., *Double Container-handling Operation for an Efficient Seaport Terminal System.* Ias-10: Intelligent Autonomous Systems 10, 2008: p. 173-182.

[43] Shinoda, T., T. Tanaka, and H. Kim, *Construction of container handling simulation model in container terminal by database analysis.* Maritime Industry, Ocean Engineering and Coastal Resources, Vols 1 and 2, 2008. **1-2**: p. 639-647.

[44] Cartenì, A. and S.d. Luca. *Simulation of a container terminal through a discrete event approach: Literature review and guidelines for application*. in *European Transport Conference, 2009* 2009. Leiden Leeuwenhorst Conference Centre , Netherlands.

[45. Baker, P., *The design and operation of distribution centres within agile supply chains.* Int. J. Production Economics, 2008. **111**: p. 27-41.

[46] Bowen, J.T., *Moving places: the geography of warehousing in the US.* Journal of Transport Geography, 2008. **16**: p. 379–387.

[47] Huifeng, J. and X. Aigong, *THE METHOD OF WAREHOUSE LOCATION SELECTION BASED ON GIS AND REMOTE SENSING IMAGES.* The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences., 2008. **XXXVII**(B2): p. 4.

[48] Skintzi, G., G. Ioannou, and G. Prastacos, *Investigating warehousing policies.* Int. J. Production Economics, 2008. **112**: p. 955-970.

[49] Baker, P. and M. Canessa, *Warehouse design: A structured approach.* European Journal of Operational Research 2009. **193**: p. 425-436.

[50] Roso, V., J. Woxenius, and K. Lumsden, *The dry port concept: connecting container seaports with the hinterland.* Journal of Transport Geography, 2009. **17**: p. 338–345.

[51] Kayikci, Y., *A conceptual model for intermodal freight logistics centre location decisions*, in *The Sixth International Conference on City Logistics*. 2010. p. 6297-6311.

[52] Turskis, Z. and E.K. Zavadskas, *A new fuzzy additive ratio assessment method (aras–f). Case study: The analysis of fuzzy multiple criteria in order to select the logistic centers location.* TRANSPORT, 2010. **24**(4): p. 423-432.

[53] Yildiz, T. and F. Yercan, *The cross-entropy method for combinatorial optimization problems of seaport logistics terminal.* TRANSPORT, 2010. **24**(4): p. 411-422.

[54] Boile, M., S. Theofanis, and K. Ozbay, *Feasibility of Freight Villages in the NYMTC Region*. 2011, Center for Advance Infrastructure and Transportation Rutgers, The State University of New Jersey: New Jersey.

[55] Azimi, P. and M.R. Ghanbari, *Simulation Modeling for Analysis and Evaluation of the Internal Handling Fleet System at Shahid Rajaee Container Port.* World Academy of Science, Engineering and Technology Proceedings, 2011. **78**: p. 644-655.

[56] Qian, J.F., et al., *Simulation and Optimization of Handling Resources Configuration in Container Terminal.* 2011 3rd World Congress in Applied Computing, Computer Science, and Computer Engineering (Acc 2011), Vol 1, 2011. **1**: p. 30-37.

[57] Erkayman, B., et al. *A Fuzzy Topsis Approach For Logistics Center Location Selection*. in *The 2011 New Orleans International Academic Conference*. 2011.

[58] Maslaric, M. and T. Backalic, *Container terminal simulation: a case study*, in *14.ICTS 2011-14th International Conference on Transport Science, .* 2011, Fakulteta za pomorstvo in promet, Univerze v Ljubljani: Portoroz.

[59] Nobel, T., *European freight villages and their success factors*, in *Economic and Social Council-Role of terminals and logistics centers for intermodal transport* 2011: Geneva.

[60] Liu, X., X. Guo, and X. Zhao, *Study on Logistics Center Site Selection of Jilin Province.* JOURNAL OF SOFTWARE, 2012. **7**(8): p. 1799-1806.

[61] Chang, D.F., et al., *A study on the configuration of handling equipments for container terminal.* Advanced Manufacturing Technology, Pts 1-4, 2012. **472-475**: p. 3326-3330.

[62] Fereidoonian, F. and A. Mirzazadeh, *A genetic algorithm for the integrated scheduling model of a container-handling system in a maritime terminal.* Proceedings of the Institution of Mechanical Engineers Part M-Journal of Engineering for the Maritime Environment, 2012. **226**(M1): p. 62-77.

63] Rodrigue, J.-P. and T. Notteboom, *Dry Ports in European and North American Intermodal Rail Systems: Two of a Kind?* Research in Transportation Business & Management 5 2012: p. 1-23.

[64] Chen, L., A. Langevin, and Z.Q. Lu, *Integrated scheduling of crane handling and truck transportation in a maritime container terminal.* European Journal of Operational Research, 2013. **225**(1): p. 142-152.

[65] Dkhil, H., A. Yassine, and H. Chabchoub, *Optimization of Container Handling Systems in Automated Maritime Terminal.* Advanced Methods for Computational Collective Intelligence, 2013. **457**: p. 301-312.

[66] Imai, A., E. Nishimura, and S. Papadimitriou, *Marine container terminal configurations for efficient handling of mega-containerships.* Transportation Research Part E-Logistics and Transportation Review, 2013. **49**(1): p. 141-158.

[67] ALAM, S.A., *Evaluation of the potential locations for logistics hubs: A case study for a logistics company*, in *Department of Transport Science*. 2013, KTH Royal Institute of Technology: Stockholm, Sweden. p. 78.

[68] Bojić, S., *LOKACIJSKI PROBLEMI U LANCIMA SNABDEVANJA I NJIHOV UTICAJ NA LOGISTIČKE TROŠKOVE*. 2013, University of Novi Sad: Novi Sad. p. 132.

[69] Mircetic, D., M. Maslaric, and S. Nikolicic, *Reengineering of terminal processes in inland container terminal*, in *International Symposium on Logistics (ISL 2013)*, K.S.P.H. Rogers, Editor. 2013: Vienna.

[70] Ye, F., H.H. Xie, and X. Jin, *Optimization on Configuration of Handling Equipment in Railway Container Terminal during Operation.* Sustainable Development of Urban Infrastructure, Pts 1-3, 2013. **253-255**: p. 1245-1248.

[71] Kaynak, R., İ. Koçoğlu, and A.E. Akgün, *The Role of Reverse Logistics in the Concept of Logistics Centers*, in *2nd World Conference On Business, Economics And Management-WCBEM 2013*. 2014, Procedia - Social and Behavioral Sciences. p. 438 – 442.

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SIMULATION OF MATERIAL FLOW IN THE FACTORY ECO-FOOD

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Abstract

This paper will show a simulation of material flow in the factory ECO-FOOD. Filling jars of olives is done manually. This paper analyzes the technology of filling, pasteurization and storage, transportation routes and the number of workers. The paper proposes the introduction of automated transport systems, based on the belt conveyor and automated guided vehicles and a new layout for the packaging hall. The concluding results of performed simulations will define variable number of automated guided vehicles, and the proposed solution of material flow.

Keywords: Simulation, Optimization, Material Flow

1. INTRODUCTION

The main activity of "ECO-FOOD" Niš is the manufacture, import, processing and packaging of olives, mushrooms, pepperoni and other products. The company's activity is carried out in a manufacturing plant in the city's industrial zone with a total of 40 employees, and has its own fleet for distribution of finished products both at home and abroad. Customers of “ECOFOOD” in the territory of the country are all major retail chains in Serbia.

Let us observe the process of processing and packaging of olives, as the most frequent product that of the factory. In the pre-processing of olives, is up to 8 workers in manufacturing, where it still needs to add a couple of workers because the labeling is done by hand and then the number of workers increases. The technological processing of olive consists of preparation, jars, marinades and olive filling jars, marinade, close the jar, pasteurization, cooling, date marking, labeling, inspection, packaging and laminating 6 jars and palletizing.

The current layout of the workspace in the process of charging of olives is shown in the figure below (Fig.1):

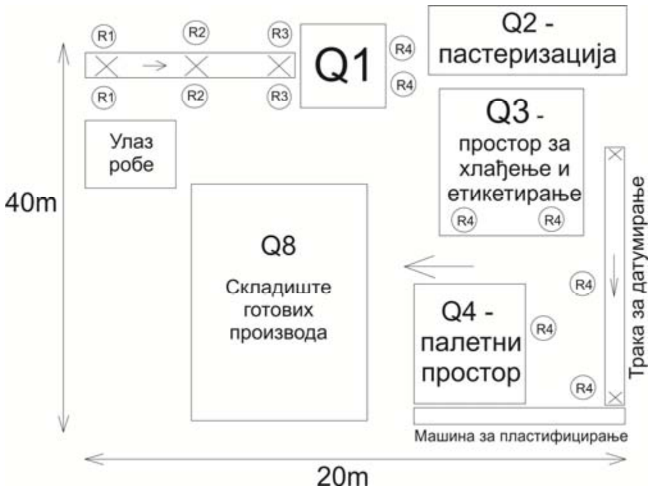


Fig. 1 Current layout of ECO-FOOD factory

The analysis of the technological process, the existing transport machinery and modern material flow solutions, derived proposed automated filling systems and processing olives.

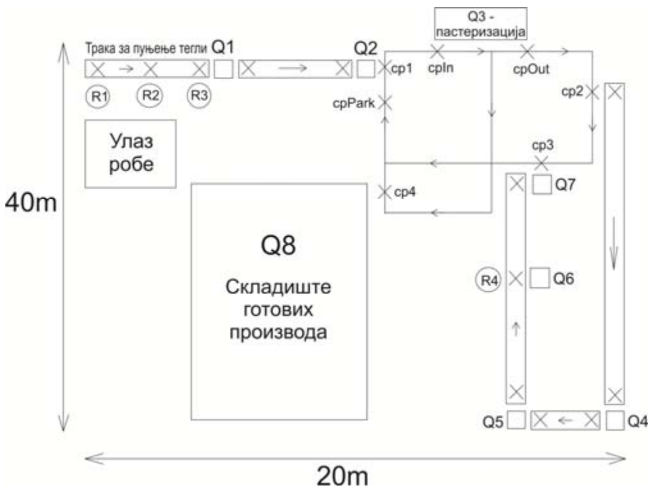


Fig. 2 Planned new automated sistem layout of ECO-FOOD factory

2. MATERIAL FLOW

To carry out the simulation you need to collect the necessary information about the duration of the process from the factory, and define all the elements in AutoMod programme. Times shown for the duration of certain operations are measured at the factory. A statistical distribution is estimated. The aim was to obtain an adequate simulation model, so that the obtained results are close to the real situation.

The new layout proposal is located in the same area. Changes are related to the introduction of automated guided vehicles (AGV) and the belt conveyor.

Processes of filling jars of olives, pickle jar and closure are performed three workers.

Input buffer to create the new jar is queue qEnter. Queue qWait1 is the buffer space in which the sealed jars are disposed. Then the jars are transferred to the conveyor belt that transports them to the queue qWait2 which is limited to 20 units that can fit in a crate that is transferred to pasteurizer.
Currently, jars are imported into crates and then the pasteurizer. A simulation provided to AGV is limited to 20 units which would correspond to the amount of the transfer trays. Queues qpInput and qpOutput are set to be at the entrance and exit of pasteurizers and their role is to collect a sufficient number of jars that can at once be transferred to how pasteurizer simulation should not calculates pasteurization each jar. Queue qPaster is a space that is reserved for the pasteurizer and its capacity is limited to 420.
A queue qCooled is an area that is designated as a foot warehouse where the jars are disposed and are cool enough to be able to continue their way through the production process. Cooling process of jars with olives is partly carried on the belt conveyor.
In queue qLabel stored jars are labeled with dates. For inspection and possible errors in jars due to damage, followed by storage of the qReject in which are placed all jars with an error due to the restoration of the system.
Queues qPaket1 and qPaket are created for understanding simulation. The five jars go to qPaket1, then leave the simulation and one in qPaket where after the exit is a package after laminating.
Six jars are packed, and the final packaging sent for sale.
The last qStore warehouse is where the packages are stored on pallets.

The following elements of the simulation are defined:
Worker *R*1 - filling a jar of olives (12,2 sec - normal distribution)
Worker *R*2 - pouring marinade in a jar (10,1 sec - a uniform distribution)
Worker *R*3 - closing jars and disposal in Q1 (8 sec - an exponential distribution)
Queue *Q*1 - waiting to get a set of 20 jars in the crib and placing crates behind the bar
Queue *Q*2 - waiting for the AGV to take the crib on point cp1 where the vehicle is on cpIn
cpIn - entering the crate into the chamber for pasteurization *Q*3 (60.5 min - uniform distribution)
cpOut - crates go out from chamber *Q*3 and going to cp2 where crates are going to tape
Queue *Q*4 - crates cooling after pasteurization (25.3 min - normal distribution) and after going to the strip behind ;
Queue *Q*5 - entry and exit crates individual jars on tape for labeling (first jar out of the *Q*5 after 20.3 seconds the normal distribution , and each jar comes in the next 5 seconds continuously after the last) ;
Queue *Q*6 - quality control, 3 % waste and thrown in *Q*6 .
Queue *Q*7 - waiting to get 6 jars and powder coating is performed (20.4 seconds - a normal distribution), i.e . real packets that are then sent to the CP3, whereby the AGV drives to the cp4, where the warehouse (*Q*8) entrance is located;
Queue *Q*8 - a warehouse of finished products.

The following processes have been defined:
pEnter, pPunjenje, pDolivanje, pZatvaranje, pPasterIN, pPasterizacija, pPasterOUT, pHladjenje, pEtiketiranje, pPlastificiranje, pReject, pPaket1 and pStore, that represent the sequence of material flow in the factory.
Also, we have defined the following transport units (load):
lTegla - jar,
lPaster - 420 jars in the chamber for pasteurization,
lGajba - 20 jars,
lPaket - 6 jars packaged for sale.
Buffer or space for loads accumulation is defined by following queues:
qEnter (input buffer in which a new jar is created)
qWait1 (interwarehouse space in which sealed bottles are disposed, jars are then transferred to the and continue the transport by means of the belt conveyor to the queue qWait2.
qWait2 (20 jars filling the boxes to be sent to pasteurization)
qpUlaz (collect 21 crates, which represent 420 jars for transfer to pasteurizer)
qPaster (the process of pasteurization , 60 minutes)
qpIzlaz (collection boxes from the pasteurizer)
qCooled (cooling of jars after pasteurization, basement storage)
QLabel (labeling jars)
qReject (jars of rejection , damaged or defective)
qPaket1 (collection jars after labeling)
qPaket (packaging jar plastic coated in a package of 6 pieces)
qStore (formation of pallet storage and packaging weight).
Each of these buffers has unlimited capacity (conditional), except qPaster which is limited because it is a pasteurizer and its maximum capacity is 420 units, i.e. jars. The capacity of each queue can be defined separately.

3. THE SIMULATION

The flow simulation in the factory is shown in the Figure 3.

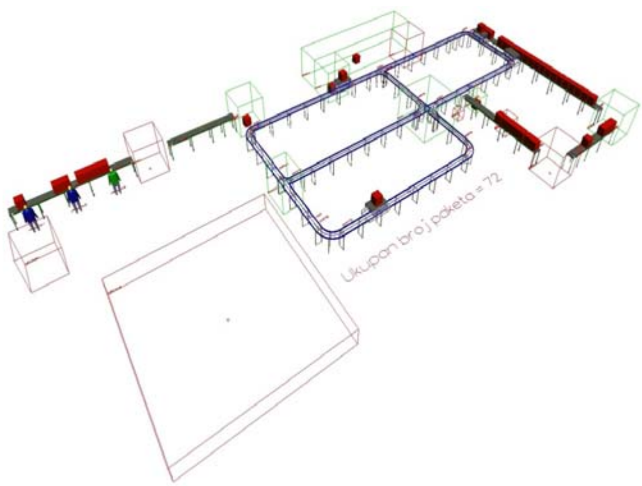


Fig. 3 Display of simulation flow

After filling jars of olives, their collection is done and they are sent to the pasteurizer.

Part of the Source file that includes the simulation of three workers filling jars of olives at the conveyor belt:

```
begin pPunjenje arriving procedure
    move into conv:sta1
    use rRadnik1 for normal 12,2 sec
    send to pDolivanje
end

begin pDolivanje arriving procedure
    travel to conv:sta2
    use rRadnik2 for uniform 10,1 sec
    send to pZatvaranje
end

begin pZatvaranje arriving procedure
    travel to conv:sta3
    use rRadnik3 for exponential 8 sec
    move into qWait1
    move into conv:sta4
    travel to conv:sta5
    move into qWait2
    move into agv:cp1
    travel to agv:cpIn
    send to pPasterIN
end
```

Part of the Source file that includes the simulation of olives pasteurization and cooling:

```
begin pPasterIN arriving procedure
    move into qpUlaz
    if qpUlaz current loads = 425 then
        begin
        order 420 loads from OL_Ulaz to continue
        end
    else wait to be ordered on OL_Ulaz
    send to pPasterizacija
end

begin pPasterizacija arriving procedure
    move into qPaster
    if qPaster current loads = 420 then
    begin
    wait for uniform 60,5 min
    order all loads from OL_Paster to continue
    move into qpIzlaz
    end
    else wait to be ordered on OL_Paster
    send to pPasterOUT
end

begin pPasterOUT arriving procedure
    wait for 5 min
    move into agv:cpOut
    send to pHladjenje
end
```

```
begin pHladjenje arriving procedure
    travel to agv:cp2
    move into conv:sta6
    travel to conv:sta7
    move into qCooled
    wait for normal 25,3 min
    move into conv:sta8
    travel to conv:sta9
    move into qLabel
    send to pEtiketiranje
end
```

The following process relates to the inspection. A procedure is defined to 3% of all jars that pass through labeling is scrap that is rejected in the buffer qReject (Figure 4).

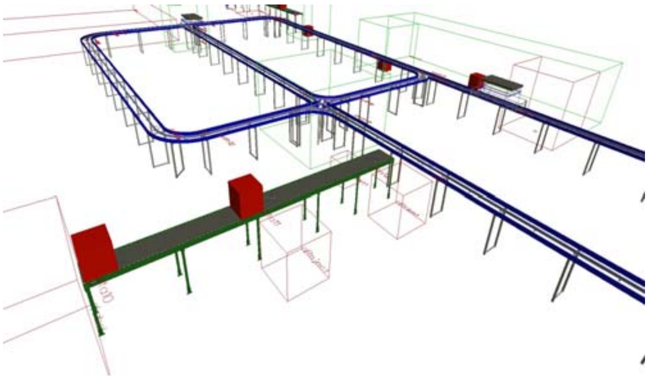
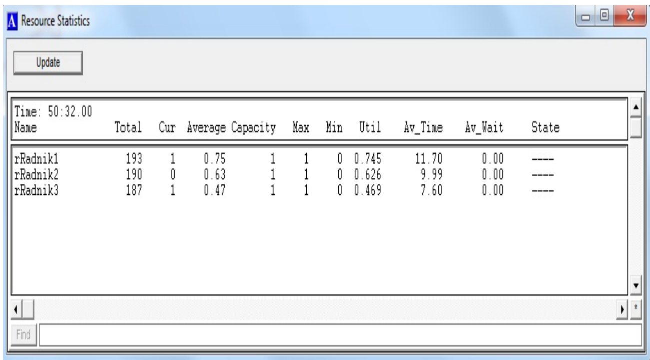


Fig. 4 Separation processes i.e. inspection and packaging

After that jars are going to labeling and packaging and laminating in a package of 6 pieces. After that packages go into storage jars.



Time: 50:32.00

Name	Total	Cur	Average	Capacity	Max	Min	Util	Av_Time	Av_Wait	State
rRadnik1	193	1	0.75	1	1	0	0.745	11.70	0.00	----
rRadnik2	190	0	0.63	1	1	0	0.626	9.99	0.00	----
rRadnik3	187	1	0.47	1	1	0	0.469	7.60	0.00	----

Fig. 5. Workers effects

It is determined the number of jars that workers can process over a period of eight hours, the approach is analyzed for the amount of time needed to empty the system. We counted the number of jars that enter the system for a certain period, and it is 1804 jars. It has been determined that it would take an additional 40 minutes to ensure that the last emptied pasteurizer after pasteurization process. Number of packages for this quantity is 270.

Because of the possibility of introducing a various number of AGV's, we are reviewing their number in the system. We consider the simulation with 2, 3, 4 and 5 AGV’s in the system. Simulations effects will be shown in the table below.

Table 1. The effects according to the number of AGV's in the system

Number of AGV’s	**2**	**3**	**4**	**5**
Number of completed pasteurization	**2**	**4**	**5**	**5**
Duration of the entire process	1:40 h	1:15 h	52 min	50 min
Duration of pasteurizer discharge	60 min	40 min	20 min	18 min

With two AGV’s in charge, duration of the process is too long and with the use of three AGV’s, results are better. The optimal effects we have with 4 or 5 AGV’s.
Since there are 3 workers in the beginning of the simulation, their effect for a shift is always equal and is approximately 1800 jars. The task implies automation of the production process by introducing AGVs. Therefore, the automation of this part of the production process has not been considered here with the aim of increasing the number of pallets. For the simulation of about 1800 jars, a number of packages has been about 270, for any number of automated guided vehicles that is placed in the system.

4. CONCLUSION

According to the obtained data, we conclude that the setting of the system and involvement in the work of at least three AGV's, we get twice the performance compared to the current situation in the factory. Also, we see that there is no significant difference in the selection of a number of AGV's. It can be 4 or 5 AGV’s and the discharge times of the simulations are similar. We come to the conclusion that the optimal number of AGV's is four for this system.

REFERENCES

[1] Leo Milošev, “Simulation of the material flow in packaging factory Eco-food” Graduated thesis, Faculty of Mechanical Engineering, University of Niš, 2014 (in Serbian).

[2] Averil M. Low, W. David Kelton, “Simulation, modeling and analysis” McGraw-Hill, 3rd edition, printed in Singapore, 2000.

[3] www.appliedmaterials.com

[4] www.ecofood.com

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GRIPPERS IN MANIPULATION PROCESSES

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Abstract

Material handling and logistics are expensive operations. Since material handling and logistic operations often involve a substantial amount of direct labor, it is very important to automate them and to use some automated handling devices such as grippers. A large range of grippers have played an important role in the development of all industrial automation solutions and especially a wide range of logistic manipulation processes. This paper present several grippers type used in manipulation processes in logistic, as well as their designing and selecting.

***Keywords**: manipulation, gripper, logistic.*

1. INTRODUCTION

The process of handling workpieces in production is often underrated as technically simple or even trivial. From the production point of view it is obvious that the workpiece itself does not increase in value during the handling process. As far as technical solutions are concerned, handling is secondary to the manufacturing process. Production time is separated into machine time and handling time [1].
Machine time is the period of time during which a machine is operating, making changes to the workpiece itself. Machine time can be further separated into pre-operating time, operating time, and post-operating time. Pre- and post-operating time include all necessary operations before and after operating time, such as supplying a tool or coolant. These intervals have been reduced to a minimum by high traverse rates and appropriate control technology over the past few years.
Handling time or auxiliary process time can be separated into single steps from setting up a workpiece to testing it. Production planning aims at synchronizing handling time and machine time in order to prevent time-consuming handling processes from taking up valuable machine time; or at least to keep handling time at a minimum and to move as many workpieces as possible per time unit. Machine time and handling time have to be coordinated: Machinery idling during workpiece handling is generally not acceptable, just as fast robots waiting for machinery do not make sense.
The handling process, Fig. 1, can be basically characterized by counting the workpieces moved per unit of time [2]. This characteristic, however, does not specify the amount of technical requirements for obtaining a desired cycle time. Complex workpieces and multiple ambient conditions can create different handling tasks to such an extent that a simple task of moving a workpiece from point A to B can become an extremely complex process. Human beings are naturally equipped with an enormously flexible “gripping technique”, efficient “sensors” and highly complex “data processing” and, therefore, tend to underrate such tasks.

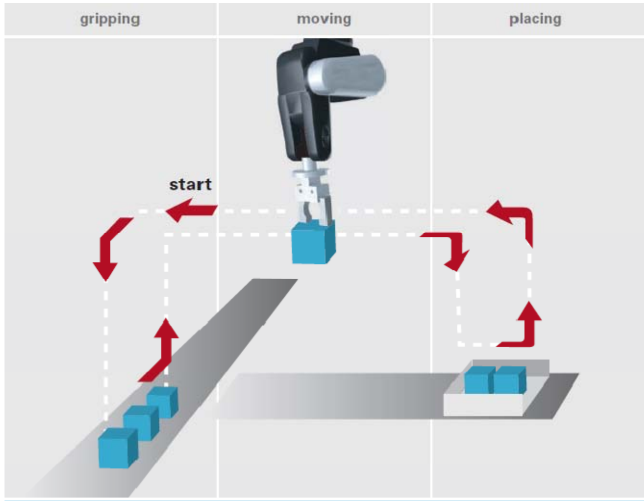

Fig. 1 Phases of handling process.

From practical experience in automation projects it is well know that unexpected technical and economic problems tend to occur especially when the handling process and all its parameters are not sufficiently analyzed and evaluated at an early stage.

2. GRIPPER TUPY

Gripper is an end-of-arm device often used in material handling applications. Grippers range in size from smaller than a matchbox to models weighing several hundred kilograms, capable of thousands of newtons of grip force. Generally, the gripper is a device that is capable of generating enough grip force to retain an object while the robot or some other device performs a task on the part such a pick-and-place operation. Each gripper must be capable of performing the task of opening and closing with a prescribed amount of force over many years of daily operation.
There are many gripper types and some basic gripper types can be summarized in Table 1.The most commonly used grippers are finger grippers. These grippers generally have two opposing fingers or three fingers like a lathe chuck. The fingers are driven together such that once gripped any

part is centered in the gripper. This gives some flexibility to the location of components at the pick-up point. Two finger grippers can be further split into parallel motion or angular motion fingers.

Table 1			
Type	**Application (Ideal Part)**	**Description**	**Mechanism**
Angular 2-jaw or 3-jaw	Pick-and- place, (spheres)	Jaws rotate about a fixed pivot point	Toggle arms, Cams, Gears
Parallel 2-jaw or 3-jaw	Material handling, (rod,billet stock)	Jaws translate, though parallel motion	Toggle arms, Cams, Gears, Wedges
Collet	Pins, contacts, round stock	Collet grips round part on OD o ID	Sliding Taper
Vacuum	Windshields, windows (Shrink wrapped products)	Suction cups grip smooth pats	Air pressure / vacuum
Magnetic	Sheet metal	Electro-magnet picks-up ferrous objects	Magnetic field
Needle	Fabrics	Sharp pins extend/retract at opposing angles	Cam
Expansion	Glassware	Inflatable bladder expands inside cavity	Air pressure

Angular jaw gripper is open and close around a central pivot point, moving in an arcing motion. An angular gripper is used when there is a need to get the tooling out of the way. The advantage for an angular gripper falls on its simple design and only requires one power source for activation. However, it has several disadvantages including jaws that are not parallel and a changing centre of grasp while closing.

Meanwhile, parallel jaw gripper moves in a motion parallel in relation to the gripper's body. A parallel gripper is used for pulling a part down inside a machine because the fingers fit into small areas better. An advantage of parallel type gripper is that the centre of the jaws does not move perpendicular to the axis of motion. Thus, once the gripper is centred on the object, it remains centred while the jaws close. Space constraints might lead to the use of parallel over angular. Fig. 2a and 2b shows the Parallel Jaw and Angular Jaw Gripper.

For some tasks however where flexible or fragile objects are being handled, the use of either vacuum [3,4,5], Fig 3, or magnetic grippers is preferable. With these, the surface of the gripper is placed in contact with the object and either a magnetic field or a vacuum is applied to hold them in contact.

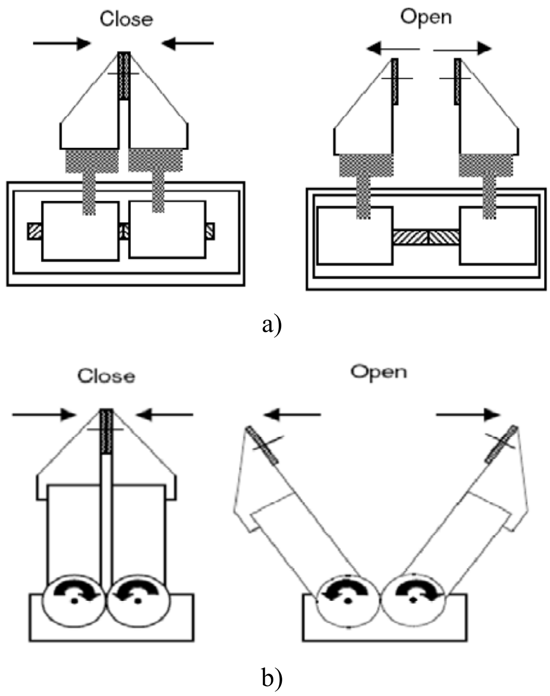

Fig. 2 Gripper: a) parallel, b) angular.

Fig. 3 Vacuum suction gripper.

There are additional two types of gripper that are used in industries. These grippers are a combination of the basic parallel and angular type. The first gripper is four-bar jaw linkage gripper, Fig. 4. Each jaw is a four-bar linkage that maintains the opposing jaws parallel while closing.

Meanwhile, the second type is the multiple jaw/chuck style, Fig. 5. This gripper is suitable for holding round and rod-like objects.

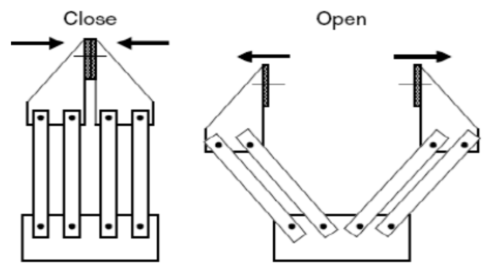

Fig. 4 Four bar linkage jaw gripper tupe.

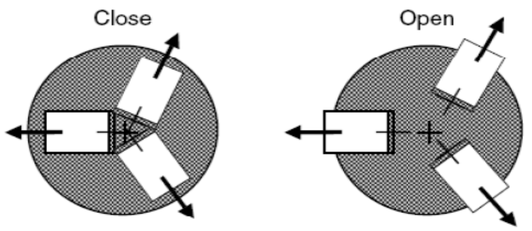

Fig. 5 Multiple jaw chuck tupe.

3. GRIPPER CALCULATION AND SELECTION

As it was shown in previous chapter, there are many gripper types. Also, there are different softwares for a gripper calculation and selection, each for the different type and manufacturer. The using of gripper calculation and selection softwares is very simple. At the start it is important to define the object of manipulation, its dimensions, shape, mass, ect., and after that, the software generates type and in some cases number of grippers, and all other necessary equipmant. In some software, there is a need for defining the manipulation path of workpiece.

As an example, the process of gripper calculation and selection is shown for selecting vacuum grippers, using program VACUUM SELECTION – Version 3.22.2.18 by FESTO. This program enables the result simulation, too.

The process of vacuum gripper selection goes through 11 pages:

- Start page,
- Workpiece,
- Positioning,
- Suction cup,
- Tube,
- Vacuum suction nozzle,
- Motion,
- Drive,
- Forces and moments,
- Suction cup load,
- Parts list.

The process of selecting follows the order of program pages. But if there is a need, it is possible to change some parameters in previous pages. Program stops and it is not possible to go on next page if some parameter is wrong or miss.

The workpiece page of the program is shown in Fig. 6.

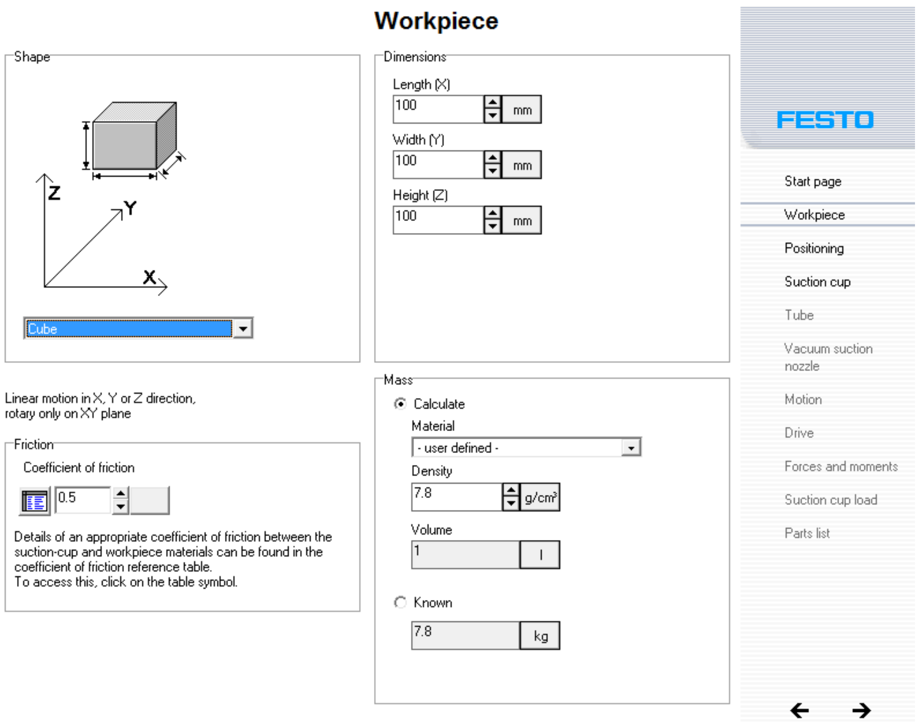

Fig.6 The workpiece page of program VACUUM SELECTION.

At the end of the gripper selecting process, in Parts list page is shown the selected gripper type and all necessary equipment, Fig. 7.

Parts list

	Art no	Order code	Description	x length	Quantity	Packaging unit
1	553907	PAN-6X1-BL	Tube		50 m	50 m
2	189177	ESG-60-EU-HDL-G	Suction cup		1	1
3	539074	OVEM-05-H-B-GN-CE-N-1N	Vacuum suction nozzle		1	1

Fig.7 The Parts list page of program VACUUM SELECTION.

4. PNEUMATIC GRIPPER - EXAMPLE

A pneumatic gripper is a specific type of pneumatic actuator that typically involves either parallel or angular motion of surfaces that will grip an object [6,7].

In Fig. 8 is presented an angular gripper for pharmaceutical application. The angular gripper is mounted to the end of a robotic arm. The gripper grips the test tube and moves it to the test station. The angular gripper provides a lighter weight gripper. Many styles and sizes of grippers exist so that the correct model can be selected for the application. The choice of gripper type is always determined by the properties of the object to be gripped and the purpose of the handling operation concerned. Some grippers act directly on the object they are gripping based on the force of the air pressure supplied to the gripper, while others will use a mechanism such as a gear or toggle to leverage the amount of force applied to the object being gripped. Grippers can also vary in terms of the opening size, the amount of force that can be applied, and the shape of the gripping surfaces. Pneumatically-driven grippers are robust and technically relatively simple; they are used in large numbers in all branches of industry. They can be used to pick up everything from very small items such as a transistor or chip for an electronic assembly board, to very large items, such as an engine block for a car.

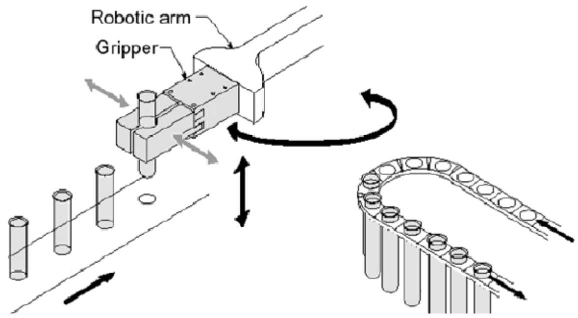

Fig. 8 Aplication of angular gripper.

Fig. 9 shows that the multi-motion actuators and grippers are used in pick and place application for some industry. It handles and transfer delicate glass containers throughout the filing, mixing and measuring process. The completed containers are loaded onto a pallet and transferred to the next station.

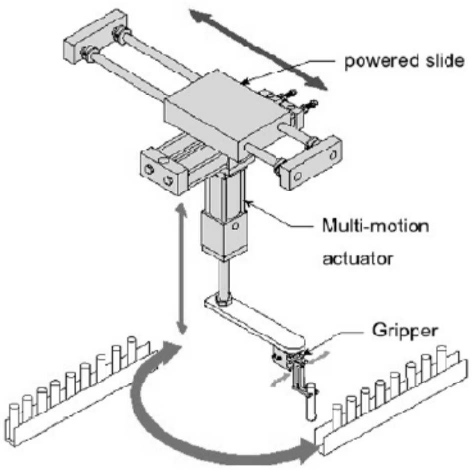

Fig. 9 Pick and place.

The gripper presented in Fig. 10 is design for long stroke, high force capability. Used as an end effector on an industrial robot the synchronized parallel action automatically centers items for operations such as sorting. The long stroke compensates for items of varying size or position.

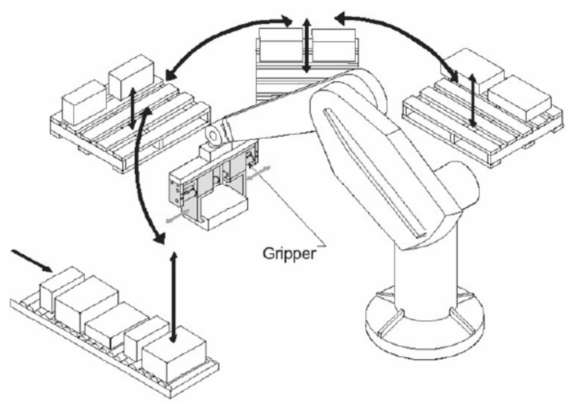

Fig. 10 Gripper for long travel.

5. CONCLUSION

Material handling is expensive operation and often involves a substantial amount of direct labor. It is very important to automate this proces and to use some automated handling devices such as grippers. A large range of grippers have played an important role in the development of all industrial automation solutions and especially a wide range of logistic manipulation processes. In this paper, several gripper types that are used in manipulation processes in production and logistic are shown. Calculating and selecting process of grippers are presented, too. It was shown the simplicity of gripper calculating and selecting by Vacuum selection program for vacuum suction gripper.

ACKNOWLEDGMENT

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REFERENCES

[1] A. Wolf, R. Steinmann, and H. Schunk, “Grippers in Motion – The Fascination of Automated Handling Tasks”, Springer-Verlag Berlin Heidelberg, 2005.

[2] L. Biagiotti, G. Lotti, C. Melchiorri, and G. Vassura, “Design Aspects For Advanced Robot Hands”, IEEE/RSJ Internation Conferece, Laussane, 2002.

[3] V. Blagojević, and M. Stojiljković, “CAD sistem za vakuumsko upravčjanje”, The Proceedings of HIPNEF 2002, Vrnjačka Banja, 2002, pp. 75-81.

[4] M. Arsić, V. Blagojević, and T. Blagojević, “Vacuum Szstems Management in Manipulation Process”, The Proceedings of HIPNEF 2008, Vrnjačka Banja, 2008, pp. 161-164.

[5] FESTO, “Vacuum Technology”, Catalog, 2014.

[6] S. Hesse, “Grippers and their applications”, Blue Digest on Automation, published by FESTO, 2004.

[7] I. Ichim, “Pneumatic Applied to Logistic System”, ANNALS of the ORADEA UNIVERSITY, Fascicle of Management and Technological Engineering, Volume VI (XVI), 2007, pp. 2282-2289.

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TECHNICAL DEVICE SOLUTION FOR KINEMATICS CONTROL OF MINING EXPORT MACHINES

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Abstract

This paper has demonstrated a new solution of industrial equipment for contact speed measurement of export containers (skips) on mining export machinery. Industrial solution is based on a stationary device that optically and periodically measures the rotation speed of the driving drum, mining export speed of machines and records kinematic peaks. The solution is obtained based on the observation that requires "Regulation on technical norms in the transportation of people and material within the mine shafts" "Službeni glasnik SRJ", no.18/92. The solution demonstrates electronic concept of technical solution and the results of experimental measurements, the developed prototype on mining equipment. The solution is derived and adapted to performances of export machines ASEA HSDE 2.5 in the mine basin Bor for rated speed of vertical transport up to 16 m/s.

Keywords*: Exporting machin, Maining, Kinematics.*

1. INTRODUCTION

Within the project [1], technical solution of industrial equipment for kinematics control of export mining machines has been developed. Activities were carried out by Mechanical and Electronic Faculty in Nis. Measuring and monitoring system is universal and enables monitoring the speed and acceleration of export machines upon vertical transport from a mine shaft. Frequent monthly, irregular and regular annual checks of export machines and their everyday performances, are the basis of the importance of existence of independent industrial equipment for monitoring performances – export machines kinematics. The device is also necessary to adjust to the automatic management of mining export machines and to set up the parameters of electric plant in the mine shaft. Setting equipment up refers to the speed upon starting, running and stopping. This system development follows the basis of the earlier developed contact speed transducer.

The concept of the equipment is universal and can be adjusted to different types of export machines by setting up the measurement system. This report briefly describes the developed system for measuring and monitoring kinematic characteristics – speed and acceleration of mining export machines. Technical characteristics of industrial equipment for mining export machines kinematic control are given in Table 1.

Table 1. Technical characteristics of measuring device

MEASURING DEVICE	
Frequent area:	0-10 kHz
Equipment/encoder mass:	6.5/0.35 kg.
Power supply:	230 V / 50 Hz.
Output:	Analogni 0-5 V DC
Encoder:	**Ei-IE-500-01**
Maximum rotation speed:	3475 ^{o}/min.
Measurement range:	0 ÷ 365 rad./sek
Resolution:	360/500
Impulses per 1 cycle	0.72 degrees.
Relative error:	ε<1%.
Response time:	0.1 sec.
Dimensions:	360x320x155 mm.
Minimum measurement speed:	100 samples/1sec
Range of transport speed:	16 m/sec.

The proposed technical solution is the original author's solution created by multi-year monitoring and experimental work with a variety of technical systems [1,2,3,4,5,6]. Common scientific basis with other solution for measuring rotation speed in the world is using optical incremental encoders as a trusted source of measurement data. There wasn't any other prototype or other technical equipment upon realization of this technical solution. The derived device has gained original purpose as a source of multiple kinematic data. The device is calibrated electronically. The derived technical solution has been improved throughout 20 years and it is completely in accordance with technological level of world measurement devices.

2. OPERATING CONCEPT OF MINING SKIP

Kinematic parameters of mining shaft skip are limited by safety regularities to 20/10/5 m/s. Rapid acceleration and deceleration are undesirable so controlled drives are applied, as well as regulated braking systems, controlled speed, and acceleration of the hoist basket. Maximum speed is controlled upon periodical maintenance. Acceleration and deceleration of the transport system ($+a_{MAX}$ i $-a_{MAX}$) is mostly the cause of the most extreme working regime where the mining export machines is located. In this extreme mode engine power activity is up to 5 [MW] and braking moments is up to 0.5 [MNm]. The masses of the vertical range often reach 80 [t] and rotation mass of the plant systems exceeding 100 [t]. Such high speeds are used for cyclic transport of ores with the intervals on 160-400 seconds, providing a capacity of some mining export machines up to 500t/hour. Such transport of ores is carried to an altitude of 500m. The risk of these plants' activities is

reduced by high-quality speed regulation and acceleration of the mining shaft skip. This is only one of the many security items in the whole range of security systems.
Regardless of all the systems, security is technically and administratively controlled externally by independent accredited state agencies and commissions. Such responsibility labor of mining export machines caused the requirements for the continued existence of additional measuring system for monitoring the kinematics of the transport process in the export panel. On the basis of previous perception we was developed original electronic measuring system that enables to display digital measuring indicators, such as:

- the current speed of the mining shaft skip *V (m/s)*,
- maximum acceleration when mining shaft skip starting *+a max* (m/s^2) and
-deceleration when mining shaft skip braking *-a max* (m/s^2).

Beside of monitoring transport system performance, there is a need for tracking dynamic behavior of the mining shaft skip. For this reason, the measuring system enables output analogue and digital measuring signals suitable for recording by using the appropriate measuring and computer equipment.

At the entrance of the measuring system there is a electromechanical converter of angular velocity – incremental encoder which is mechanically connected with the winch of a mining export machines and provides information about skip movement speed.

The encoder at the exit provides digital information (transformation coefficient is 500 impulses per cycle x coefficient of tachometer disc on the measuring system). Additional transformation of the signal, then scaling is done in the input circuit of the measuring system in order to get more measuring range and level adjusting.

In order to obtain measuring signal of speed, F/V converter is used in the range 0-10 kHz. Additional processing of the measuring signal is performed in the block of Signal Processor which contains integrator, NF filter (Butterworth of the second order), and the calibrator, resulting in a precise and accurate measuring speed signal. In previously conducted researches and in this paper, using such a principle of measuring, measuring errors was less then 1%.

For the analysis of performance of the transport system, measuring system contains data acquisition module with 2 inputs for A/D conversion, memory card, and a communicational interface with a USB connection. Measurement system is powered from electrical network of 230V/50 Hz, and there is also a variant with autonomous battery power.

3. INSTALLATION OF MEASURING DEVICE

Physical control device is portable and designed for use in the operating rotating drum system of a mining export machines. Figure 1 illustrates a control device in a folded position.

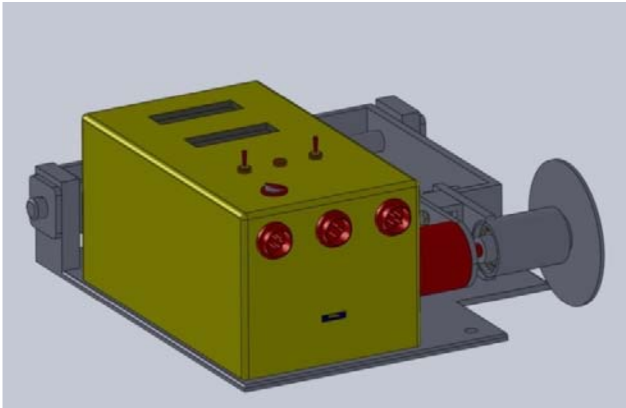

Fig. 1: The geometric model of the assembly of industrial control devices

Measuring devices are located on the plane of the brake disc. Brake Disc is located at drum export machinery. A mining export machines (fig. 2) contains of a direct current electro-engine (1), tachogenerators and devices for marking positions (electric signaling of the control – 2), Koeepe-drum with braking discs and grooves for the hoisting ropes (3), braking system with hydraulic disc brakes (4), support (plant) ropes (5), export container (6), counterweight (7), balancing (bottom) ropes (8), connecting tools (9), and the controller (10).

The speed control device with its friction disk touches the smooth cylindrical surface of the export machines braking disc. Moving of the encoder is enabled by export machines braking disc. That is how the input digital signal is obtained.

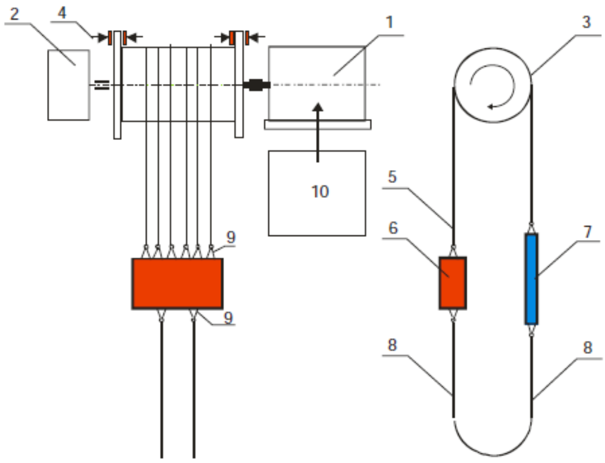

Fig 2: Scheme of main export machines with Koeepe drums

4. CONTROL DEVICE TESTING

Detail of measuring contact on speed examination in the north shaft of RBB in Bor on ASEA HSDE 2.5 machine is illustrated in fig. 3. In figure 4 and 5 the original diagrams of the kinematic records of the empty/full skip movement (upon the highest disbalance with the counterweigth) to a depth of about 400 m are illustrated. Regulation is done manually with continuous acceleration and braking od the engine, as well as with the final braking deceleration and a final full stop. In the diagrams we can see smooth speed change with moderate acceleration and deceleration, and sudden deceleration upon stopping with two braking discs. That indicates an extreme deceleration and impact dynamic regime which is controlled by setting up the brakes of the device.

Fig. 3 Detail of measuring contact

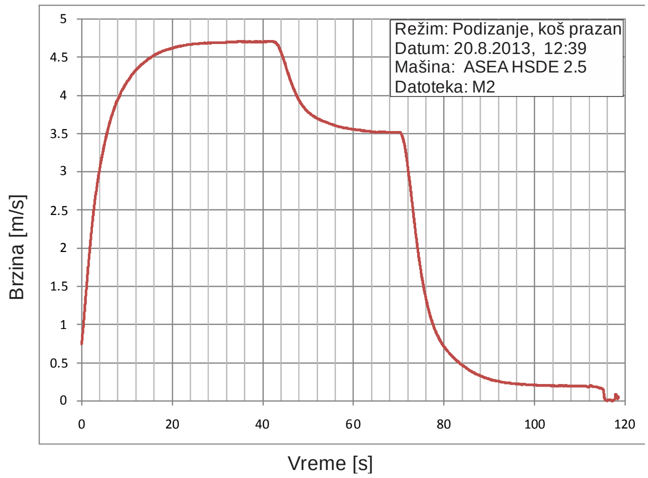

Fig. 4 Measuring the speed of the basket: Mode: Lifting the basket, load: Q=0 t, Speed: V_{MAX}= 4.709 m/s

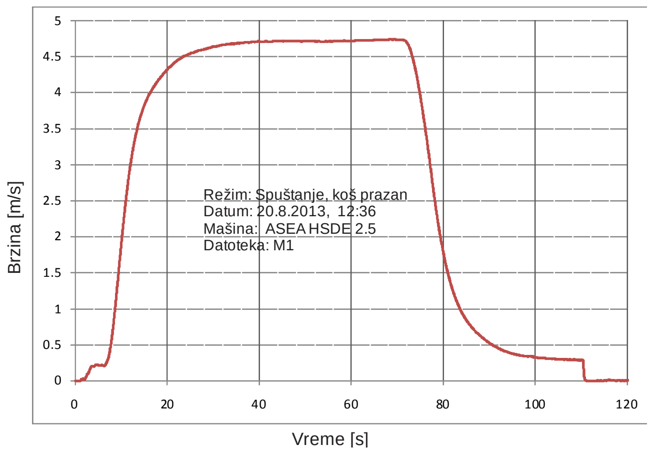

Fig. 5 Diagram of kinematics lowering the skip in the pane speed 4,70 m/s (starting, running and stopping)

5. TECHNICAL REALIZATION OF THE IDEA

The device is designed, that after the measurement it gets folded. The handle is lifted upon measuring and set up in the operationg position, figure 6, in the differentiator block, which provides time-varying acceleration function. That solution is adapted to industrial use, it is robust and durable. The handle is derived in such a way that it allows dumping of the low mechanical spectrum of frequencies. Measuring disc is made of a light material, because of that does not manifest its own inertia in measuring. A plastic box with electronics is fixed on the basic stand. Inside the box, there are 3 electronic boards placed parallel. The forth board is a digital interface for outputs towards other systems by the USB 2.0 protocol.

There are two displays on the box. The first shows the current speed and it quickly processes information. The second display is for calculation and illustration of the highest acceleration separated in the observed time interval up to the memory reset. The selection of the maximum positive or negative acceleration is done on the right switch. The beginning of the new measuring is done on the left switch. To turn on the device, there is a main switch on the top surface, and on the back of the box there is a bayonet fuse.

Fig. 6.a,b Control device with electronic boards

6. CONCLUSION

Presented concept of technical solutions in the form of industrial measuring devices and control kinematics of mining export machines is the reality of modern and practical technology. This procedure can be successfully applied to the structures exposed to special actions. Therefore, it can be concluded:

1. The developed device is used for industrial purposes of contact measuring based on the rotation of a measuring disc and optical incremental encoder.
2. Industrial device has been tested on several types of rotor vehicles and cranes [7,8,9] and represents final electronic version for industry.
3. Such a developed technical solution in the form of an industrial device offers the possibility of reading and recording kinematic value significant for mining.
4. In addition to applications in the mining industry where the industrial device is used for monitoring the kinematics of mining export machines, it is also widely applicable in many other industries.
5. The industrial device has electronically and experimentally tested. Testing was passed successfully and the results are evident.
6. The solution is both simple and practical for mass production.

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REFERENCES

[1] Jovanović M., Arsić M, Radoičić G., Tomić V, Marković D: Teorijsko eksperimentalna istraživanja transportnih mašinskih sistema, Projekat Ministarstva prosvete, nauke i teh. razvoja RS, TR35049, Mašinski fakultet Niš, 2013.

[2] Arsić M., Jovanović M., Merenje dinamičkih parametara pogonskog mehanizma dizalice, Elektrotehnički fakultet, Zbornik radova JUKEM '90, Sarajevo 1990.

[3] Jovanović M., Arsić M, Manić M., Merenje dinamičkih parametara kočnica železničkih vozila, časopis Železnice 12/94, pp. 917-919, Beograd.

[4] Jovanović M., Manić M., Arsić M, Denić D, Merenje specifičnih dinamičkih parametara kod transportnih mašina, 13. Int. konferencija za rukovanje i uskladištenje materijala, Mašinski f. Beograd 1994.

[5] Denić D., Arsić M., Djordjević G., Jovanović M., Digitalne tehnike merenja brzine obrtanja motora, IX Simpozijum Energetska Elektronika Ee-97, pp. 600-607, Novi Sad 1997.

[6] Jovanović M., Mijajlović R., Marinković Z., Arsić M., Denić D., Živanović D. Primena elektronskih rešenja u pozicioniranju radnih mašina, IV Međ. naučni skup IPS'97, Podgorica - Bečići,

[7] Jovanović M., Mijajlović R., idr. APD - automatska regalna dizalica, Inovacioni projekat MNT Srbije I.5.1333, Mašinski fakultet - MIN Niš 1996/97.

[8] M.Jovanović: Ispitivanje izvoznih mašina Servisnog i Izvoznog okna RBB Bor, MIN Institut, maja 2010.

[9] M.Jovanović i drugi: Vanredni tehnički pregled izvoznih mašina Servisnog okna u RBB Bor, Ekspertiza, Mašinski fakultet Niš, Oktobar 2013.

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THE APPLICATION OF RFID TECHNOLOGY IN THE TOOLS SUPPLY OF CNC MACHINE

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Abstract

The RFID technology is recognized as the best automatic identification technology aimed to accelerating and facilitating the information flow and products monitoring. RFID technology based on radio-frequency data exchange greatly simplifies and accelerates the process of keeping records of working time tools, the abillity to replace tools and to monitor in real time. RFID technology has shown the greatest improvement in the SCM (Supply Chain Managment) who becomes an example of use of new communication and information techologies in monitoring products. This paper presents the basic functioning of RFID technology, its application in practice, with special emphasis on the implementation of the automated supply tools with CNC machines.

***Keywords**: RFID, CNC, Tool, Supply Chain Management.*

1. INTRODUCTION

Today's modern machining centers frequently use fully automated CNC programmable systems. These machines are often used to produce application critical and expensive parts. It is important to guarantee that a part is processed with the right tool, that the CNC controller has received the correct setup parameters, and that the controller is running the proper program.
Radio Frequency Identification Systems or RFID has been in existence in some form for over 50 years. It is simply the wireless transmission of information from a transponder (tag) to a transceiver (head). It started as a simple binary coded system where only a few bits of information could be stored at short read ranges and has evolved to thousands of bytes of storage at very long distances.
It is used to identify, track, sort and detect an infinite variety of objects, including people, vehicles, garments, containers, totes and pallets. It can be used in applications such as industrial closed loop tracking, pet/animal identification, package routing, passports, container tracking, inventory control, tollbooth auto payment, logistics, and access control.
The exact selection of the right tool is accomplished using an RFID tag that is permanently mounted on the tool carrier. The tool carrier and tool form a unit. With this information the work process, the installed tool, and the selected CNC program can be verified.

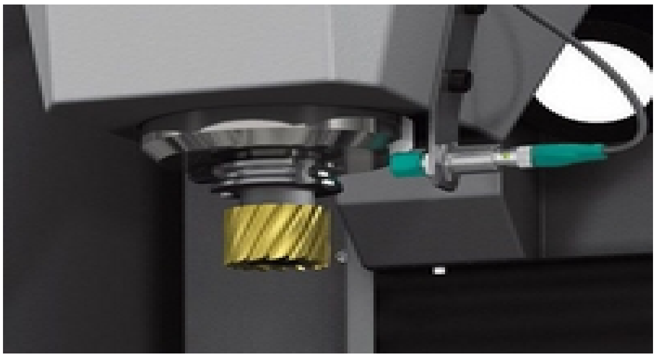

Fig. 1 Machine tool verification with RFID

Using the RFID data, a verification check is performed before the machining process begins. With this process in place, almost scrap-free processing of parts and minimal machine downtime, plus fast, automatic setup and changeover can be accomplished.
This application is particularly well addressed using the IDENTControl Compact interface in conjunction with small read heads and fully-embeddable RFID tags. Those parts can be integrated without the fear of interference. Reliable operation, even under the harshest application conditions, is assured. RFID interfaces supporting commonly available industrial communication networks make this a global solution.

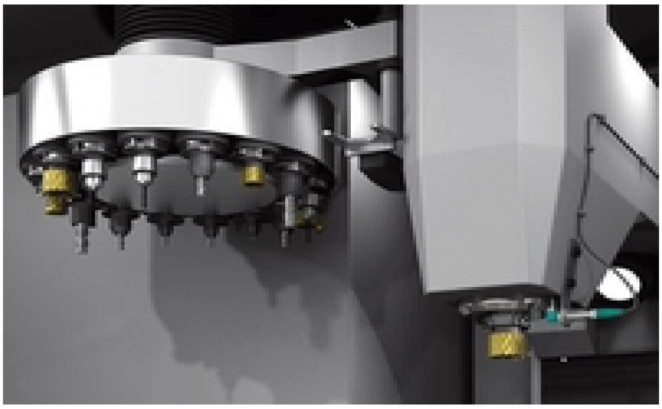

Fig. 2 The RFID system enables the automatic tool changer setup to securely pick the right tool

IDENTControl Compact industrial RFID satisfies the requirements of machine tool builders world wide: Robust, reliable, and with support for all commonly-used communication interfaces.
Insufficient support material and services materials such as maintenance, repair, operation (MRO) and capital equipment supply, often leads to excessive downtime costs,while at the same time these spares have a low demand rate making it

difficult to predict their availability. Without the preventive control, the production process might shut down due to the tool downtime. Tool downtime translates to reduced profitability, higher variance in lead-time and reduced competitiveness. Thus, improving tool management performance dramatically impacts company profitability. With the advent of RFID technology, a sensor (RFID) driven maintenance system of cutting tools can be examined as an effective approach for tool management. RFID, which has the same purpose as a bar code, provides an unique identifier for the objects. The most significant advantage of RFID over the bar code is that the RFID does not have to be positioned precisely and can function approximately 20 feet from the scanner. RFID technology not only can help businesses satisfy customer requirement, but also increase productivity to stay competitive. Most applications in the manufacturing field focus on using RFID in the finish goods to monitor the product logistic flow [1]. However, RFID technology offers the possibility of significantly enhancing tool management and tool procurement process. In the industrial procurement process, high-value materials are usually procured via the Request for Quotation (RFQ) process which allows the purchaser to be determined by various attributes, involving not only price, but also quality, lead time, supplier reputation, and contract terms. The process lets manufacturers reveal their preferences and permits the suppliers to compete on their own specializations [2]. A typical RFQ process starts when a request for quotation is sent out to a variety of business partners; the returned quotes are received, and finally the best quote is selected [3]. However, the RFQ process is usually time-consuming process such as the negotiation with business partners. Therefore, there is an increasing trend to automate the RFQ process to reduce procurement lead time and cost. One of the key enables for such business process automation is the Business Process Execution Language (BPEL). BPEL is currently the preferred workflow language providing the flexibility [4]. The detail description of BPEL will discuss in the next section. Based on the RFID, RFQ, and BPEL background study, this paper builds an RFID-based workflow system for tool quotation process within and between the supply chains.

2. RFID SYSTEM

An RFID system is an integrated collection of components that implement an RFID solution. An RFID system consists of the following components (in singular form) from an end-to-end perspective:

- Tag. This is a mandatory component of any RFID system.
- Reader. This is a mandatory component, too.
- Reader antenna. This is another mandatory component. Some current readers available today have built-in antennas.
- Controller. This is a mandatory component.

However, most of the new-generation readers have this component built in to them.

- Sensor, actuator, and annunciator. These optional components are needed for external input and output of the system.
- Host and software system. Theoretically, an RFID system can function independently without this component. Practically, an RFID system is close to worthless without this component.
- Communication infrastructure. This mandatory component is a collection of both wired and wireless network and serial connection infrastructure needed to connect the previously listed components together to effectively communicate with each other.

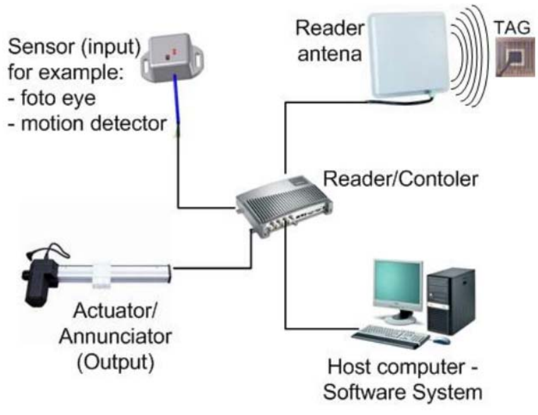

Fig. 3 An RFID system with example components

Fig. 3. shows an instantiation of this schematic with example components. RFID technology implemented in disassembly system enables upgrading of information distribution about product at specific working places (e.g. description of partial working (disassembly) operations), process real-time control, supervision of free workers at individual working places, tracking accomplishment of individual operations, etc.

3. FRAMEWORK OF SPARE PARTS SUPPLY CHAIN MANAGEMENT

The demand of cutting tool is triggered from the shop floor layer. Each Computer Numerical Control (CNC) tool is attached with a RFID tag thatrecords tool's preset data (projection, edge radius, and effective diameter), operation data (speeds, feeds and depth of cut) and the usage time. When the tool is attached to the spindle, the RFID reader on the CNC machine is configured to read the data from the RFID tags. This avoids most common sources of potential data entry errors, tool-offsetting errors and possible tool crashes. After the completion of each operation, the RFID encoder on the CNC machine is programmed to write the usage time of the tool onto the RFID tag and further update the Quality Performance Management (QPM) system. Based on the demand for tool replacement as scheduled by QPM, a purchase order can be created from ERP in advance to avoid shortages and reduce downtime.

Process Automation with Web Services (PAWS) is an automatic workflow systemfor tool quotation process within and between the supply chains. In PAWS, ERP broadcasts the tool requirements to the web services of certificated suppliers registered with the Universal Description Discovery and Integration (UDDI) server. Suppliers Web Services (SWS) locating in each supplier's server verifies the inventory and price in its own database and respond to the quotation based on its current status. The business logic of the Request for Quotation (RFQ) process in PAWS decides the candidate supplier and starts another RFQ process for logistic provider. This automation workflow system not only integrates the inner-business process including QPM, ERP, and mailing system, but also combines the business-to-business (B2B) process in the supply chain. In the following sections, individual layer with prototype systems are discussed.

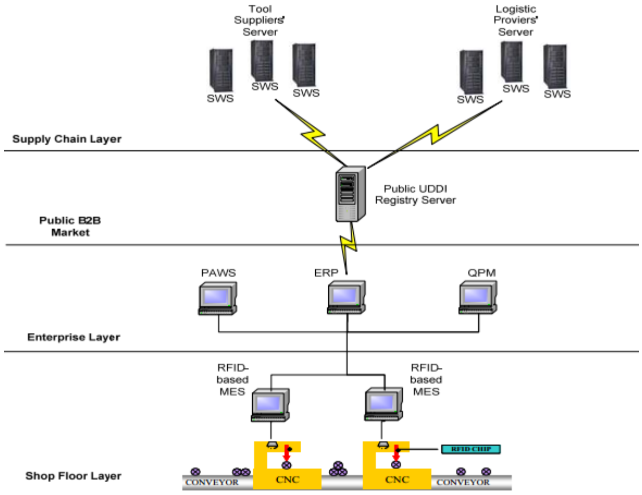

Fig. 4 Framework of applying RFID in cutting tool supply chain management

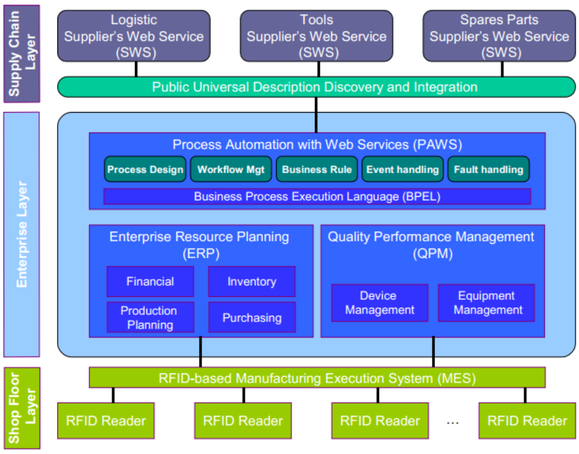

Fig. 5 Software Architecturet

Supply Chain Layer is a layer, where a tool replenishment process is enabled by RFID and response to request for quotation (RFQ). The RFID information providing tool specification is used for procuring replacement of cutting tools from among several vendors. To illustrate the variety of supply chain, we emulate external actors including tools vendors, spare parts vendors and logistic vendors. SWS in each supplier's server verify the inventory and price in its own database and responds to the quotation based on its current status. Onthe procurement side, the main business process will be supplier selection based on responses to RFQ.
Enterprise Layer consists of some components. The main software components in this layer include ERP, QPM, PAWS.
ERP: The core system for enterprise operation includes foundation data (customer profile, supplier profile, and product profile), and production information (material requirement planning, bill of material, and routing). According to the production planning and inventory, ERP create shop orders to produce the product, purchase order to buy raw material, and spare parts. The financial module supports the purchasing transaction. In the proof-of-concept implementation, we used the TEAM (Total Enterprise Application Manager) as the ERP system.
QPM: A critical business system which capturing data, processing data, and reporting information that is required for ISO/QS9000 fills the gaps of ERP systems. This paper adopted the solution provided by IQS, Inc. as the implementation platform. The QPM system accumulates the tool usage time for cutting tools and CNC machines, and triggers the demand for the tool replacement in the device management module and preventive maintenance time for the CNC machine in the equipment management module. Based on the demand of tool replacement scheduled by QPM system, the ERP systemcreate the purchase order to the spare parts vendors in advance to avoid shortages and reduce downtime.

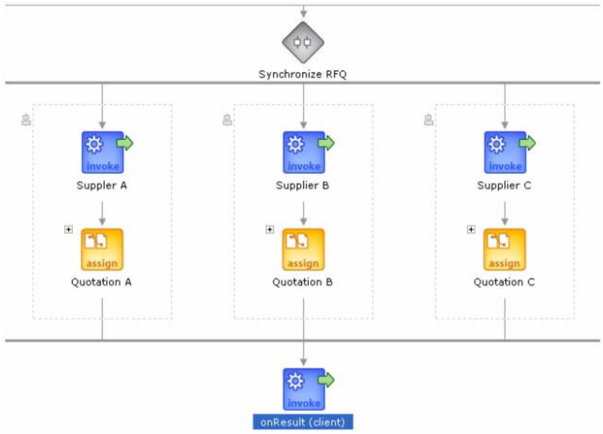

Fig. 6 BPEL plug-in in Eclipse environment

PAWS: Based on one kind of process description languages, BPEL, PAWS constructs the automatic business process mechanism. BPEL is a combination of graph-oriented and procedure workflow language to describe the business process. It specifies the business process and interaction protocols [5]. In BPEL, each task unit is defined as an activity. The basic activities include messaging (receive, invoke, and reply), data handing (assign) as well as many other kinds of control element: branch, iteration, event handling, fault handling, and compensation (canceling of committed actions). Figure 6 shows BPEL plug-in in the Eclipse environment. The advantage of BPEL is that the business process can incorporate different functions provided by web service partners which also solves the business integration implicitly. By representing a workflow that coordinates activities among other web services, BPEL allows the web services to invoke other web services, manipulate data and handle exceptions.
PAWS is an automatic workflow system for tool quotation process within and between the supply chains. The business logic of the RFQ process in PAWS decides the candidate supplier and starts another RFQ process for logistic provider. Business analysts and managers are able to easily compose business processes graphically with tools such as Oracle BPEL Manager. These development tools allow for the logic

of the business process to be specified by graphically linking together desired activities.The flowchart in Fig. 7 is a screen from Oracle BPEL Manager. It is a graphical representation of the BPEL process implementing the RFQ process. As shown in the flowchart, the BPEL process broadcasts the RFQ synchronous to each supplier. Thus, PAWS demonstrates the use of workflow systems with the accuracy of RFID data collection to automatea transaction process to reduce the lead-time for the RFQ process.

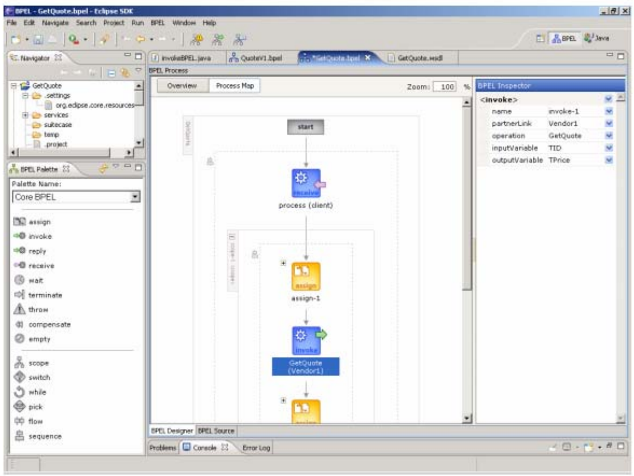

Fig. 7 Broadcast RFQ to each supplier in PAWS

RFID devices: This paper adopted the RFID device and RFID tag provided by Balluff, Inc. in the proof-of-concept implementation. The RFID device can function as RFID reader as well as RFID encoder. The RFID tag attached on the cutting tool recorded the tool information and production parameters (Fig. 8, Fig. 9).

Fig. 8 Cutting tool with embedded RFID tag

RFID device functioned as reader detects the tag and transfers data into RFID-based manufacturing execution system. RFID device functioned as encoder writes operation status, remaining tool life, and calibration data into RFID tag. The tool usage time for cutting tools and CNC machines in the RFID tag trigger the demand for the tool replacement and preventive maintenance time for the CNC machine.The tool usage time accumulation process is executed automatically by RFID technology, eliminating potential data entry errors and lost data.

Fig. 9 Cutting Tool on the CNC machine

4. CONCLUSIONS

The adoption of Radio Frequency Identification (RFID) technology or other related technologies for real-time sensing and communication provides strong capabilities for real-time service. In this paper, RFID is applied to solve the tool management problem, and the analysis of the RFID information flow help to understand the impact of integrating this technology into existing IT infrastructure and enterprise software. RFID-based automated process reducing more than 50% of data entry time and improving accuracy. The implementation for this application proved the benefit of applying RFID in spare parts supply chain. In the RFQ process, we only adopt the mandatory quotation data field.

ACKNOWLEDGMENT

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REFERENCES

[1] S. Lahiri, RFID Sourcebook: IBM Press, 2005.

[2] D. R. Beil and L. M. Wein, "An Inverse-Optimization-Based Auction Mechanism to Support a Multiattribute RFQ Process," Management Science, vol. 49, 2003.

[3] J. Loehler, G. Tirenni, and S. Kumaran, "From Business Process Model to Consistent Implementation: A Case for Formal Verification Methods," presented at Proceedings of the Sixth International Enterprise Distributed Object Computing Conference, 2002.

[4] "BPEL. Business Process Execution Language for Web Services Version 1.1," 2003.

[5] A. Akram, D. Meredith, and R. Allan, "Evaluation of BPEL to Scientific Workflows," presented at Sixth IEEE International Symposium on Cluster Computing and the Grid (CCGRID'06) 2006.

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INVESTIGATION OF INTERNET B2B/B2C MODELS SELECTION OF USED CRANES

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Abstract

The objective of market research is to reach the precise cost of used equipment. Observing the market of used transportation machines required is the best offer for the given characteristics. Starting from the value of new transport machinery subtracting the amortization values, can be better determine the value of used equipment. These individualized offers can be obtained by applying B2B/B2C e-business models. Offer of Internet market can be better analyzed using the amortization criterion. In this paper we have used three well-known models of criterion amortization. For them, it was determined the degree of proximity to the market. On the basis of this study, proposed a new interpolation model that is valid for one domain of tower cranes in today's e-business. The results are illustrated graphically and numerically.

Key words: *Tower crane, e-business, B2B/B2C model, rate of amortization*

1. INTRODUCTION

This work describes the online research for the purchase of used transportation machines. Given the value of these resources, it is more accurate to approach an objective value of the machines. That is determined by economic business models and market laws. This research provides an overview of the economic model of determining the price of selected categories of equipment (class tower cranes). For this purpose, the Web service and B2B/B2C model of electronic commerce were used. Using this electronic model, European and Asian markets were searched, and the results which were statistically analyzed were presented. Processing these results involves the classification of offered machines or tower cranes on the market, their classification into classes, sizes and individual depreciation.

2. INTERNET MODEL B2B/B2C

The future of e-commerce and trade payments lies in the online performance of all marketing activities, from production to consumption. Internet has become not only an alternative communication medium, but also the electronic version of the physical market. Internet primarily reduces the cost of search of the customer himself and of obtainment of information about prices and product characteristics, as well as the seller's costs of conveying information about prices and product characteristics. B2B-Companies doing business with each other such as manufacturers selling to distributors and wholesalers selling to retailers. Pricing is based on quantity of order and is often negotiable. B2C- Business that sells its products or services to consumers over the Internet for their own use. Online Retailers (Amazon.com) Online Banking, Travel Services, Health Information, Real Estate. [1,3]

Table 1. Benefits of B2B/ B2C models [5]

Benefits	Example
The geographical range	Geographical distance is not a barrier from the standpoint of electronic sales of goods and services to customers or engaging in interaction with suppliers.
Speed	Almost instantaneous exchange of information means that the interaction between sellers and buyers performs at high speed.
Productivity	The productivity of individuals is much greater if they are able to perform a greater amount of work for the same time. Using a lesser amount of time for aquiring information means means more time for their use, which directly increases the work efficiency.
The division of information	All forms of information - text, audio, video, graphics and animation - can be sent to all participants in the network.
New features	Products and services offered through the communication network can have new features added to them, including their personalization, automatic logging activities and immediate delivery .
Lower costs	Operating costs are reduced if you can contact companies and individuals quickly and regardless of their geographical distance, while at the same time efficiency is improving, which occurs due to the possibility of electronic information exchange.
Competitive advantage	Companies that are able to develop and implement effective e-commerce strategy achieved significant business benefits.

3. AMORTIZATION

Amortization is the value spending of fixed assets. This is the amount of money which is, during the lifetime of fixed assets, calculated and allocated for compensation and reproduction (regeneration) of fixed assets. Its amount is calculated in the selling price of the finished product or service.
The law provides for the longest service life of fixed assets in which it should be amortized . The basis for the calculation is the purchase value of a fixed asset. When calculating the depreciation two main methods can be used [3,7]:
The method of amortization time (proportional , digressive , progressive) . As as a basis for the calculation the purchase value of fixed assets is used and a aspecific depreciation rate is applied to it. Annual amortization is calculated based on that.
Method of functional amortization is based on the expected use or performance of the funds, it is used for assets whose intensity of use can be measured (the number of pieces , mileage, hours of work) . This method begins with the assumption that the amount of annual depreciation is proportional to the intensity of use that is the performance of the underlying asset .
Methods weather depreciation are:

- Proportional - depreciation rates are equal
- Degressive - depreciation rates are declining
- Progressive - depreciation rates rise

The proportional method

The sum of depreciation rate at the end of lifetime of an asset should be equal to 100% regardless of the applied method of calculation. Depreciation is calculated at the end of each calendar year. The table contains the following fields:
Name of fixed asset
Purchase value
Written down value - the value of assets that was written off during the previous calculation of depreciation.
Written down value = new write-off for the previous year
Depreciation - the value calculated on the basis of depreciation rates for a given type of fixed asset
Depreciation = Cost of depreciation rates *
The new write-off - calculated value of the total write-off values after calculating depreciation for the current year
The new write-off = written off value + Depreciation
The actual value - the value of assets at the end of the year after writing-off Amortized
Actual value = Cost of - New write off
Here is the weather depreciation applied. The method of amortization time
Depreciation is carried out using the formula

The annual amount of depreciation = Cost of fixed asset * (Amortization rate 1 / 100) (3.1)

Amortization rate 1 of 100% / service life (3.2)

Degressive method

This method results in a decreasing depreciation expense over the lifetime of a fixed asset. This method assumes that the funds are not spent evenly throughout their life span, but are spent the most at the beginning of the century, and later their effect decreases, and therefore depreciation rate. The annual depreciation rate is calculated as follows:

Amortization rate 2= 100*{[t-(Z-1)/t]^2) -[(t-Z)/t]^2} (3.3)

Annual amount of amortization = Purchase value fixed assest * (Amortization rate 2 / 100) (3.4)

Where:
Z - observed years of fixed asset
t - the lifetime of the fixed asset

Progressive methods

The result of this method is increasing depreciation expense during the life of a fixed asset depreciation rates due to growth from year to year. This method assumes that the funds are not spent evenly throughout their life span, but are spent less in the beginning, and that over time their performance increases and with that the intensity of spending and the amount of annual depreciation. The annual depreciation rate is calculated as follows:

Amortization rate 3= 100*[(Z/t)^2 –((Z-1)/t)^2] (3.5)

Annual amount of amortization = Purchase value fixed assest* (Amortization rate 3 / 100) (3.6)

Where:
Z - observed years of fixed asset
t - the lifetime of the fixed asset [7]

4. RESULTS OF INTERNET MARKET RESEARCH

Picture 1. Liebherr 22HM tower crane (example)

During the research, for an example we took the crane Liebherr 22HM which belongs to small capacity cranes with the following features:

The hight of lifting: 19 m, Reach: 27 m,
Capacity: 2t, Load capacity at 27.0-m radius: 700 kg
Year of manufacture: 2010, Price: 105.000 €

Example:
Calculation of depreciation for the three models:

Purchase value of Crane Liebherr 22 je 105,000.euros, service lifetime 20 years [6].

Table 2.
Declining balance method for calculating amortization

Year	Purchase values [€]	Amortization Rate [%]	Annual amount AM [€]	Accumulated depreciation [€]	Present value [€]
1.	105.000	9.75%	10237.5	10237.5	94762,5
2.	105.000	9.25%	9712.5	19950	85050
3.	105.000	8.75%	9187.5	29137.5	75862,5
4.	105.000	8.25%	8662.5	37800	67200
5.	105.000	7.75%	8137.5	45937.5	59062.5
6.	105.000	7.25%	7612.5	53550	51450
7.	105.000	6.75%	7087.5	60637.5	44362,5
8.	105.000	6.25%	6562.5	67200	37800
9.	105.000	5.75%	6037.5	73237.5	31762,5
10.	105.000	5.25%	5512.5	78750	26250
11.	105.000	4.75%	4987.5	83737.5	21262,5
12.	105.000	4.25%	4462.5	88200	16800
13.	105.000	3.75%	3937.5	92137.5	12862,5
14.	105.000	3.25%	3412.5	95550	9450
15.	105.000	2.75%	2887.5	98437.5	6562,5
16.	105.000	2.25%	2362.5	100800	4200
17.	105.000	1.75%	1837.5	102637.5	2362,5
18.	105.000	1.25%	1312.5	103950	1050
19.	105.000	0.75%	787.5	104737.5	262,5
20.	105.000	0.25%	262.5	105000	0

Table 3.Progressive method for calculating amortization

Year	Purchase values [€]	Amortization Rate [%]	Annual amount AM [€]	Accumulated depreciation [€]	Present value [€]
1.	105.000	0.25%	262.5	262,5	104737,5
2.	105.000	0.75%	787.5	1050	103950
3.	105.000	1.25%	1312.5	2362,5	102637,5
4.	105.000	1.75%	1837.5	4200	100800
5.	105.000	2.25%	2362.5	6562,5	98437,5
6.	105.000	2.75%	2887.5	9450	95550
7.	105.000	3.25%	3412.5	12862,5	92137,5
8.	105.000	3.75%	3937.5	16800	88200
9.	105.000	4.25%	4462.5	21262,5	83737,5
10	105.000	4.75%	4987.5	26250	78750
11	105.000	5.25%	5512.5	31762,5	73237,5
12	105.000	5.75%	6037.5	37800	67200
13	105.000	6.25%	6562.5	44362,5	60637,5
14	105.000	6.75%	7087.5	51450	53550
15	105.000	7.25%	7612.5	59062,5	45937,5
16	105.000	7.75%	8137.5	67200	37800
17	105.000	8.25%	8662.5	75862,5	29137,5
18	105.000	8.75%	9187.5	85050	19950
19	105.000	9.25%	9712.5	94762,5	10237,5
20	105.000	9.75%	10237.5	105000	0

Tabela 4.Proportional method for calculating amortization

Year	Purchase values [€]	Amortization Rate [%]	Annual amount AM [€]	Accumulated depreciation [€]	Present value [€]
1.	105.000	5%	5.250	5.250	99750
2.	105.000	5%	5.250	10.500	94500
3.	105.000	5%	5.250	15.750	89250
4.	105.000	5%	5.250	21.000	84000
5.	105.000	5%	5.250	26.250	78750
6.	105.000	5%	5.250	31.500	73500
7.	105.000	5%	5.250	36.750	68250
8.	105.000	5%	5.250	42.000	63000
9.	105.000	5%	5.250	47.250	57750
10.	105.000	5%	5.250	52.500	52500
11.	105.000	5%	5.250	57.750	47250
12.	105.000	5%	5.250	63.000	42000
13.	105.000	5%	5.250	68.250	36750
14.	105.000	5%	5.250	73.500	31500
15.	105.000	5%	5.250	78.750	26250
16.	105.000	5%	5.250	84.000	21000
17.	105.000	5%	5.250	89.250	15750
18.	105.000	5%	5.250	94.500	10500
19.	105.000	5%	5.250	99.750	5250
20.	105.000	5%	5.250	105.000	0

The curve of the progressive method indicates the her present value is the biggest unlike the other two The curve of the degressive method indicates that in the beginning the amount of amortization is the biggest and it decreases with time passing.
The curve of the proportional method - the prise of the crane uniformly decreases with time.
The dots were taken from the example and the curve is interpolated through them.
The interpolated curve shows which method is the best for determining the price on the internet market.
On the apcisa chart inflicted are the age, and on the ordinate are the prices of cranes from the previous table. Curves (in Fig.1) are interpolated through the points of the given prices, with time prices decrease.
The attached graphics clearly show that the best method of use is the digressive method, because the amount of depreciation in the early years of the greatest, and subsequently decreases with age.

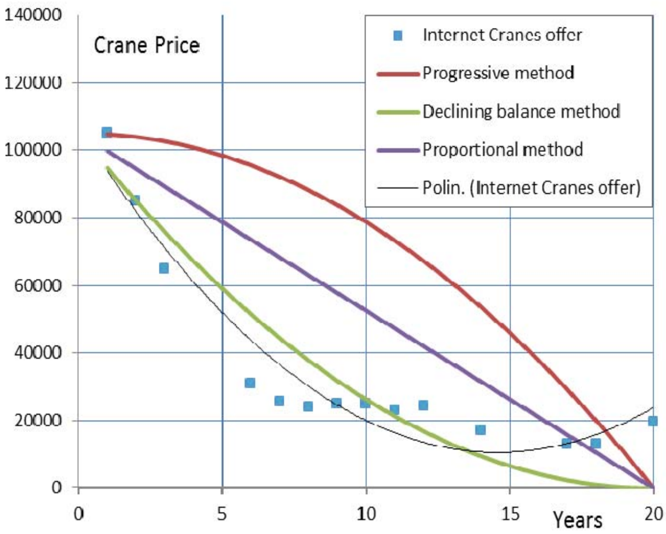

Fig.1. *Using amortization on Liebherr 22 HM tower crane*

5. CONCLUSION

On the previous chart it is clearly visible that the best method for determining – predicting the price of used transport equipment (cranes) is on the Internet market, using the digressive method of calculating depreciation. Identification of this method is based on a sample of 13 found cranes. The number of samples isn't so small considering that Internet was searched, B2B/B2C space capacity of 2.5-3.0 t with the reach between 24-30 m.

Models B2B/B2C trained using this studyof the market reflect the real market funds on whose basis the final price is determined. The model is recommended for the modern economy as the most effective way of determining approximate values of cranes. Also, using the electronic way, what can also be offered is that price that deviates from the market but must be based on additional factors (equipment, condition, number of working hours). Shopping should be done after several days of monitoring the market (stock exchange model) in order to avoid speculation.

REFERENCES

[1] Seen J: (2004). *Information tehnology - principles, practices, opportunities*, Pearson Prentice Hall, ISBN 978-86-7310-338-9, pp.564-600

[2] Ćosić, D.; Bogavac, M.: (2012) *E-commerce and datebase*, University Union of Belgrade, Faculty of Business and Industrial Management, Belgrade,

[3] Ćuzović, S.; Ivanović, P.: (2010), *Innovations in trade managment*, University of Niš, Faculty of Economics, ISBN 978-86-6139-002-9, pp112-140,

[4] Milosavljević, M.; Mišković, B. (2011): *E-commerce* , Univerzitet Singidunum, Beograd,

[5] Jovanović, R.; Milovanović, S.: (2010), *Electronic bussines*, University of Niš, Faculty of Economics, ISBN 978-86-6139-010-4, pp73-79 ;

[6] Agovic, T.; (2013) *Research of the Internet market of used cranes using B2B/B2C models*, Master work, University of Niš, faculty of Mechanical Engineering

[7] Krstić, J.; Jezdimirović, M.; Đukić, T.: (2013), *Financial accounting* , University of Niš, Faculty of Economics, ISBN 978-86-6139-073-9, pp186-189 ;

[8] http://www.allcrane.com/LeasingFinancing.aspx

[9] http://www.webopedia.com/TERM/C/cloud_computing.html

[10] http://en.machinerypark.com/verkauf/_47_101044058.php

[11] http://www.machineryzone.fr/occasion/1/grue-montage-rapide.html

[12] http://www.tfzr.uns.ac.rs/Content/files/0/V12%20SRFM%20-%20Obracun%20amortizacije.pdf

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CRITERIA SYSTEM DEFINING IN MULTICRITERIA DECISION MAKING PROBLEM AT TRANSPORT – STORAGE SYSTEM ELEMENTS CHOICE

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Abstract

Combining the methods for determining the relative importance of criteria and classical alternatives ranking methods, the optimal decision is made about certain multicriteria problem regardless the nature of parameters describing it. Solving the decision - making problem requires firstly defining the criteria system, and then determining their relative importance. Starting base at criteria defining is the fact that at solving each problem we can adopt various number and kind of criteria depending on corresponding decisions and information available. Also, an unique set of criteria of considered problem usually is not available to a decision maker. In this work the correlation test was used for getting the set of independent criteria and reducing their number to operating and acceptable level.

Key words: *criterion, correlation, decision- making*

1. INTRODUCTION

In the field of operational researches, theorists and practitioners have developed a great number of methods and approaches in multicriteria decision-making. Making a base for designing a new solution of logistics concept is basically coincided and connected to the proces of development of logistics centers (LC) , which unite different subsystems and provide complex logistics services [9].

Key part of every logistics strategy, or part of a big chain of supply that connects the manufacturers, deliverers and customers also represents the transport – storage system. Modern transport engineering is characterized by constant development of devices for transport and manipulation and is the base for planing and designing.

Generally, at considering any problem in domain of logistics and logistics systems (either choice of location or equipment in transportation and storage of materials) there is a great number of technically feasible alternatives, and the task of designer is to choose from the set of possible solutions the one that best meets the technical and economic conditions defined by the terms of reference.

Decision maker, in great number of such real problems/situations, must meet one or more goals as well as the numerous conflict criteria (multicriteria analysis). Final order of a problem's alternatives thus depends on applied technique of multicriteria decision-making, and especially on the procedure of defining the evaluation criteria, transformation (normalization) of criteria and determination of their relative significance. When relative significance of criteria is considered, to every criterion is added its weight value, on the base of expert evaluation and evaluation of other participants in decision-making, which is why it is desirable to involve a wider circle of experts and all other interested parties [19].

Solving the decision-making problem, in the domain of logistics and logistics systems, requires firstly defining the criteria system and later determination of their relative significance. At solving any problem we can adopt different number and kinds of criteria depending on corresponding decisions and information available. Also, an unique set of criteria of considered problem usually is not available to a decision maker. So, within the application of multicriteria decision-making model, mostly the carrying out of the following steps is required [1]:

- defining relevant criteria and alternatives,
- giving numerical values for relative importance (weight), as well as alternatives influence on these criteria,
- getting numerical values that determine final result of alternatives ranking.

In literature, researchers during the application of multicriteria decision-making model, mostly direct their attention to second and third step, while the first step, connected to criteria defining, is significantly neglected.

In application of multicriteria decision-making approach, the choice criteria are directly defined without certain tests of their independence or other characteristics [20].

Because of the independent nature of criteria it is very important to limit their number and in that way provide sufficient models sensitivity to changes in criteria weight, as well as the easier determination of their relative significance .

From survey of literature [3,10,13], notable is the fact that generally the choice of criteria requires application of formal procedures of set determination of approximately seven plus or minus two independent criteria.

On the other hand, it is necessary to point out the fact that in procedure of determining the relative criteria weights, subjective decisions have crucial role, and in literature there is a tendency that it is easier to expres a subjective attitude on criteria weights (significance) by comparing criteria importances by pairs instead of individually.

Therefore, classical technique makes the comparing process too complicated and bulky with the aim of collecting, in the right way, the decision maker's estimate, so in order to eliminate this deficiency while comparing at all hierarchical levels of problems, a fuzzy logic, that is fuzzy AHP (Analytic Hierarchy Process) technique is used. Respectively, for the purpose of easier carrying out the procedure of relative weights determination by AHP technique or fuzzy AHP, a set of approximately 7 independent criteria is required [10,13].

The research in this work is directed to the possibility of correlation test application for comparing the independent criteria and reduction of their number to operational and acceptable level. The correlational analysis aim is to determine if there is a quantitative concurrence (correlational link) between the observed phenomena variations (in this case criteria), and if there is, at what degree. In other words, correlational analysis shows the degree of dependence between variables, that is, it measures the intensity of already determined connection between two variables. Application of correlational analysis is illustrated in multicriteria problem of decision-making in the procedure of material handling equipment selection (forklift).

2. CORRELATION ANALYSIS

Statistical methods are used for determining the representative characteristics of significantly different elements' sets. Statistics is subjective: statisticians are trying to explain or predict the material world in arbitrary, but sensible way, by using the theory of probability, mathematics and common sense. Unlike statistics, the theory of probability gives a unique and repeatable solution for the defined problem.

Namely, the change of one feature of statistical set often influences the change of other features due to interconnection. Connection between features can be differentiated both by direction and intensity of connection.

The strongest or the narrowest connectioin between features is functional connection, that is, such connection that each value of one feature responds exactly to certain value of the other.

Looser link between features which are subject to smaller or larger deviations, is called correlative (or stochastic) link. Set of statistical methods used for studying interconnections of statistical features and phenomena (direction, intensity, shape) is called the theory of correlation, and main indicators of correlational links are the regression equation and correlation coefficient.

Hence, dependence research in statistical analysis has two main directions:

1. form of dependence, researcehed by regression analysis and
2. intensity of dependence, determined by correlational analysis.

Connection intensity degree between the variables which are in linear relation is measured by:

- covariance as absolute measure of correlation intensity and
- coefficient of simple linear correlation, as a relative measure of correlational link intensity.

If we observe two phenomena, it is a simple correlation, and if there are more phenomena, then it is a multiple correlation. It is also possible to examine if it is a linear or curvilinear link. Unlike regression analysis, in correlation analysis both observed phenomena are treated as random variables. Here there is no difference between dependent and independent variables. It does not matter which phenomenon we shall mark with X and which one with Y, because we shall get the same results.

Therefore, in further analysis we introduce the term of correlation coefficient, which represents the degree indicator of quantitative concurrence between variables.

On the ground of correlation test results it is possible to conclude that if there is a relation between two criteria, one of them will be sufficient to predict their behaviour, while the other one will be eliminated.

3. HYPOTHESES ON CORRELATION COEFFICIENT – MATHEMATICAL BACKGROUND

Popular method of theorem proving in mathematics is *deductio ad absurdum*, bringing to contradictions if opposite assertion is assumed [11]. In most of the fields where statistics is applied it is not possible to derive a rigorous proof, but the method of bringing to contradictions is essentially the base of statistical proof.

In statistics, unlike mathematics, absolute contradiction rarely occurs. The task of hypotheses testing statistics theory is to quantify the degree of doubt in some hypothesis. Choice between two hypothesis, let us call them H_0 – zero hypothesis and H_1 – alternative hypothesis, occurs in different fields of application. Actually, whenever it is necessery to prove some assertion or verify a new theory.

So, if we want to prove some assertion, then we take the opposite assertion (or neutral or existing state) as zero hypothesis, and assertion itself for hypothesis H_1.

Aim of examination procedure is to examine, on the base of results, if there are proofs against hypothesis H_0 and in favour of hypothesis H_1. Test is done if the statistics is defined S (test statistics) and the set of values for S for which we reject the hypothesis H_0 (rejection area or critical area) [11]. The conclusion of the test can be one of the following two:

- We reject H_0, because we obtained S in the rejection area and as an explanation we offer hypothesis H_1;
- We do not reject H_0, because we obtained S outside the rejection area and we do not have proof against H_0.

At hypotheses testing, two kinds of mistakes are possible:

- first kind error appears if H_0 is rejected when H_0 is correct,
- second kind error appears if H_0 is rejected when H_1 is correct.

Considering the hypotheses interpretation, it is usually more important not to make the first kind error, because in that way we would prove assertion that is not correct (hypothesis H_1). First kind error value maximum is the level of test significance and is marked with α. For the significance level value usually are taken the standard values 0.1,0.05,0.01. Standard choice is a convention which we do not need to stick to, but it provides comparison of different results, and it also facilitates calculations because standard tables can be used. By reducing the level of significance, the probability of second kind error increases. Let (X,Y) be a random vector. From two-dimensional distribution of vectors (X,Y) we take a circumference sample n: (X_1,Y_1), (X_2,Y_2),…, (X_n,Y_n). Here the pairs (X_i,Yi) are independent, while the random values from the same pair have specified common distribution and can be dependent, with correlation coefficient ρ. By method of moments we get evaluation for ρ:

$$r = \frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)\cdot\left(Y_i - \overline{Y}\right)}{\sqrt{\left(\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2\right)\cdot\left(\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2\right)}} \qquad (1)$$

Statistics r is called the sample coefficient of correlation or the estimated value of the parameter ρ. For hypotheses testing, as for finding the confidence interval, of use is the following theoreme:

Theoreme 1: If random vector (X,Y) has two-dimensional normal distribution with ρ=0, then the statistics

$$t = r\sqrt{\frac{n-2}{1-r^2}} \qquad (2)$$

has t(n-2) distribution.

Testing of hypothesis about simple linear equation coefficient on the basic set ρ, on the ground of its estimate from random sample r is based on the assumption about normality of common distribution for variables X and Y. During the testing we use t distribution of probabilities. Shown theoreme is used for testing the hypothesis Ho: ρ=0 in case when vector has normal distribution, or when the sample's circumference is big, so normal approximation can be accepted. Therefore, two hypothesis, in the order: Zero hypothesis H_0: ρ = 0 (in basic set there is no linear correlation between two variables) and Alternative hypothesis H_1: ρ ≠ 0 (in basic set there is linear correlation between two variables) are tested by correlation test.Simple linear correrlation coefficient in basic set ρ, ie. in sample r, can take values only in the interval -1 and 1, ie. $-1 \leq \rho \leq 1$ and $-1 \leq r \leq 1$. If the empirical points are scattered all over the diagram, then between the two variables there is no linear correlation and r ≈ 0. If variables are not connected, r is equal to zero. When greater values of independantly variable X respond also to greater values of dependently variable Y and vice versa: by decrease in value of independent X, decline the values of dependent Y – then it is a positive correlation (r>0). Conversely, when greater values of independently variable X respond to smaller values of dependently variable Y, i.e. by decrease in value of independent X, increase the values of dependent Y – then it is a negative correlation (r<0). The general rule is: the closer the coefficient value of simple linear correlation to one, the interdependence between the observed phenomena is stronger. The correlation coefficient never has the values 1 or -1, because it would mean that between the phenomena there is a mathematical, not statistical connection.

Most commonly used parametric test of significance for testing the zero hypothesis is the Student's t-test. It is used for testing the significance of differences between two arithmetic means. Conditions for t-test application:

- both variables that are tested must be numerical,
- in case that the sample value is less than 30 units, the disposition should be normal or at least symmetrical.

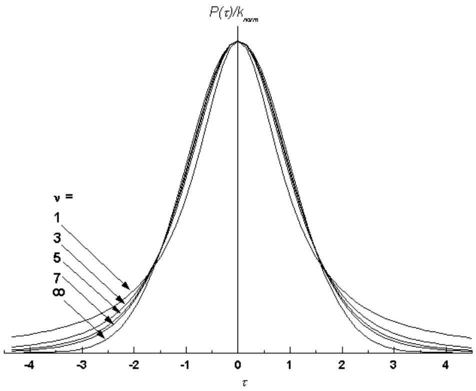


Fig.1 Student's t – distribution with ν degrees of freedom

Interpretation of obtained value of t-test is based on Student's t – disposition with ν degrees of freedom (Fig. 1) and Student's tables of t – disposition critical values. Function of t – distribution is symmetrically decreasing, and with increase in leeway degrees the surface enveloped by tails decreases, and the distribution increasingly approaches the standard normal distribution.

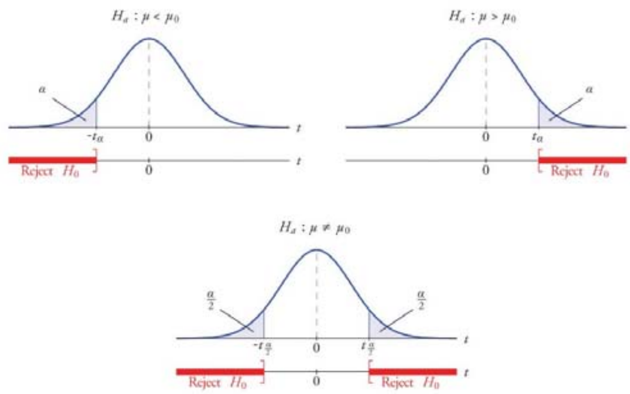


Fig. 2 Rules of accepting the H_0 hypothesis as correct, nd rejecting the alternative H_1

If the realized t-value is less than border table value for appropriate number ν and threshold (level) of significance, zero hypothesis is accepted as correct, and the alternative hypothesis is rejected:

- t-realized < t (ν and 0,05) ⇒ Ho is not rejected because the risk is bigger than 5% (p>0).

Reversely, if the realized t-value is equal or greater than the border table value, for corresponding number ν and threshold of significance, zero hypothesis is rejected as incorrect, and the alternative hypothesis is accepted:

- t-realized ≥ t (ν and 0,05) ⇒ zero hypothesis is rejected for risk level p=0,05, respectively for safety level P=0,95(95%);
- t-realized ≥ t (ν and 0,01) ⇒ H_0 is rejected for risk level p=0,01, respectively for safety level P=0,99 (99%).

4. CORRELATIONAL TEST CARRYING OUT ILLUSTRATION AT DETERMINING THE CRITERIA IN FORKLIFT CHOICE PROCEDURE

Generally, for the needs of multicriteria problems in choice of material handling equipment, different approaches have been developed [2,6,7,17,18]. Namely, at solving the multicriteria decision-making problem, and especially when it comes to the choice of material handling equipment, there is a variant when the criteria for choice of the most acceptable alternative are taken directly from manufacturers'catalogues. In that case, by applying the correlational test we expect to get the reduced and independent set of criteria. The reason for test application lies in the already mentioned fact that in literature there is no clearly defined procedure of criteria choice.

Therefore there is no unique set of criteria for choice, i.e. it varies and, besides that the criteria of choice must be independent, in literature prevails a tendency that their number has to be approximately seven. It is expected, at the same time, that models with fewer criteria become more sensitive to changes of criteria weights and lead to more expressed mutual distance of ranking results [21]. The aim is to establish the final number of independent criteria in situations when it is necessary, and then to apply some of the approaches for determination of relative weights or their significance (for example fuzzy AHP technique). On the base of correlational test it is possible to determine the intensity of already established connection between two variables, ie. for this purpose it is necessary to determine the degree of correlarion between two random variables.

For numerical illustration of correlational test in further works there will be considered an example of three wheel electro forklift choice within one logistical centre, in particular for the needs of handling the material within its transport – storage system. It is a multicriteria problem of equipment choice where, let us suppose, for ranking more alternatives of forklifts that satisfy in advance required parameters, for choice criteria the initial set of 20 characteristics was observed (Table 1). At this moment, the considered alternatives could be left aside because the goal is to show the procedure of defining the set of independent criteria for evaluation of alternative solutions. Starting sample that is considered consists of 25 forklifts of different manufacturers. Basic (starting) criteria are, one after the other (characteristics from manufacturers catalogs): A-Capacity (kg), B-Maximum lift height (mm), C- Travel speed with the load (km/h), D-Travel speed without the load (km/h), E-Lift speed with the load (m/s), F-Lift speed without the load (m/s), G-Turning radius (mm), H-Length to fork face (mm), I-Engine power (kW), J-Wheelbase (mm), K-Total width (mm), L-Noise level (dB), M-Battery voltage (V), N-Battery capacity (Ah), O-Tilt angle (°), P-Forklift mass (kg), Q-Forks length (mm), R-Oil pressure in the installation (bar), S-Battery weight (kg) and T-Total height to top of overhead guard (OG) (mm). Their initial values are collected from appropriate catalogs. The task is to, from sample of 25 different values that takes 20 variables, using the correlational test, determine the intensity of connection between two variables and in this way reduce the initial number of independent criteria for evaluation of alternative solutions.

So, from two-dimensional distribution of random vector (X,Y) there was taken a sample of circumference n=25: (X_1,Y_1), (X_2,Y_2),…, (X_{25},Y_{25}). Here the pairs of variables (Xi,Yi) are independent, while random values from the same pair have specified mutual distribution and can be dependent, with correlation coefficient r.

In the use of equation (1), n corresponds to the sample value of 25 forklifts, Xi, Yi represent the criteria pairs for which we calculate the correlation coefficient, and $\overline{X}$ and $\overline{Y}$ their average values.

$$r = \frac{\sum_{i=1}^{25}\left(X_i-\overline{X}\right)\cdot\left(Y_i-\overline{Y}\right)}{\sqrt{\left(\sum_{i=1}^{25}\left(X_i-\overline{X}\right)^2\right)\cdot\left(\sum_{i=1}^{n}\left(Y_i-\overline{Y}\right)^2\right)}} \quad (3)$$

Table 1 Forklifts characteristical values for 20 criteria

Manufacturer	Model	Capacity (kg)	Max. lift height (mm)	Travel speed with the load (km/h)	Travel speed without the load (km/h)	Lift speed with the load (m/s)	Lift speed without the load (m/s)	Turning radius (mm)	Length to fork face (mm)	Engine power (kW)	Wheelbase (mm)
TOYOTA	**7FBEST10**	1000	3310	12	12.5	0.32	0.52	1230	1565	7.5	985
TOYOTA	**7FBEST13**	1250	3310	12	12.5	0.31	0.52	1400	1725	7.5	1145
TOYOTA	**7FBEST15**	1500	3310	12	12.5	0.3	0.52	1450	1780	7.5	1200
CAT	**2ET2500**	1300	3000	16	16	0.48	0.6	1440	1774	11.5	1249
CAT	**2ETC3000**	1600	3000	16	16	0.49	0.6	1548	1887	11.5	1357
CAT	**2ETC3500**	1800	3000	16	16	0.44	0.55	1548	1887	11.5	1357
CAT	**2ETC4000**	2000	3000	16	16	0.4	0.55	1655	1995	11.5	1465
HYSTER	**J30XNT**	1361	3032	15.7	15.7	0.39	0.65	1481	1808	4.8	1290
HYSTER	**J35XNT**	1588	3032	15.7	15.7	0.36	0.65	1577	1903	4.8	1386
HYSTER	**J40XNT**	1814	3032	15.7	15.7	0.34	0.65	1577	1903	4.8	1386
NISSAN	**TX30N**	1350	3300	14.5	14.5	0.34	0.515	1525	1895	10.7	1300
NISSAN	**TX35N**	1600	3300	14.5	14.5	0.31	0.515	1525	1895	10.7	1300
NISSAN	**TX40N**	1800	3300	16	16	0.32	0.6	1635	2005	14.6	1410
YALE	**ERP13VC**	1250	3320	12	12.5	0.3	0.51	1398	1724	6	1168
YALE	**ERP15VC**	1500	3320	12	12.5	0.3	0.51	1452	1778	6	1222
YALE	**ERP15VT**	1500	3320	16	16	0.43	0.59	1476	1805	12	1290
YALE	**ERP16VT**	1600	3320	16	16	0.43	0.59	1476	1805	12	1290
YALE	**ERP18VT**	1800	3390	16	16	0.41	0.58	1676	1896	12	1494
YALE	**ERP20VT**	2000	3390	16	16	0.4	0.58	1676	1999	12	1494
JUNGHEINRECH	**EFG110**	1000	3000	12	12.5	0.29	0.5	1293	1623	6	1038
JUNGHEINRECH	**EFG113**	1250	300	12	12.5	0.25	0.5	1401	1731	6	1146
JUNGHEINRECH	**EFG115**	1500	3000	12	12.5	0.24	0.5	1455	1785	6	1200
JUNGHEINRECH	**EFG213**	1300	3000	10	16	0.48	0.6	1440	1774	11.5	1249
JUNGHEINRECH	**EFG218**	1800	3000	10	16	0.44	0.55	1655	1995	11.5	1465
JUNGHEINRECH	**EFG220**	2000	3000	10	16	0.4	0.55	1655	1995	11.5	1465

Manufacturer	Model	Total width (mm)	Level of noise (dB)	Voltage (V)	Battery capacity (Ah)	Tilt (°)	Forklift mass (kg)	Forks length (mm)	Installation pressure (bar)	Battery weight (kg)	Total height to top of OG (mm)
TOYOTA	**7FBEST10**	990	62.4	24	400	5	2550	800	140	372	2055
TOYOTA	**7FBEST13**	990	62.4	24	700	5	2820	800	140	600	2055
TOYOTA	**7FBEST15**	990	62.4	24	800	5	2930	800	140	676	2055
CAT	**2ET2500**	1060	66	24	400	7	2698	1150	200	679	2040
CAT	**2ETC3000**	1060	66	24	500	7	2957	1150	200	812	2040
CAT	**2ETC3500**	1120	66	24	500	7	3213	1150	200	812	2040
CAT	**2ETC4000**	1120	66	24	600	7	3331	1150	200	974	2040
HYSTER	**J30XNT**	1050	69	36	750	5	2313	1067	155	670	2070
HYSTER	**J35XNT**	1050	69	36	800	5	2372	1067	155	670	2070
HYSTER	**J40XNT**	1116	69	36	1000	5	2390	1067	155	700	2070
NISSAN	**TX30N**	1105	61	36	680	4	2955	1070	140	700	2110
NISSAN	**TX35N**	1105	61	36	680	4	3155	1070	140	700	2110
NISSAN	**TX40N**	1105	61	48	750	4	3365	1070	140	1050	2110
YALE	**ERP13VC**	996	59	24	735	5	2700	1000	155	570	1980
YALE	**ERP15VC**	996	59	24	840	5	2905	1000	155	642	1980
YALE	**ERP15VT**	1050	65	48	500	5	2990	1000	180	673	2070
YALE	**ERP16VT**	1050	65	48	500	5	2990	1000	180	673	2070
YALE	**ERP18VT**	1116	65	48	750	5	3280	1000	180	962	2070
YALE	**ERP20VT**	1116	65	48	750	5	3290	1000	180	962	2070
JUNGHEINRECH	**EFG110**	990	63	24	625	5	2570	1150	160	481	2090
JUNGHEINRECH	**EFG113**	990	63	24	875	5	2760	1150	185	648	2090
JUNGHEINRECH	**EFG115**	990	63	24	1000	5	2870	1150	210	730	2090
JUNGHEINRECH	**EFG213**	1060	66	24	400	7	2698	1100	200	679	2040
JUNGHEINRECH	**EFG218**	1120	66	24	600	7	3156	1100	200	974	2040
JUNGHEINRECH	**EFG220**	1120	66	24	600	7	3331	1100	200	974	2040

After the calculated value of correlation coefficient for every pair of criteria, further testing of linear correlation coefficient is based on already mentioned Student's disposition with n-2 degrees of freedom, while the obtained t – value is interpreted in the same way as in the classic Student's t-test.

Statistical test p-value (significance level) is compared to predefined significance level α which is a proof of positive relation between two criteria. In this research $\alpha=0.01$ was chosen as critical value.

In case that p-value is less than 0.01, we conclude that there is a proof of positive relation between two criteria and one of them can be eliminated.

It should be mentioned one more time that the test is mathematically defined by formula (2).

For the needs of this work, because of easier carrying out the extensive calculations when getting the values of correlation coefficient and statistical p-value, the shown procedure is automatized by development of program tools in the environment of Microsoft Excel. Given program tools have restrictions regarding the number of criteria, maximum 25.

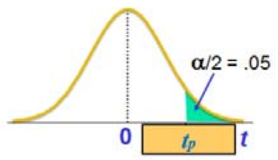
For arbitrary criteria pair (eg. Criterion A: Capacity and G: Turning radius) the program addition calculates t-value, twosided t-distributions with 23 (n-2) degree of freedom, by using the expression (2). For this arbitrary criteria par, $t=12{,}263$ and $r=0.935$. The program then determines, one after the other, onesided and twosided p – value in t – distribution (Table 2).

Table 2. Correlation coefficient and p-values for criteria pairs: A – to G; B – to G, C – to G D – to G; E – to G, F – to G

r	**0.179**	**0.345**	**0.657**	**0.344**	**0.339**	**0.935**
t_p	**0.871**	**1.763**	**4.176**	**1.759**	**1.729**	**12.683**
p	0.804	0.954	1.000	0.954	0.951	1.000
p-1	0.196	0.046	0.000	0.046	0.049	0.000
p-2	**0.393**	**0.091**	**0.000**	**0.092**	**0.097**	**0.000**
r		**0.196**	**0.203**	**0.242**	**0.172**	**0.157**
t_p		**0.956**	**0.995**	**1.194**	**0.838**	**0.763**
p		0.826	0.835	0.878	0.795	0.773
p-1		0.174	0.165	0.122	0.205	0.227
p-2		**0.349**	**0.330**	**0.245**	**0.411**	**0.453**
r			**0.546**	**0.330**	**0.569**	**0.371**
t_p			**3.124**	**1.674**	**3.318**	**1.914**
p			0.998	0.946	0.999	0.966
p-1			0.002	0.054	0.001	0.034
p-2			**0.005**	**0.108**	**0.003**	**0.068**
r				**0.826**	**0.764**	**0.727**
t_p				**7.019**	**5.680**	**5.073**
p				1.000	1.000	1.000
p-1				0.000	0.000	0.000
p-2				**0.000**	**0.000**	**0.000**
r					**0.592**	**0.397**
t_p					**3.521**	**2.077**
p					0.999	0.975
p-1					0.001	0.025
p-2					**0.002**	**0.049**
r						**0.419**
t_p						**2.215**
p						0.982
p-1						0.018
p-2						**0.037**

Values, in Table 2 are one after the other: r – correlation coefficient, t_p-obtained value for Student's distribution for significance level p, and p-1 and p-2 corresponding onesided and twosided p-value in t-distribution.

When p-value for every criteria pair is calculated, twosided p-value is entered into the matrix under the main diagonal (Table 3), whereby the pairs, whose p-values are less than previously defined value 0.01, are marked above the main diagonal by the sign "X".



ν	Values of t for various probability levels, p							
	.75	.90	.95	**.954**	.975	.99	.995	.9995
21	.686	1.233	1.721	.	2.080	2.518	2.831	3.819
22	.686	1.321	1.717	.	2.074	2.508	2.819	3.792
23	.685	1.319	**1.714**	**1.759**	**2.069**	2.500	2.807	3.767
24	.685	1.318	1.711	.	2.064	2.492	2.797	3.745
25	.684	1.316	1.708	.	2.060	2.485	2.787	3.725
26	.684	1.315	1.706	.	2.056	2.479	2.779	3.707
27	.684	1.314	1.703	.	2.052	2.473	2.771	3.690
28	.683	1.313	1.701	.	2.048	2.467	2.763	3.674
29	.683	1.311	1.699		2.045	2.462	2.756	3.659
30	.683	1.310	1.697		2.042	2.457	2.750	3.646
:	:	:	:		:	:	:	:

Interpolation:

$$\left[\left(0{,}95-t_p\right)/\left(0.95-0.975\right)\right]/\left[\left(1.714-2.013\right)/\left(1.714-2.069\right)\right]=0.954$$

$$one-tailed\ p\text{-}value\ \left[\left(1-0{,}954\right)=0.046\right]$$

$$two-tailed\ p\text{-}value\ \left[2*0.028\right]=0{,}092$$

Fig.3. Values of t_p for Student's distribution with ν degrees of freedom

Elimination procedure itself, or reduction of criteria number (variables) that are in mutual correlation, from the shown table, could be presented through the following steps:

1. check if there are criteria which are not correlated to any other criteria (both by kind and column of given table), and if this is the case, they should be chosen for independent criteria;
2. check the correlation of every criteria (by kind) with other members, and if there is such criterion, choose it as independent one, other criteria in corelation discard;
3. If there are undeleted criteria left, go back to step 1, otherwise the process of correlation analysis is finished.

By using the listed rules of elimination procedure, the number of rules in this particular case is reduced from the original 20 to the following six criteria: A-Capacity (kg), B-Maximum lift height (mm), C- Travel speed with the load (km/h), E-Lift speed with the load (m/s), Q-Forks length (mm) and T-Total height to top of overhead guard (mm).

Thus obtained, the set of independent criteria satisfies the suggested number (seven plus or minus two) and it is possible to use it further on in the following stage of solving the multicriteria decision-making problems, i.e. in the procedure of determining their relative weights, and later also in the final ranking of suggested alternatives of the considered multicriteria problem.

All attention in the work is directed only to the representation of necessary criteria choice procedure for the procedure of solving the multicriteria decision-making problem in the procedure of equipment choice within one logistical system such as logistics centre.

Other steps of solving such a problem (multicriteria analysis), given in the introductory lines of the work, in this case were not considered.

Table 3 Criteria pairs correlation(pairs in correlation marked with "X")

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
A				X			X	X		X	X					X			X	
B	0.393																			
C	0.091	0.349		X		X							X							
D	0.000	0.330	0.005		X	X	X	X	X	X	X	X							X	
E	0.092	0.245	0.108	0.000		X			X	X	X	X		X	X			X		
F	0.097	0.411	0.003	0.000	0.002					X		X								
G	0.000	0.453	0.068	0.000	0.049	0.037		X	X	X	X					X			X	
H	0.000	0.479	0.088	0.000	0.068	0.057	0.000		X	X	X					X			X	
I	0.013	0.219	0.184	0.001	0.001	0.543	0.009	0.005		X	X			X		X			X	
J	0.000	0.377	0.038	0.000	0.009	0.009	0.000	0.000	0.006		X					X			X	
K	0.000	0.299	0.035	0.000	0.004	0.028	0.000	0.000	0.001	0.000						X			X	
L	0.081	0.716	0.094	0.000	0.002	0.000	0.060	0.105	0.970	0.018	0.033									
M	0.079	0.162	0.001	0.014	0.465	0.016	0.034	0.064	0.066	0.025	0.042	0.533			X					
N	0.408	0.317	0.910	0.079	0.000	0.682	0.383	0.482	0.003	0.685	0.496	0.555	0.601		X					
O	0.200	0.640	0.437	0.035	0.000	0.417	0.301	0.320	0.137	0.173	0.185	0.015	0.008	0.006				X		X
P	0.000	0.443	0.643	0.113	0.314	0.230	0.001	0.001	0.000	0.003	0.005	0.241	0.256	0.499	0.414				X	
Q	0.217	0.064	0.405	0.039	0.205	0.400	0.109	0.067	0.434	0.089	0.051	0.113	0.629	0.969	0.049	0.625		X		
R	0.079	0.203	0.862	0.031	0.004	0.602	0.128	0.188	0.083	0.075	0.190	0.029	0.286	0.172	0.000	0.139	0.001			
S	0.000	0.713	0.229	0.000	0.065	0.197	0.000	0.000	0.000	0.000	0.000	0.234	0.119	0.667	0.142	0.000	0.075	0.034		
T	0.993	0.442	0.158	0.625	0.248	0.736	0.669	0.520	0.518	0.836	0.354	0.682	0.015	0.347	0.009	0.808	0.536	0.276	0.676	

5. CONCLUSION

In the work itself, the fact was pointed out that solving the problem of decision-making requires firstly defining the criteria system, and then determining their relative significance before final ranking of the considered multicriteria problem alternatives. Also, the fact was pointed out that a unique set of criteria of considered problem most often is not available to decision-maker. Correlation test was used for getting a set of independent criteria, more precisely reduction of their number to operative and acceptable level for determining the relative weights and later on the procedure of ranking the alternatives.

In the end, it is also necessary to mention a few important limitations that follow the carrying out of correlation test. Firstly, correlation test determines only the level of correlation for every criteria pair, and as it is determined there is not a unique way of obtaining the set of independent criteria (seven plus or minus two). Set of independent criteria can be different for the same value of correlation coefficient, but also by changing the values of significance level, the number of pairs in correlation changes. In this way the pairs in correlation become the pairs without correlation and vice resa. It becomes clear that defining the set of independent criteria requires, in that case, repetition and check of procedure for choosing the set of seven plus or minus two independent criteria. However, the result of such approach can lead to a situation where the available criteria, i.e. the most commonly used ones in previous researches, can become preferential to the less significant criteria, and as such be used for solving the equipment choice problem. It is obvious that the model becomes more sensitive to changes of criteria weights, so for that purpose it is necessary to analyse also the statistically significant differences between the original and the reduced set of criteria to final ranking. In this way, by application of correlation test, we could come to a cognition whether and to which extent the final ranking of alternatives differs for the reduced number of criteria in relation to the original set.

REFERENCES

[1] Arslan, MC.: “A decision support system for machine tool selection", M.S. Thesis, Sabanci University, Spring, 2002

[2] Chan, F.T., Ip, R. W. L., Lau, H.: “Integration of expert system with analytic hierarchy process for the design of material handling equipment selection system”, Journal of Materials processing Technology, 116, 137-145, 2001

[3] Chen, S-J, Hwang, C-L.: “Lecture notes in economics and mathematical systems”, Springer, Berlin, Germany, 1992.

[4] Chu, H. K., Egbelu, P. J.,Wu, C. T.:“ADVISIOR: A computer-aided material handling equipment selection system“, Int. J. Prod. Res., 33 (12):3311-3329,1995

[5] Dagdeviren, M.: “Decision Making in equipment selection: an integrated approach with AHP and PROMETHEE“, Journal of Intelligent Manufacturing,19,397-406, 2008

[6] Fisher, E.L., Farber, J. B., Kay, M. G.: “MATEHS: An expert system for material handling equipment selection”, Engineering Costs and Production Economics,14,297-310,1998

[7] Kim, K. S., Eom, J. K.: “An expert system for selection of material handling and storage systems”, Int. J. Ind. Eng., 4(2),1997,81-89

[8] Lee, A.R.: ”Application of modified fuzzy AHP method to analyze bolting sequence on structural joints”, PhD Dissertation, Lehigh University, A Bell & Howell Companz, UMI Dissertation Services.

[9] Marković,G., Gašić, M., Marinković, Z., Tomić, V.:’’ Essence and significance of forming the regional logistical concept – essence and significance, 4 Serbian symposium with international participation – Transport and logistics, page.7-14, Niš, 2011.

[10] Miller, G.A.:”The magic number seven plus or minus two”, Psychol rev 63:81-97, 1965

[11] Merkle, M.: “Probability and Statistics – for engineers and students of engineering “(In Serbian),Second edition, Akademic Mind, Belgrade, 2006 (321 pages) ISBN 86-7466-229-3

[12] Montgomery, D.C:”Design and analzsis of experiments”,4th edn., Wiley, USA, 1996

[13] Park. Y.:ICMESE: “Intelligent consultant system for material handling equipment selection and evaluation“, Journal of Manufacturing Systems, 15(5),325-333, 1996

[14] Čupić, A.: “Technical system choice methodology for automatic package processing at main postal centres“, Master's thesis, Faculty of Traffic Engineering Belgrade, 2007

[15] Saaty, T.: “The Analytic Hierarchy Process“, McGraw-Hill, New York, USA,287 p., 1980.

[16] Saaty, T.: Analytical Planning: “The organization of systems”, Pergamon Press, 1985

[17] Tabucanon, M. T., Batanov, D. N.,Verma, D.K.: “Intelligent decision support system (DSS) for the selection process of alternative machines for flexible manufacturing systems (FMS)”, Comuters in Industry, 25, 131-143, 1994

[18] Taha, Z., Rostam, S.: “A hybrid AHP-PROMETHEE decision support system for machine tool selection in flexible manufacturing cell”, J. Intell. Manuf. (2012) 23:2137-2149, 2012

[19] Vasiljević, T.: “Application of GIS, analytic-hierarchic process and phase of logic at location choice of regional landfills and transfer stations”, PhD thesis, Novi Sad, 2011

[20] Yager, R. R.: “A procedure for ordering fuzzy subsets of the unit interval”, Information Sciences,24, 143-161,1981

[21] Yurdakul, M., Tansel, IC. Y.: “Application of correlation test to criteria selection for multi criteria decision making (MCDM) models”, International Advanced Manufacturing Technology (2009) 40:403-412, 2009

[22] http://www.toyota-forklifts.eu/en/Products/electric-counterbalanced-trucks/toyota-traigo-24/Pages/Default.aspx

[23] http://www.cat-lift.com/_cat/index.cfm/north-america/english/products/lift-trucks/class-i-electric-counterbalanced/2500-4000-lb-capacity-3-wheel-pneumatic-tire

[24] http://www.hyster.com/north-america/en-us/products/3-wheel-electric-trucks/

[25] http://nissanforklift.com/forklifts/TX-3Wheel-AC-ElectricRider.htm

[26] http://www.yale.com/emea/en-gb/our-products/product-overview/3-wheel-electric-trucks/electric-fork-lift-truck-rear-wheel-drive-1250-1500kg/

[27] http://www.jungheinrich-lift.com/_jh/index.cfm/products/forklifts-and-lift-trucks/electric-counterbalanced-forklifts/efg-110k-115-electric-3-wheel-counterbalanced-forklift

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SIMULATION OF MATERIAL FLOW IN THE ZONED ORDER PICKING SYSTEMS

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Abstract

Order picking is the activity by which a small number of goods are retrieved from a warehousing system to satisfy a number of independent customer orders. Order picking area, due to its volume, can be divided into several parts – zone. Zoning is the problem of dividing the whole picking area into a number of smaller areas and assigning order pickers to pick requested items within the zone. Zone picking is a flexible and highly structured order picking concept. There are several methods of the pick and pass zone picking – fixed zone, bucket brigades and zoned bucket brigades. Besides the above mentioned, the work will be described the zone picking using developed bound cavities methods. Based on the simulation on the models of zoned order picking systems, will give an analysis of the obtained results.

***Keywords**: order picking, zone, bound cavities methods*

1. INTRODUCTION

As an alternative to single order picking, picking area can be divided into several parts - zone, wherein each picker assigned a zone. The advantage of the zone picking is movement pickers in a relatively small area, thus reducing the possibility of each other interference and the possibility that each picker to become familiar with the items in their area.
The zoning is classified into synchronized zoning, where all pickers work on the same orders at the same time, and progressive zoning (pick and pass), where each orders is processed at zone at a time. Because only one order is handled at a time, pick and pass zone picking reduces the pick rate of pickers, but eliminates the requirement of a sorters system. Zone picking can be used for a wide range of applications and is highly efficient, especially when pickers can pick directly into shipping cartons or totes.
Pick and pass zone picking involves the execution of one or more orders sequentially through multiple zones that are arranged in a series. Each pickers fulfills certain portion of order, which includes items in the area that it covers, and then sends the tote (by hand or conveyor) in which he placed the selected items, the following pickers, which covers the next area and so on, fig. 1.
In this method of picking a small consumption of time, if it the working volume of the equipment is sufficient to accept the complete order. To increase the efficiency of this method it is necessary to use the conveyor or rail, in which the moving totes, or carts. Not suitable for large distances between the zones or the lack of high-speed transport device that connects zone. It is necessary to pass through all the zones, even when the individual zones have no items that need to be taken. Execution of orders by using this method is very effective when the individual orders evenly (uniformly) distributed by zones, or when from each zone takes the same number of items. Using this method requires the same order picking technology and similar equipment in all zones.

Fig. 1 Pick and pass order picking

2. ZONED PICK AND PASS ORDER PICKING SYSTEMS

During the zone picking is often the case that transport totes with items to be accumulated between individual zones. On the other hand, it happens that some pickers waiting for totes to carry out taking items out of their zone. In both cases, it can be concluded that the picking zone are not well coordinated and balanced. These situations can always occur when it happens unexpected the structure of orders.
Solution in such situations is the deployment of items within the zone to the previous analysis of the structure of orders, the additional storage conveyor which would accept the transport totes that are waiting, increasing the space that occupies the order picking area, ...
The first solution means that it is necessary to constantly transfer items from one to another place to equalize the demand for products in certain zones and thus equalize

pickers operation time. This means that it is necessary, at the beginning of the execution of each orders group, the physical transfer from one to another place, the large number of items that are found in the zone. This of course requires considerable time, as well as the appropriate involvement manpower and technology, and the additional problem may be if there is a difference in the size and weight of the items, as well as fragile and sensitive materials.
Another possible solution is to add the storage conveyor, usually a roller conveyor between the zones, which would act as temporary storage for transport totes (buffer). By placing the tote on the conveyor in order to solve the imbalance in the work, so that the previous picker continued to work and not have to wait for the next picker. The specified solutions can not completely solve the problem of imbalances in the the work of pickers, especially in situations of significant differences in the orders structure.
Therefore, they applied the dynamical zones. Dynamical zones are flexible pickers workspaces, that would allow change zone boundaries over time, adapting to the current orders that are executed. The basic principle of the dynamical zones is that the zone boundaries harmonize with the volume of work and the borders of neighboring pickers and appropriate orders. Instead of pickers zones finished in the same place in all orders, after pickers come back to the same fixed location where the zone starts, picker execute the order until the next picker of the series did not end with the execution of previous orders, and while not ready (did not come to appropriate location). Each previous and next picker works on the same principle. Size of the zone is defined by the current available pickers load, and not according to pre-arranged items, so there are no need to change the layout of items. In this way avoiding the picker waiting, and the accumulation conveyor totes, allowing continuous operation, which leads to increased productivity.
When using dynamic zones, each picker execute one order, and no orders that are pending between the individual zones. The advantages of dynamical zones are:

- if the change the number of pickers, the execution order is carried out continuously, without interruption,
- changes in the structure of order and quantity of certain items does not affect the reduction in the flow and speed of execution of orders,
- the slowest picker can not significantly affect the flow reduction,
- productivity and picking accuracy increases,
- minimized the pickers waiting time,
- the dynamic zones automatically adapt to existing conditions without a change in the schedule of items and needed transportation equipment.

Type of zone picking, which are called bucket brigades, reminiscent of the cooperative behavior of ants, when transferring foods, [4]. At work brigades execution order is accomplished in the following way: when the last picker in the series is complete with the exception of items for a particular order, it returns to the previous pickers, takes the transport totes and continues to work. The penultimate picker is then returned to its predecessor from whom also takes the the transport tote and continues to work. This procedure is repeated, and thus executes the order picking. If there is a difference in picking speed between the individual pickers, the slowest picker is placed at the beginning and then the end of the row where to set the fastest picker.

In order to reduce time losses in zoned order picking systems, the method of zoned bucket brigades was developed, [4], as a combination of classical zones order picking and order picking with bucket brigades, fig. 2. The picking line is divided into (m) zones, at whose boundaries an (m-1) temporary storage is placed. The work areas of individual pickers are shown in the figure, thus the theoretical work area of each picker begins at the beginning of the picking line, and ends at the end of their assigned zone. The principle of operation is as follows: after the execution of an order, a picker leaves the tote in the temporary storage at the end of their zone and returns either to the previous temporary storage, where he takes the tote and begins to execute the next order, or, if the previous temporary storage is empty, he goes to the previous picker from whom he takes a tote and continues with the execution of the order.

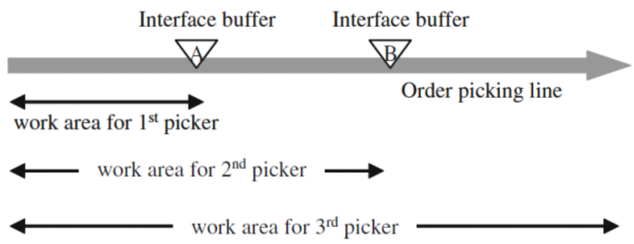

Fig. 2 Pickers' work zones in zoned bucket brigade systems [4]

3. BOUND CAVITIES METHOD

When performing order picking, a picker is moving along the picking line, stopping at picking places, where an item is to be picked for actual order (marked with black spots in Fig. 3), and passing by the places where there is nothing to be picked – empty spaces [5]. If the number of items, which are to be picked, is small compared to total number of items, there is great number of empty spaces. Also, there are the regions with successive places where there is not necessary to take the items for the actual order (see fig. 3, the places 12-13 and 18-20). These regions are called "bound cavities''.

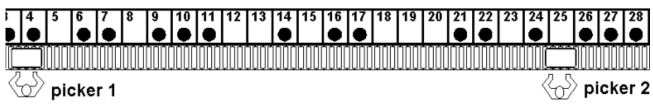

Fig. 3 Picking line with two pickers

Within picking time structure we distinguish between the times for item picking and the times for picker travel. If we analyze the work of two pickers in the system with zoned pick and pass order picking, it is clear that the time periods concerning item picking are inevitable, which means that they can only be distributed among pickers. Regarding the travel time, if technical predispositions exist to send the tote via conveyor from the first picker to the second one, it would be optimum that zone interchange happens on the spot with the longest picker travel without item picking, which means on the spot with the longest bound cavity (according to the Fig. 3, from places 18 to 20). In this way it would be possible to avoid regarding the activities and also used time, the travel

of the picker in both directions, in the zone where there is anyway not necessary to pick any items.
This is the reason why the bound cavities method was developed, which strives to have the change of pickers, or zones, performed precisely at the position where the largest bound cavities occur.
If we observe the start of the work and analyze which order should be executed first from a group of processed orders, it can be concluded that the order which requires minimal input from the first picker should be executed first, so that the second picker would spend the least time waiting. On the other hand, if we analyze which order should be executed last, we come to the conclusion that it should be the order that requires the least work from the second picker, in order to minimize the time that the first picker is without work.
In order to avoid, or maximally reduce the waiting time of the pickers after the first order in which the first picker has a lot less work than the second one, in the next order it is necessary for the first picker to have a lot more work than the second one. The situation is similar at the end as well.
In order to meet these requirements, we come to a diagram of the sequence of order execution during order picking which resembles the letter X, hence the name of the procedure, fig. 4, where the lines represent the loads on the pickers.

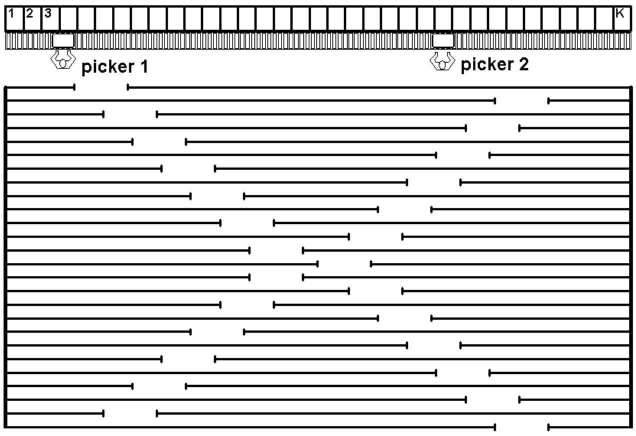

Fig. 4. The sequence of order execution according to the X procedure of the bound cavities method

4. MODELS OF THE ZONED PICK AND PASS ORDER PICKING SYSTEMS

A formal mathematical record of behavior and characteristics zoning order picking pick and pass system can be represented by a mathematical model. Often, in practice, impossible to make absolutely accurate mathematical model, so you can then access certain approximations and neglect of less influential characteristics.
In a zoned pick and pass picking system each picker execute one order, whereby it can be complete or part of the order, in the case of a distribution center with a large number of different articles.
In a zoned pick and pass picking system, of which the model is formed, there are two roller conveyors, fig. 5. By roller conveyor 2 which is powered, arrive empty totes and stop under the picker place where begins the first zone for the current order. Picker 1 transferred and pushing the transport totes by roller conveyor 1, which is unpowered. Order picking system is equipped with pick by light technology, so that each picker after taking the required number of pieces with a certain picking places, presses the button which confirms that he has taken a sufficient number of pieces. At that moment a light turns on to the next picking place, where picker need to takes item. Picker comes to lighted lights, and in the display seen how many the pieces should take, and then begins taking. This procedure is repeated until the moment according to the information from the information system (eg, beep or flashing light), picker transferred the transport tote to roller conveyor 2, and moving toward the beginning and the fulfillment of the following orders. When picker 1, after completion of taking items for a particular order, put the tote on the roller conveyor 2, it is transported to the picking place where starting zone for the next picker.

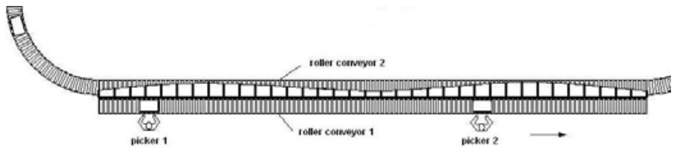

Fig. 5 Pick and pass zoned picking system

Basic assumptions and requirements, for a given order picking model are:

- picking places are always full, which means that in all places have enough pieces of the individual item, to satisfy the need to fulfill all orders,
- the analysis does not take into consideration replenishment items from storage,
- speed of pickers is viewed as a constant, ie there is no acceleration or deceleration,
- the assumption is that the picking speed the same for all pickers, where the model can set different picking speed for individual pickers,
- content of orders, within a single picking line, is such that one can be placed in a one transport tote,
- it is necessary to appropriately transport system which includes two parallel roller conveyor, wherein one non-powered conveyor, and other conveyor powered,
- arrangement of items in picking lines is random.

There are many analyzes about the influence of various parameters (grouping of orders, sequence of taking items, deployment items strategy, execution of orders by zone, the arrangement of objects within the system, the type of order picking equipment and complexity of the information system) on system performance – total picker traveled distances and total picking time.
Many researchers have carried out simulations of system operation, which have been models developed in different programs of general purpose (*Visual Basic, C + +, Excel, Java, ...*) as well as specialized programs for the simulation of material flow (*Flexsim, AutoMod, Enterprise Dynamic, Showflow,. .*). In the simulations, the number of items and their distribution in the picking lines was different, the structure and number of orders were different, as well as number of repetitions.
In [1] is formed model with three groups of the articles A, B, and C, with the probability of finding items in the order of 50, 30 and 20%, relative to the total number of items. Number of items per order was 100, 500 and 1000, and was carried out of 10 reps for each variant.

Roodbergen and De Koster are applied the pickers speed of 0.6 m/s (36 m/min), and the average number of exempted items per order was 30. [2]
Ho is used in the simulations average pickers speed of 30 m / min, and exercised five reps for all variants, where it was 250 orders with 100 different items. The same author has carried out simulations with orders of 30, 60 and 90 items. The structure of orders was 80/20, 60/40 and 50/50. The picking lines has a total of 520 different items, and generated 200 orders. [6]
Petersen is analyzed order picking system in which the size of the picking lines was 96, 288 and the items 576. The structure of the order consisted of 1, 5, 10, 20 and 30 products.[3]
Petersen and Aase are distributed the items by random and classes arrangement. The size of orders were 5, 10, 15, 20, 25, 30, and 40 items. The structure of orders was 80/20 and 60/20 rule. The pickers speed was 45m/min. [7]
In the program Flexsim, Peng is formed model on which the simulation is carried out, which indicated the existence of bottlenecks in the material flows within the production logistics systems. [8]
The advantages of using spreadsheets (as Excel), in the systems of material flows, for solving transport problems, have shown in [9].
Model of zoned picking systems is formed in Flexsim, which allow easy creation of models, because the program has a user functions to manage the process. In fig. 6 is shown model with two pickers.
For simulation of the material flow in the zoned picking systems, using bound cavities method when defining the order of execution of the group order, it was necessary to manipulate with large amounts of data and a large number of calculations, including:
- assigning data about picking places from which to exclude item (one or more) in each order, for example. 300 items and 50 orders in the group amounts to 15.000 data,
- finding the bound cavities and select those that will be the border area, according to the rules described in 1,
- define the order of execution.

The above data and calculations was not possible to implement in Flexsim, especially when one takes into account their quantity. It is possible to perform calculations in another program, for example Excel, and then information about the order of execution and the zone boundaries imported into Flexsim.
The problem, however, then appeared in defining which pickers should be execute which part of the order, as they are not be used priority rules that offered a program. Then it was necessary to manually specify what pickers execute. Due to these problems, simulation model of the zoned picking systems established in the spreadsheet.
The table structure of the program allows the calculations and the results can be organized in a natural and intuitive way. It should be noted that the many years of practice has shown that many stochastic models in the field of logistics and engineering can be conveniently simulated in a spreadsheet. A large number of functions for performing mathematical, statistical and calculation related to databases are available in most spreadsheet, so that simulation are faster and more reliable.

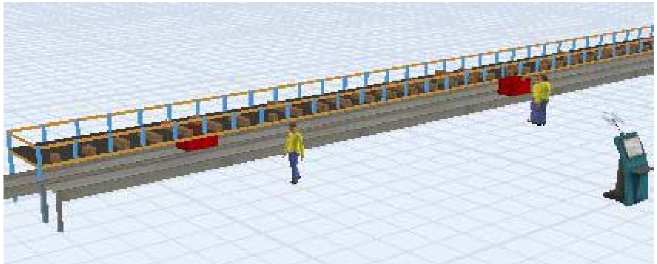

Fig. 6. Model of zoned order picking systems with two pickers in Flexsim

Due to these advantages in a spreadsheet and based on the mathematical models of different zoned picking systems described in the previous section, have been formed corresponding models in Microsoft Office Excel, fig. 7. The models were used to perform simulations in the course to calculate the distance traveled by the pickers and total picking time when processing a group of orders.

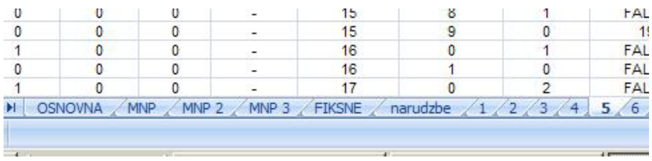

Fig. 7 Part of mathematical models of different zoned picking systems in Microsoft Office Excel

To illustrate the structure and complexity of the program, given a program loop that calculates the picking time for individual orders:

= IF (K17 = LARGE ($K$7:$K$510,3), O17 *$S$1 + 2 * (MIN ($L$7:$L$510)-MAX ($E$7:$E$510)) * $S$2 + Q17 * $H$1, IF (K17 = LARGE ($K$7:$K$510,2), (O17 -MIN ($O$7:$O$510)) * $S$1 + 2 * (LARGE ($L$7:$L$510,2) - LARGE ($K$7:$K$510,3)) * $S$2 + (Q17 – LARGE ($Q$7:$Q$510,3)) * $H$1, IF (K17 = LARGE ($K$7:$K$510,1), (O17 – LARGE ($O$7:$O$510,2)) * $S$1 + 2 * (LARGE ($L$7:$L$510,1) – LARGE ($K$7:$K$510,2)) * $S$2 + (Q17 – LARGE ($Q$7:$Q$510,2)) * $H$1,0)))

Examined several variants of the zoned picking systems with the following variable parameters:
- the number of pickers - 2 and 3,
- the number of orders in the group - 20 and 50,
- the number of picking place in picking line - 80, 160 and 300,
- the number of analyzed bound cavities (bound cavities method) - 1, 2 and 3 (in a system with a two pickers) and 2, 3 and 4 (in a system with a three pickers),
- the average number taken from the total number of items per order - 10-15% and 25-30%,
  percentage of items which takes more than one piece, in comparison with the number of items which are taken - 17 to 32%,
- the weight criteria for defining the boundaries of the zone - (1:1) and (1:4), (bound cavities method), explained in [5].

Simulation of zoned picking systems for different structures of orders (80/20 and 60/20), with a random deployment of items, get the same results. [7]

Therefore, in this study, considering that the the deployment of items was random, not considered variants for different structures of orders.

In order to noticed the effect of defining the zone boundaries and the sequence of execution of orders, using bound cavities method were formed simulation models and calculated values for the following zoned picking systems:

- fixed zone – zone boundaries in the middle of picking lines, random order of execution, in the order of orders arrival,
- fixed zone – zone boundaries in the middle of picking lines, the order of execution according to bound cavities method,
- zoned bucket brigades,
- dynamical zones - zone boundaries according to bound cavities method, random order of execution, in the order of orders arrival,
- dynamical zones - zone boundaries according to bound cavities method, the order of execution according to bound cavities method,

5. RESULTS

In the systems with 2 pickers, the cases with 1, 2 and 3 bound cavities were dealt with, whereby the one was chosen providing most even picker loads. In the systems with 3 pickers the cases with 3 and 4 bound cavities were dealt with, whereby the criteria for adoption were an even picker load and that second picker load is approximately 1/3 of total load.

In the course to define order structure, the sequences of random numbers with an exponential distribution were generated. For different variants sufficient amount of suitable random numbers was generated, playing the role of data concerning location and number of articles to be picked pro separate orders.

For instance, for variant with 80 articles and 50 orders there were 4000 random numbers generated, whereby the random numbers in places 1 to 80 were assigned to first order, in places 81 to 160 to second order etc.

A basic assumption in the model was that there always are sufficient articles in picking places. 5 passes were always made for each variant.

As the reference value for the picking times and for traveled distances, in all variants the results for "bucket brigades"-system were used.

The calculations were made using:

- the average picker velocity - 30 m/min, (Erlang distribution of second-order),
- the roller transporter velocity - 1 m/s,
- picking time for one article - 2 s, (Erlang distribution of second-order),
- time for registering light signal and pressing the taster - 2 s (Erlang distribution of second-order), and
- picking place width - 0,5 m.

The fig. 8 shows a basic table, loaded with the values from the all orders to be processed, for a system with two pickers (part of the table). [5]

	Tr1	Tp1	Tr2	Tp2	Tk	kraj 1. zone	pocetak 2. zone	% prvog	vreme pocetka	vreme kraja	ukupan broj artikala
1	59.0	33.0	91.0	35.0	5.5	34	45	0.4220	1.0	3.0	23
2	107.0	55.0	32.0	12.0	6.0	56	68	0.7864	2.0	4.0	20
3	99.0	37.0	67.0	35.0	3.5	38	45	0.5714	0.0	8.0	26
4	55.0	33.0	54.0	32.0	7.0	34	48	0.5057	1.0	11.0	13
5	110.0	42.0	62.0	28.0	4.5	43	52	0.6281	1.0	0.0	28
6	99.0	41.0	67.0	29.0	4.5	42	51	0.5932	1.0	6.0	28
7	58.0	22.0	89.0	45.0	6.0	23	35	0.3738	1.0	8.0	22
8	84.0	28.0	98.0	44.0	3.5	29	36	0.4409	0.0	1.0	31
9	82.0	38.0	80.0	28.0	6.5	39	52	0.5263	4.0	3.0	30
10	72.0	34.0	89.0	35.0	5.0	35	45	0.4609	1.0	0.0	27
11	46.0	28.0	128.0	42.0	4.5	29	38	0.3033	4.0	1.0	30
12	73.0	31.0	86.0	42.0	3.0	32	38	0.4483	1.0	8.0	23
13	103.0	49.0	42.0	18.0	6.0	50	62	0.7170	1.0	1.0	23
14	51.0	23.0	62.0	38.0	9.0	24	42	0.4253	0.0	4.0	15
15	113.0	43.0	55.0	23.0	6.5	44	57	0.6667	1.0	0.0	28
16	158.0	56.0	19.0	11.0	6.0	57	69	0.8770	1.0	0.0	31
17	82.0	30.0	100.0	40.0	4.5	31	40	0.4444	3.0	6.0	33
18	75.0	37.0	68.0	32.0	5.0	38	48	0.5283	8.0	0.0	21
19	90.0	38.0	71.0	33.0	4.0	39	47	0.5517	8.0	5.0	26
20	58.0	26.0	108.0	46.0	3.5	27	34	0.3529	4.0	2.0	28

Fig. 8 The basic table, loaded with the values from the all orders to be processed, for a system with two pickers (part of the table)

The fig. 9 shows a table with basic calculations in a system with two pickers (part of the table). [5]

artikli	9. narudzbina	mesta izuzetih artikala	pocetak prve zone	kraj druge zone	podatak za kraj druge	suma uzastopnih praznina	brojac uzastopnih praznina	brojac otpozadi	ukupan b artikala ispred
1	0	0	1	0	-	0	0	3	FALSE
2	0	0	2	0	-	0	1	2	FALSE
3	0	0	3	0	-	0	2	1	FALSE
4	0	0	4	0	-	0	3	0	FALSE
5	1	1	5	0	-	1	0	14	FALSE
6	0	0	0	0	-	1	1	13	FALSE
7	0	0	0	0	-	1	2	12	FALSE
8	0	0	0	0	-	1	3	11	FALSE
9	0	0	0	0	-	1	4	10	FALSE
10	0	0	0	0	-	1	5	9	FALSE
11	0	0	0	0	-	1	6	8	FALSE
12	0	0	0	0	-	1	7	7	FALSE
13	0	0	0	0	-	1	8	6	FALSE
14	0	0	0	0	-	1	9	5	FALSE
15	0	0	0	0	-	1	10	4	FALSE
16	0	0	0	0	-	1	11	3	FALSE
17	0	0	0	0	-	1	12	2	FALSE
18	0	0	0	0	-	1	13	1	FALSE
19	0	0	0	0	-	1	14	0	1
20	1	1	0	0	-	2	0	2	FALSE
21	0	0	0	0	-	2	1	1	FALSE
22	0	0	0	0	-	2	2	0	FALSE
23	2	1	0	0	-	3	0	0	FALSE
24	1	1	0	0	-	4	0	2	FALSE
76	0	0	0	0	-	17	2	0	FALSE
77	1	1	0	77	77	18	0	3	FALSE
78	0	0	0	78	78	18	1	2	FALSE
79	3	0	0	79	79	18	2	1	FALSE
80	2	0	0	80	80	18	3	0	FALSE

MNP | MNP 2 | MNP 3 | FIKSNE | narudzbe | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11

Fig. 9 Table with basic calculations in a system with two pickers (part of the table)

The complete results and analysis are given in the [5]. In this paper is displayed only some.

The fig. 10 shows percentage picking time savings by applying bound cavities methods in relative to system of bucket brigades, for more variants.

The fig. 11 shows percentage reduction in picker traveled distances in variants with max. bound cavities as the zone boundaries, using the bound cavities method in relative to system of bucket brigades.

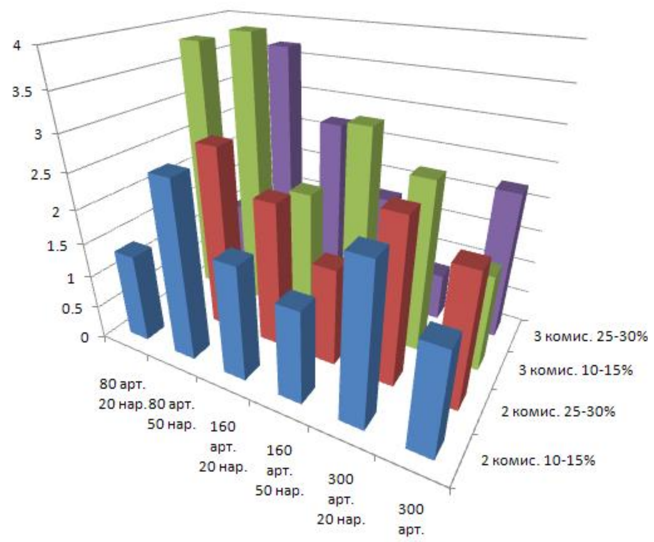

Fig. 10. Percentage picking time savings by applying bound cavities methods in relative to system of bucket brigades, for more variants

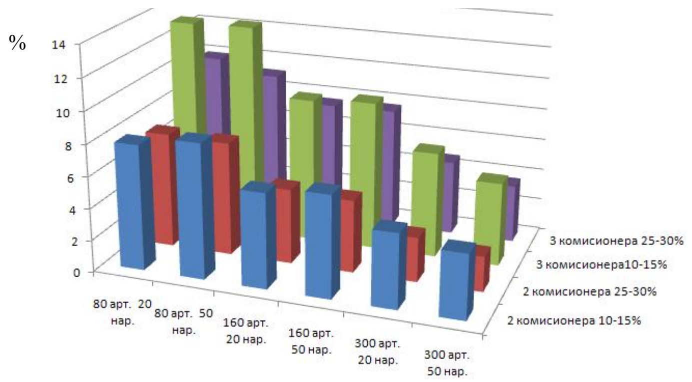

Fig. 11 The percentage reduction in picker traveled distances in variants with max. bound cavities as the zone boundaries, using the bound cavities method in relative to system of bucket brigades

CONCLUSION

The order picking operation represents the highest cost element in a typical distribution center. Although modern distribution centers are automated in a large extent, it is in most cases impossible to replace the human with the machine. Order picking systems can be very simple systems in small operations or become very complex systems using a little quantity of different articles. In such situations only the application of zoned pick and pass picking systems with pick to light technology can lead to satisfactory performances.

Simulation of material flow in the zoned picking system enables monitoring and collecting data on the number of excluded items and paths traveled individual pickers, on the basis of which it can calculate the output of each picker. Also, it is possible to to track and locate mistakes, and increase productivity by stimulating work based on output and accuracy.

Simulation results, achieved under the application of formed mathematical models, show that, when bound cavities method is used, performances of picking system get better – total picking time and picker traveled distances are significantly reduced. Better performances are achieved also in the systems with fixed zones if order fulfilling sequence is defined according to bound cavities method. At the same time, as the requests for performance improvement immerge even load of all pickers and, in systems with 3 and more pickers, an necessary request is that in all orders the load of all pickers, which are not located at the end of picking line, is equal 1/n of total load, whereby n represents the number of pickers.

When applying bound cavities method it is possible to achieve performance increase in zoned pick and pass order picking systems whatever the order structure, whereby it is not necessary to relocate the articles within picking zone with the aim of balancing picker load and it is not necessary to apply sorter system.

REFERENCES

[1] S.C. Rim, I.S. Park, "Order picking plan to maximize the order fill rate," Computers & Industrial Engineering 55, 2008., pp. 557–566,

[2] K.J. Roodbergen, R. De Koster, "Routing order pickers in a warehouse with a middle aisle," European Journal of Operational Research 133, 2001., pp. 32–43,

[3] C. Petersen, "Considerations in order picking zone configuration," International Journal of Operations & Production Management, Vol. 22, No 7, 2002., pp. 793-805,

[4] P. Koo, "The use of bucket brigades in zone order picking systems," OR Spectrum 31, 2009., pp. 759-774.

[5] D. Živanić, "Logistics and Material Flows Simulation as a Foundation for optimum Transport-warehouse Systems Choice," Doctoral dissertation, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, 2012.

[6] Z.C. Ho, S.P. Chien, "A comparison of two zone-visitation sequencing strategies in a distribution centre," Computers & Industrial Engineering 50, 2006., pp. 426–439,

[7] C. Petersen, G. Aase, "A comparison of picking, storage, and routing policies in manual order picking," International Journal of Production Economics 92, 2004., pp. 11–19,

[8] J. Peng, "Optimization on the improvement schemes of production logistics system based on Flexsim simulation," Advanced Materials Research, Vols., 225-226, 2011., pp. 852-856,

[9] I. Hristoski, Ð. Mančeski, "Obtaining the initial solutions of the transportation problem using Microsoft Excel and VBA programming," The third serbian symposium with international participation TRANSPORT AND LOGISTICS, Niš, 2008., pp. 12.1-12.6.,

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