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A REVERSE LOGISTICS MODEL DESIGN FOR MANAGING INDUSTRIAL WASTE STREAM

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Abstract

The paper considers the key problem of industrial waste management, with special emphasis on environmental protection. Industrial waste management is a fundamental task of reverse logistics. The main objective of this paper is development of a model for solving the location problem of waste / byproduct treatment facilities, taking into consideration the territorial distribution of raw materials, the type and the quantities of raw materials and the distance between the industries. In this manner, the resource usage could be optimized by an interaction between the companies through the exchange of by-products as well as through integrated systems management of industrial waste. Global optimization methods, i.e. heuristic algorithms, were applied to determine the location of by-product (waste) treatment facility.

***Key words**: reverse logistics, industrial waste, facility location.*

1 INTRODUCTION

Composing a comprehensive system of industrial waste management demands an insight into the processes of waste generation, handling, storage, transport, treatment and disposal. One of the overall objectives in the field of waste management is to reduce the amounts of waste and ensure its reuse or disposal in a manner that does not lead to environmental degradation, but rather facilitates significant improvement of resource efficiency.

A so-called "linear industrial system", based on the assumption that resources are abundant, available, convenient to be used easily and disposed of cheaply, has been developing from the Industrial Revolution to the present day. The European Union produces about 3 million tons of waste on an annual basis. The production sector (industry) generates 360 million tons of waste annually, construction sector produces 900 million tons of waste, while the sector of water supply and energy production produces 95 million tons of waste [1]. In recent years, waste recycling in the European Union has been stimulated by the appropriate regulations, while EU legislation provides a compelling incentive for national governments in their efforts to improve the recycling systems [2, 3].

Seeking a competitive management, industrial entities improve their production processes, reduce overall operating costs and prices of end products, and increase productivity, efficiency and cost-effectiveness of product delivery to the final consumer. Having been used, the products become waste, and waste issue becomes a matter of paramount importance. On the other hand, production processes also generate certain amounts of waste that must be handled in an adequate way.

The changes in legislation, conditioned by the need to protect the environment, and the development of new service sectors affect a growing number of companies to reconsider the reverse flows in their logistics systems, i.e. flows which refer to the movement of the product residues from the customer to recycling centers and back to the industrial plants. Applying reverse logistics in a system of integrated business operations raises the level of corporate responsibility of an industrial entity, enhances credibility and market advantage.

Despite the outstanding environmental benefits of recycling, there are various costs incurred in the process of collection and transportation of by-products; therefore, it is important to minimize these costs in order to maximize total profit for the environment [4, 3]. Applying the principles of sustainable development requires a change of priorities in the majority of supply chains, including reverse logistics in industrial waste management. One of the sizeable environmental problems in the Republic of Serbia is inadequate waste management (more exactly, infrequent use of industrial waste, limited capacities of waste intended for recycling and insufficient waste-to-energy use), where consequences are negative impact on the environment and tremendous exploitation of natural resources.

In line with the problems that rise in the waste management system in Serbia, it is significant to create the financial instruments that would provide systemic support to recycling industry, having in mind that the reduced use of resources cut companies' operating costs. Investing in environmentally safe technologies can improve competitiveness on an international market, while reaching the EU standards at the same time.

2 MANAGING INDUSTRIAL WASTE IN SERBIA

In its efforts to achieve industrial development in various sectors, Serbia is faced with threats of generating considerable volumes of waste. Large industrial plants are considered the most critical generators of waste.

Serbian approach to waste management is based on the EU standards and adopted waste hierarchy principle prescribed by the Law on Waste Management ("Official Gazette of the

Republic of Serbia”, No. 36/09, 14/16) [5] as well as in the National Waste Management Strategy, 2010-2019 (“Official Gazette of the Republic of Serbia”, No. 29/10) [6]. This hierarchy states that the most preferred option for waste management is prevention, followed by re-use and recycling, energy recovery and, least favoured of all, disposal. Serbia is in the process to establish national targets for waste recycling.

According to the Law on Waste Management, industrial waste is “waste from any industry or location of industry, in addition to mining and quarrying waste” [5], while Directive 2008/98/EC categorizes waste as “any substance or object which the holder discards or intends or is required to discard” [2].

According to the national document - Report on the State of the Environment in the Republic of Serbia for 2014 by the Serbian Environmental Protection Agency, the amount of industrial waste generated in 2014 was about 6.12 million tons. Of these, 5.9 million tonnes comprised non-hazardous waste, whereas approximately 210 thousand tons were hazardous waste [7]. Of the total amount of waste produced, approximately 26% of waste was treated in an acceptable manner while about 74% of waste remained at the sites where it was generated [7].

Based on the State of Environment Report of the Republic of Serbia, the volume of industrial waste generated in 2013 was about 8.7 million tons. Of this, 8.2 million tonnes were non-hazardous waste, and about 580 thousand tons comprised hazardous waste. Of the total quantity of industrial waste, about 16% was disposed of/treated or exported, whereas about 10% was delivered to the operators to reuse. Even 75% of waste remained on-site [8].

Table 1 shows the manner of handling waste generated in 2014 and 2013, while Figure 1 is a graphical representation of industrial waste management in 2014 and 2013.

With reference to the data above, it can be concluded that the prevailing method of industrial waste treatment is long-term on-site storage in the producer’s facilities or disposal with municipal solid waste in municipal landfills.

The fact is that Serbia is lagging behind other countries in the region which necessitates significant investment in the field of industrial waste management. The focus of development should be recycling industry, turning waste into a resource and striving for circular economy. It is mandatory to apply the latest technical standards and solutions relating to the establishment of centers for the collection of industrial waste, in accordance with the current Serbian and the European Union Directives.

Table 1 Manner of handling industrial waste generated in 2014 and 2013 [7, 8]

Waste type	Produced quantity of waste (t)	Waste stored on the producer’s site (t)	Amount of waste intended for long-term storage (t)	Amount of waste intended for disposal (t)	Amount of waste intended for treatment (t)	Exported waste (t)
2014.						
Hazardous	209.877	2.544	168.811	6.538	30.215	1.769
Non-hazardous	5.915.105	4.543.248	565.038	204.883	591.158	10.778
Total (t)	6.124.982	4.545.792	733.849	211.421	621.373	12547
2013.						
Hazardous	577.605,92	336.167,76	150.740,86	6.973,10	81.364,23	2.359,97
Non-hazardous	8.203.392,06	6.254.140,25	984.044,87	165.840,64	756.082,70	43.283,60
Total (t)	8.780.997,98	6.590.308,01	1.134.785,73	172.813,74	837.446,93	45.643,57

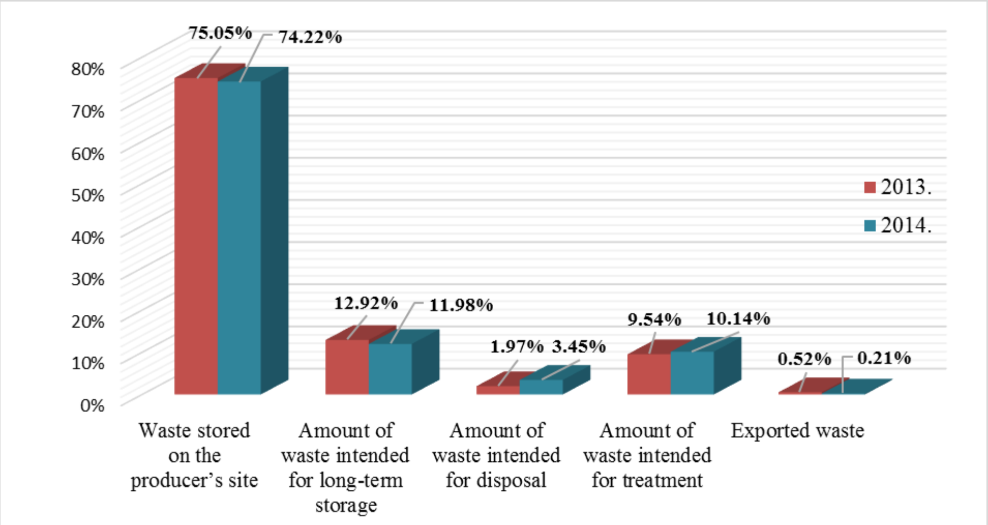

***Fig. 1** Handling produced quantities of industrial waste in Serbia in 2014 and 2013* [7, 8]

3 REVERSE LOGISTICS – DEFINITION AND BASIC CONCEPTS

Spatial and temporal transformation processes that are typical for logistics are conditioned by limited natural resources, restricted choice of energy sources, as well as growing degradation of the living environment. The European Union has brought increasingly stringent regulations on product packaging, transportation and waste management, which points to the fact that logistics shall be given a special role in the area of waste management and disposal.

Integrated logistics systems generally allow the flow of products toward the consumers. However, with the aim to reduce the environmental pressures, logistics systems must allow the reverse flow of products from consumers to other entities in the supply chain. This system is known as reverse logistics system. Reverse logistics refers to the activities of logistics and management skills that are used for reduction, management and disposal of waste starting from disposable containers to various products [9]. The measures aimed at minimizing the amount of waste start at the very first phase of product design and involve a range of measures related to product's life cycle, including transportation and final disposal.

The research on reverse logistics have evolved over the years, and the authors who have studied the concepts of reverse logistics suggest diverse definitions. Traditional supply chains (so-called "forward supply") that include the flow of raw materials to the finished product and consumers have expanded into the reverse flow of products, from the consumers to the sources of raw materials [10]. Some authors [11] have emphasized the purpose of reverse logistics and brought their own definitions based on an earlier formulation of the Council of Logistics Management where "reverse logistics is the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and information from the point of origin to point of consumption for the purpose of conforming to customer requirements".

The above mentioned authors defined the reverse logistics in the following way: "Reverse logistics is the process of planning, implementing and controlling the efficient, cost effective flow of raw materials, in-process inventory stocks of semi-products and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or for proper disposal" [10]. Since then, the definition of reverse logistics has received new dimensions and modifications of its meaning.

In the literature of reverse logistics, many authors have pointed to the key reasons why companies participate in the process of reverse logistics. Reverse logistics programme can bring direct profits for companies by: reducing the use of primary raw materials, increasing the value of returned products and reducing waste disposal costs.

The concept of reverse logistics was adopted by the industries as a strategic tool for economic profit and a better image in society [12], which raised the possibility of providing competitive advantages in the market [13].

Reverse logistics encompasses a range of activities aimed at the environmentally friendly disposal of products or the implementation of an acceptable treatment without any impact on the environment. These activities cover the collection of products, testing and sorting operations, product disassembly, storage, transportation and the process of recovery. To conclude, reverse logistics appertains to all operations which refer to the reuse of products and materials. Reverse logistics is a development path from the "waste" generation to the site where it will be reused.

Some of the reasons why reverse logistics and logistics management of industrial waste have been given more attention are the following:

– The legal framework that obliges companies (producers) to receive back their products after their lifetime. For example, the EU Directive 2012/19 / EC on waste electrical and electronic equipment (WEEE) [14] regulates the collection, recycling and proper disposal of electronic products at the end of the life cycle (End-of-Life products);

– Economic benefits of the refurbished products, instead of high costs of waste disposal;

– A complex industrial waste management system that covers all industrial operators (waste producers), which demands significant infrastructure investments and proper estimates of logistics costs. A great deal of products can be either recycled or reused in another production. Designers of reverse logistics systems are challenged to reconsider in what way to encourage the consumers to return the end-of-life products. The companies worldwide offer various financial incentives to consumers if they send used products to recycling centers.

4 METHODOLOGY OF SELECTING THE LOCATION OF THE INDUSTRIAL WASTE TRETMAN FACILITY

The model that will be discussed here has been designed with the aim to facilitate better cooperation between the industrial entities within the boundaries of an observed system (a region). The advantages of such exchanges involve the reduced consumption of resources and energy, and thereby reduced generation of by-products, which directly affects the minimization of waste storage costs and the increase of environmental responsibility in the industrial sector.

The reliability of secondary raw materials supply depends on their availability, as well as on logistics costs of supply, i.e. the location of waste treatment plants (or the location of industrial production in which a certain by-product can be used as a raw material in another production process).

With the aim to make the secondary raw materials generated by industries available for any kind of treatment, it is essential to develop an efficient recycling network which would provide the means for collection, sorting and recycling of these materials. Industrial facilities that generate certain types of waste (secondary raw materials) represent the first level of reverse logistics network. Generated industrial waste is then forwarded to the next level in the network which is specified by the locations for waste collection and treatment.

In this paper, the authors analyzed a reverse logistics network consisting of two levels: the first level involves the locations of industrial waste producers, while the second one represents a recycling plant for selected type of waste. Modelling the process of site selection for waste treatment facilities is based on location optimization using the p-median model.

The methodology of selecting the appropriate location for building waste treatment facilities incorporates the following elements [15]:

1. Defining a geographical area (a territorial area).
2. Identifying industrial entities / industrial waste producers within the specified geographical area, collection and preparation of data about their geographical location using Google Maps and the amounts of waste generated. In order to direct the flows of industrial waste efficiently, it is necessary to generate the reports on individual producer's waste quantities and the owners of waste at local and regional level. The generators of waste report to the Environmental Protection Agency in accordance with the Regulation on the methodology for the development of national and local register of pollution sources and the methodology for types, methods and deadlines for data collection ("Official Gazette of of the Republic of Serbia", No. 91/2010 and 10 / 2013) by filling in the Annual report on waste generated by waste producers which, among other data, contains the information about the six -digit code of waste (included in the Waste Catalogue) and the amount of waste generated for the reporting year (t).
3. The existing database of the National Registry of Pollution Sources of the Environmental Protection Agency can be used to create secondary databases that would match the model of managing the flow of secondary raw materials. This would aid the establishment of the collaboration between and inside the industrial sectors.
4. Developing a secondary database with all the necessary information on the industrial entities within the observed region and the amounts of waste generated in the reference year according to the six-digit code for waste.
5. By applying the p- median model in the designated area - in the nodes of a waste generator network, it is possible to locate waste treatment plants where the input would be a secondary raw material comprised of industrial waste generated in that area. Therefore, it is necessary to find the location of waste treatment plants, so that the sum of distances is minimal (in this way, it is possible to minimize the overall transportation costs). The problem is considered taking into account facility macro location.
6. On the basis of the amounts of waste and the road distances between the industrial entities (waste producers) in the designated regions, and by applying the p- median model, it is possible to locate *p* new industrial facilities / waste treatment plants with defined capacity for a chosen six-digit code for waste.

4.1.The p- median model

Due to the fact that modelling refers to the optimization of a designated location of industrial production (depending on the materials), and that the main optimization criterion is total transportation costs and the amounts of secondary raw materials (waste) in the supply chain, the p-medial model could be used to present the balanced allocations of resources within the observed region.In case of the p-median problem, it is necessary to locate one or more facilities in the network so as to minimize the average distance (or the average travel time or the average transportation costs) from the facility to the user or from the user to the facility [16]. Hakimi [17] showed that there was at least one set of p-medians in the nodes of a network that has *n* nodes, which means that *p* optimal locations of facilities in the network must be located in the network nodes only [18]. The facilities can be located in any of *n* nodes. This fact significantly simplifies the procedure of finding p median, since the locations in the nodes only should be examined.

Mathematical formulation of the p median model refers to the problem of linear programming in the center of which there is a symmetric distance matrix d_{ij}, which represents the distance between the location *i* that should be serviced and the candidate *j*, in order to provide the optimal solution. In the above context, the p median model can be defined by the following parameters:

$i = \{1, 2, 3, 4, \ldots, I\}$ the set of candidate locations,
$j = \{1, 2, 3, 4, \ldots, J\}$ the set of demand nodes,
a_i – demand of customer *I*,
p – number of facilities,
d_{ij} – distance between demand node *i* and site *j*.

Decision variables x_{ij} i X_j:
$x_{ij} = 1$, if demant at node *i* is served by a facility at site *j*;
$x_{ij} = 0$, otherwise.
$X_j = 1$, if a facility is located at site *j*;
$X_j = 0$, otherwise.

With this notation, we can formulate the *p*-median problem as follows:

$$\min F = \sum_{i\in I}\sum_{j\in J} a_i\, d_{ij} x_{ij} \qquad (1)$$

subject to:

$$\sum_{j\in J} x_{ij} = 1 \quad \forall i \in I \qquad (2)$$

$$\sum_{j\in J} X_j = p \qquad (3)$$

$$X_j \ge x_{ij} \quad \forall i \in I, \forall j \in J; i \ne j \qquad (4)$$

$$X_j \in \{0,1\} \quad \forall j \in J \qquad (5)$$

$$x_{ij} \in \{0,1\} \quad \forall i \in I\,, \forall j \in J \qquad (6)$$

The objective function (1) minimizes the demand-weighted total cost. Constraints (2) mean that all of the demand at demand site *i* must be satisfied. Constraints (3) require exactly *p* facilities to be located. Constraints (4) state that demand nodes can only be assigned to open facilities. Constraints (5) stipulate that the location variables must be integer and binary. Finally, constraints (6) state that the assignment variables must be non-negative.

4.2. The application of the p median model to determine the location of waste treatment facilities

For the purpose of verifying the methodology described, we assumed there was a need to build a new industrial waste treatment plant in which waste aluminium would be used (a six-digit code in the Waste Catalogue is 17 04 02). The p median method was used for the region of Southern and

Eastern Serbia, where we systematized the database of waste aluminium producers according to the statistics from the National Registry of Pollution Sources of the Environmental Protection Agency.

The period intended for collecting data on the amounts of waste from the National Registry of Pollution Sources is determined on the basis of the legislation that obliges the companies to report regularly (once a year for the previous year) on the amounts of waste generated. In the region of Southern and Eastern Serbia, we identified 11 industries / waste generators for the aforementioned type of waste.

To solve the p median problem in this study, we used a Greedy heuristic algorithm. When defining the parameters of p the median model we considered the existence of the following issues: the set $i = 1,2,3 \ldots, I$ nodes in which the industries (waste generators) are located; the set $j = 1,2,3, \ldots, J$ nodes in which it is possible to locate new industrial waste treatment plants; the available amounts of waste in the node $I - a_i$; the number of facilities that need to be located in the network - p, where $p = 1, 2, \ldots, \leq J$, and the distance between the node i and the node $j - d_{ij}$.

Table 2 presents a secondary database of the facilities that generate aluminium in the South and East Serbia region, while Table 3 shows the matrix of road distances of the monitored waste generators in the network (the waste generators are represented by ordinal numbers in the secondary database).

Minimum solution of the function F represents the optimal solution for the location of waste treatment facility (Equation 1).

Fig. 2 *The view on the locations that generate waste aluminium on Google Maps [15]*

Table 2 Secondary database of aluminium generating facilities

No.	Place of facility	Address	Facility	Six-digit code for waste (aluminium)	Amounts of waste for 2014 year (t/year)
1.	Negotin	Samarinovački put bb	The Iron Gate II Hydroelectric Power Station, Negotin	17 04 02	0,5
2.	Village Kostolac	Nikola Tesla, no. 5-7	Economic Association “Thermal Power Plants and Mines Kostolac”, Thermal power plant Kostolac B	17 04 02	88,8
3.	Village Drmno “”	Drmno	Economic Association “Thermal Power Plants and Mines Kostolac”, Ltd, Open-pit mine Drmno	17 04 02	0,1
4.	Leskovac	Stojana Ljubića, no. 16	Electricity distribution company “Jugoistok” Ltd Niš, Branch ED Leskovac	17 04 02	0,2
5.	Niška Banja	Bulevar Svetog cara Konstantina bb	Company for aluminium processing NISSAL NEWMET Ltd Niš	17 04 02	91,2
6.	Niš (Medijana)	Bulevar dr Zorana Đinđića no. 46a	Electricity distribution company “Jugoistok” Ltd Niš, Branch ED Niš	17 04 02	0,4
7.	Pirot	Takovska 3	Electricity distribution company “Jugoistok” Ltd Niš, Branch ED Pirot	17 04 02	0,2
8.	Smederevska Palanka	Industrijska 70	Factory of Railway Vehicles “Goša”	17 04 02	1,4
9.	Velika Plana	Milorada Stankovic 47	Feropromet98	17 04 02	3,5
10.	Zaječar	Negotinski put bb	Cable factory “TF Kable” Ltd Zaječar	17 04 02	35,3
11.	Zaječar	Trg Oslobođenja no. 37	Electricity distribution company “Jugoistok” Ltd Niš, Branch Elektrotimok Zaječar	17 04 02	0,4

Table 3 The matrix of road distances of the monitored waste producers in the network

No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1.	0,00	170,00	170,00	213,00	159,00	161,00	169,00	229,00	218,00	63,00	66,00
2.	170,00	0,00	0,00	248,00	220,00	212,00	279,00	61,30	66,10	161,00	165,00
3.	170,00	0,00	0,00	248,00	220,00	212,00	279,00	61,30	66,10	161,00	165,00
4.	213,00	248,00	248,00	0,00	50,50	46,10	78,10	199,00	188,00	151,00	149,00
5.	159,00	220,00	220,00	50,50	0,00	7,40	63,80	170,00	159,00	95,00	93,00
6.	161,00	212,00	212,00	46,10	7,40	0,00	71,00	162,00	151,00	98,40	96,60
7.	169,00	279,00	279,00	78,10	63,80	71,00	0,00	229,00	218,00	106,00	104,00
8.	229,00	61,30	61,30	199,00	170,00	162,00	229,00	0,00	13,60	167,00	165,00
9.	218,00	66,10	66,10	188,00	159,00	151,00	218,00	13,60	0,00	156,00	154,00
10.	63,00	161,00	161,00	151,00	95,00	98,40	106,00	167,00	156,00	0,00	3,40
11.	66,00	165,00	165,00	149,00	93,00	96,60	104,00	165,00	154,00	3,40	0,00

The sums of weighted distances of the given type of waste in all industries / waste generators in Southern and Eastern Serbia regions are presented in Table 4. According to the survey, the first median was located in Niš, on the territory of the Company for aluminium processing NISSAL NEWMET Ltd. and it represents the optimal location in the network. In this location, the sum of weighted distances is least compared to other nodes in the network. We also measured the distances between the waste generators (Table 3) taking into account the road restrictions which allow transportation on the motorways and main roads only.

Table 4 The sums of weighted distances in distributing chosen type of waste

No.	Facility	The sums of weighted distances
1.	The Iron Gate II Hydroelectric Power Station, Negotin	33.101,10
2.	Economic Association “Thermal Power Plants and Mines Kostolac”, Thermal power plant Kostolac B	26.437,87
3.	Economic Association “Thermal Power Plants and Mines Kostolac”, Ltd, Open-pit mine Drmno	26.437,87
4.	Electricity distribution company “Jugoistok” Ltd Niš, Branch ED Leskovac	33.150,06
5.	Company for aluminium processing NISSAL NEWMET Ltd Niš	23.867,52
6.	Electricity distribution company “Jugoistok” Ltd Niš, Branch ED Niš	23.912,74
7.	Electricity distribution company “Jugoistok” Ltd Niš, Branch ED Pirot	35.638,38
8.	Factory of Railway Vehicles “Goša”	27.260,57
9.	Feropromet 98	26.246,33
10.	Cable factory “TF Kable” Ltd Zaječar	23.880,32
11.	Electricity distribution company “Jugoistok” Ltd Niš, Branch Elektrotimok Zaječar	24.163,04

5 CONCLUSION

Appropriate management of industrial waste is of particular importance for preventive environmental protection. The amounts of generated industrial waste, and a tendency of their increase, are one of the key factors which influence rapid degradation of the environment. The existing environmental burden can be diminished by the implementation of convenient solutions, more exactly, the establishment of the appropriate options for waste treatment, especially if we take into account the fact that the waste materials should be regarded as a resource.

Depletion of primary resources was the reason why the optimization of supply chains and the search for new solutions to exploit great quantities of recyclable materials have turned into one of the biggest challenges. In such an environment, a strategic approach in optimizing the supply chains, as well as the flow of products and waste materials that can be used as secondary raw materials, become an imperative. The first step in the strategic approach to supply chain optimization is to determine the optimal location of the facilities in the chain.

The development of the methodology for selecting a suitable location for new industrial plants/waste treatment facilities was accomplished with the aim to encourage the re-use of secondary raw materials and waste recycling in an economically viable manner, and promote the extraction of valuable recyclable materials from the main industrial waste flows. Given the fact that the management of secondary raw materials is one of the most relevant activities in reverse logistics, this paper presents a potential approach to solving the issue of secondary raw materials.

The main objective of modelling is the selection of optimal locations for a new industrial plant/ waste treatment facility. For solving the facility location problem, we used the p-median model and heuristic optimization method. The p-median model observed the location allocation in terms of minimizing transportation costs, which have the greatest impact on logistic costs and total costs of secondary raw materials treatment. A developed methodology facilitates the systematization and the usage of the information on the types and amounts of waste generated in the company, relying on the National Registry of Pollution Sources database.

In such a way, it is possible to determine the *P*-optimal locations of the waste treatment facility (where $p = 1, 2, ..., \leq J$) in which *n* types of waste is generated, and consequently, to apply the above described methodology for the development of macro-industrial areas. According to the research, the first optimal location is located in the city of Niš, on the territory of the Company for aluminium processing NISSAL NEWMET Ltd. Furthermore, the benefit of this methodology is the possibility to determine a larger number of optimal locations depending on a defined geographical area or the need for secondary raw materials, by including an additional restriction that would refer to the capacity of the optimal locations for waste treatment facility. Also, the industrial operators - waste generators could be allocated in the located facilities for waste treatment.

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