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# MULTI-CRITERIA MODEL FOR DISASTER LOGISTICS PERFORMANCE ASSESSMENT AT STRATEGIC LEVEL

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***Abstract***

*The nature and character of disasters have changed. Good and efficient disaster logistics system is essential for reduction and mitigation of some outcomes of adverse events. Positive effects can only be achieved if disaster logistics system is effective and continuously improved. Strategic efficiency evaluation is usually based on the analysis of a small number of indicators. We propose the model for disaster logistics assessment based on performance indicators and multi-criteria group decision making. Performance indicators are classified into groups, describing institutional basis, local community ability, and disaster logistics system organization.*

***Key words****: emergency logistics, disaster, performance framework, group fuzzy analytic hierarchy process (GFAHP).*

## 1 INTRODUCTION

The frequency of disasters and technical accidents has increased significantly during last 50 years. Negative impact of humans on the environment, making settlements on locations often affected by natural disasters, as well as industrialization near densely populated areas has led to increased damage and number of casualties. Although there was no precisely disaster statistics for previous centuries, on the basis of geo-morphological analysis and existing documents, compared to modern databases, such as EM-DAT, in some regions of the world the number of disasters is increased more than 10 times compared to previous centuries [1]. In order to minimize adverse effects of disasters on a society, it is necessary to make preventive actions. These actions are based primarily on the analysis of potential risks and development of defence resources that allow the society to acquire coping capacity, reduce the vulnerability and increase the resilience. The application of latest measures and protection devices have not reduced the number of accidents, primarily due to increased population, lack of awareness on potential risks, settlement of dangerous areas in the zones of increased risks of disasters and technical accidents in plants.

According to [2], the resilience of a society is not defined by a disaster type, but the existence of local security strategies, risk mapping, definition of protection and rescue plans, economic potential of a local community and cooperation with neighbouring regions and countries.

When considering disaster resilience of a society and disaster management system, it is important to consider logistics support. The temporal aspect of logistics support, in the context of predictability and duration of a disaster, defines the periods before, during and after a disaster. This type of logistics is called emergency logistics, disaster logistics, or humanitarian logistics [3]. Due to the volume of inventories, specific requests and response speed, disaster logistics is significantly different from a classical logistics chain [4, 5]. This paper presents the model of multi-criteria analysis of key performance indicators of the logistics chain for disaster management, based on fuzzy logic.

## 2 MODEL

Different methods and models are applied for the analysis of industrial supply chains. Stable or predictable demand, yield, efficiency and effectiveness are basic characteristics of these chains [3, 5]. Unlike them, supply chains related to disasters are characterized by unpredictable and sudden demands, short lead times, unpredictable locations, limited available resources, lack of previous experience, and short response time (according to [5]).

Logistics and supply chain include efficient and effective storage and transport of goods, materials and information, from the initial location to end users affected by a disaster. The main difference between the disaster management chain and commercial chains is seen in a variety of patterns of initiating events, where a disaster occurs unpredictably in time, location and extent, and demands considerably change over time, based on consequences of a disaster [6-9]. Lead time is almost equal to zero, and distribution network is defined by requests, after the occurrence of an undesired event, at unknown location and with undefined requirements [2, 4, 10]. The main limitations are defined by strategic objectives, based on minimization of the number of casualties and reduction of suffering of affected persons, and increase of the possibility of fulfilling the needs of affected persons.

Fig. 1 shows important activities are related to the disaster logistics, and which are carried out before, during and after disaster.

Before the occurrence of an undesirable event, there are activities of preparation of a society, training of individuals, improving coping capacity, risk assessment and risk mapping, fundraising, collecting necessary equipment, strategic and operational resource allocation, and securing the critical infrastructure.

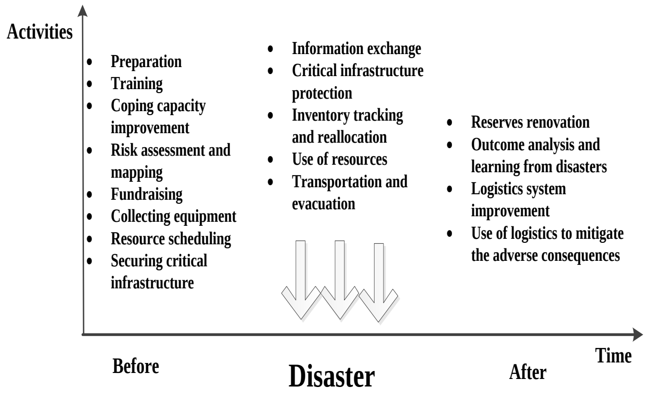


***Fig. 1*** *Activities before, during, and after disaster*

During the occurrence of a disaster, in case of sudden-onset disasters, only thing that can be done is reducing the number of victims. In case of slow-onset disasters, evacuation is possible, as well as reallocation of resources and parts of the logistics system. During a disaster, the most important is to monitor the inventory, preserve critical infrastructure, efficiently implement transportation and evacuation, and exchange reliable information. After a disaster, in the short term, logistics system attempts to reduce human suffering by helping people, distributing the aid, and mitigating some negative consequences of a disaster. In the longer term, it is important to learn from experience, improve the logistics system, and update resources.

Fig. 2 presents the disaster logistics management algorithm. It starts by identifying entities in the disaster logistics system. To properly use disaster logistics, it is necessary to perform a detailed analysis and risk mapping, and identify critical points around which necessary elements of the logistics system should be concentrated [10, 11]. Disasters are usually localized, and it is important logistics development at local level, as well as coordination with regional, national and international organizations. If there is increased disaster risk, it is necessary to develop monitoring systems that enable timely response, especially in case of slow-onset disasters.

The most important analysis after the occurrence of a disaster is the evaluation of local availability of resources and the level of logistical support. If there are sufficient local resources, we can use local logistics system. Most often, there are not enough local resources, and it is necessary to engage emergent orders, allocate additional resources and continuously monitor the situation in the field. Insufficient development of a region, underdeveloped infrastructure, poor dynamics and poor organization of protection and rescue systems generates more disaster consequences due to a lack of resources or impossibility of their use [2]. Communication and collaboration is important for the efficient use of resources during disaster management [4, 12].

In the aftermath of a disaster, logistics is used for mitigation purposes. After a disaster, the evaluation of the performance of the disaster logistics system has to be done. The main result of that evaluation is proposal of improvement measures. If it is possible to improve the system, these improvements are implemented, new entities are identified, further risk assessment is done, and risk maps are improved. Based on this new organization, disaster logistics support is defined, capacity of local communities in the danger zone of the disaster is increased, and monitoring and alarm systems is improved.

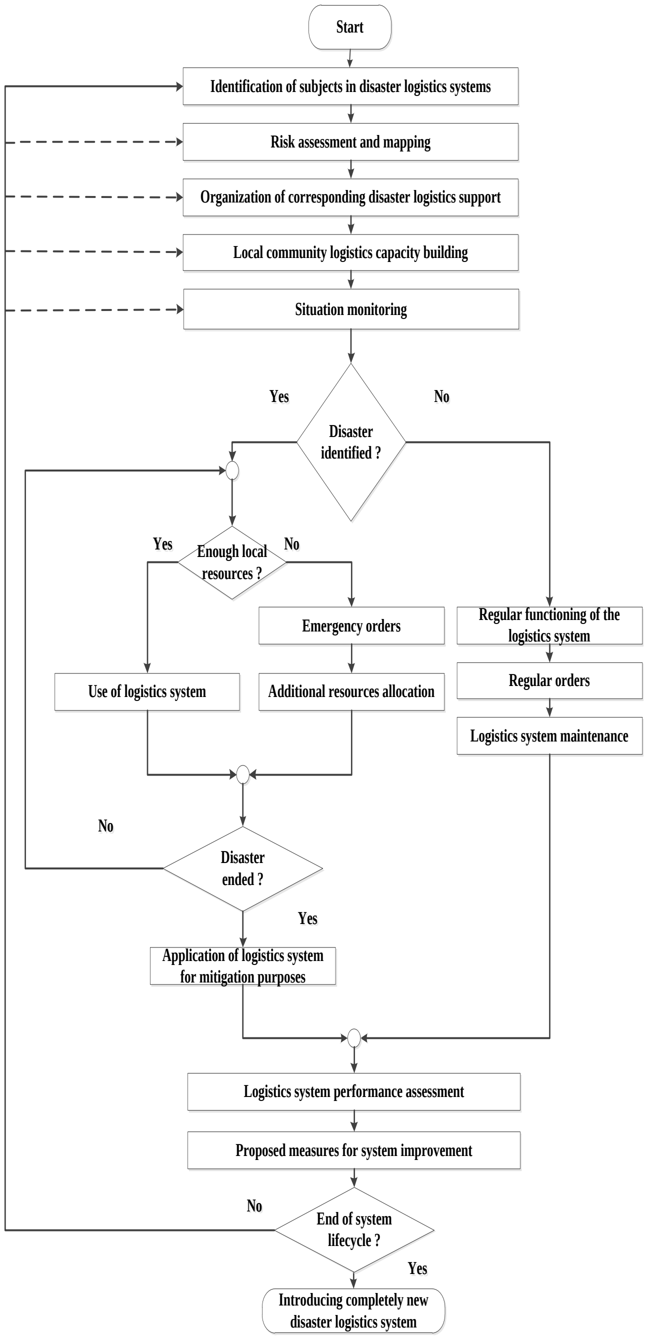


***Fig. 2*** *Disaster logistics management algorithm*

On the basis of defined algorithm, certain factors and indicators are important. They affect the quality of the disaster logistics system. These factors and indicators are shown in Table 1.

We identified three basic factors: institutional basis (*a*); local community ability (*b*); and logistics system organization (c). The institutional basis is significant, as disaster management system functions in accordance with defined legal framework. A disaster is usually localized, so the ability of a local community in the context of logistics is very important in the first stage of the response after a disaster. Finally, the organization of the logistics system should be such that it can respond to various types of natural and man-made disasters.

**Table 1** Decision hierarchy for strategic assessment of disaster logistics systems

| Factors | Indicators |
|---|---|
| Institutional basis ($a$) | Planning ($a_1$)<br>Funds ($a_2$)<br>Politics ($a_3$)<br>Laws ($a_4$)<br>Partnership institutionalization ($a_5$) |
| Local community ability ($b$) | Analysis of available resources ($b_1$)<br>Critical infrastructure assessment ($b_2$)<br>Logistics system monitoring and control ($b_3$)<br>Knowledge management ($b_4$)<br>Active participation of the community and individuals ($b_5$) |
| Logistics system organization ($c$) | Information-communication system ($c_1$)<br>Transportation and storage diversification ($c_2$)<br>Plans operationalization ($c_3$)<br>Logistics inventory management ($c_4$)<br>Activity coordination ($c_5$) |

Indicators used in this hierarchical structure are grouped according to three previously described factors. Each group of indicators contains five indicators. The indicators describing the institutional basis describe planning, funds, politics, laws, and institutionalization of partnerships with neighbouring regions or countries. The indicators describing local the ability of a local community are analysis of available resources, critical infrastructure assessment, logistics system monitoring and control, knowledge management, and active participation of the community and individuals. The logistics system organization is described by the following indicators: information-communication system, transportation and storage diversification, plans operationalization, logistics inventory management, and activity coordination.

The hierarchical structure of the model allows the application of the fuzzy analytic hierarchy process (FAHP). Based on the FAHP, it is possible to rank pre-defined key performance indicators of a disaster logistics system, using the assessment of experts described by fuzzy numbers.
FAHP method consists of the following steps:

1. Identification of the goal;
2. Identification of factors and criteria that affect the attainment of the goal;
3. Establishment of a hierarchical structure;
4. Comparison of factors and indicators in pairs by means of fuzzyfied Saaty's scale;
5. Consistency checking of judgments of individual experts, and among different experts;
5. Determination of weight vectors based on the eigenvalue method, the analysis of fuzzy measures and principles of aggregation during group decision-making;
6. Defuzzification and ranking of factors and indicators.

Group FAHP phase method is used for ranking indicators describing disaster logistics efficiency. Triangular fuzzy numbers, $M=(l,m,u)$, are applied. Expert group evaluated relative contribution of each indicator according to the scale 1-9. Based on the set of experts $E$, the duration of work in logistics assessment $B$, and the experience with disaster logistics systems, the gamma coefficient is calculated, and used during creation of aggregated fuzzy judgment matrix, as described in [13].
The aggregation of experts' weights is based on row geometric mean method [14], where gamma coefficient defines the influence of an expert on aggregated decision described by the fuzzy judgment matrix [13]. The consistency among experts is checked by centric consistency index (CCI) [15, 16]. The following weight vector is obtained to describe the importance of disaster logistics indicators:

$$W_a=(w_{a1},...,w_{a5},w_{b1},...,w_{b5},w_{c1},...,w_{c5}) \tag{1}$$

This model is applied for strategic assessment of disaster logistics system in Serbia.

## 3 CASE STUDY

According to EM-DAT database and national statistics, Serbia is classified as moderately affected by natural and technological disasters. In Serbia, the protection and rescue system is defined by the Law on emergency situations [17]. This law promotes an integrated protection and rescue system. Together with other acts, it defines subjects of protection and rescue during disasters, adverse events, and ways to avoid or mitigate the effects of disasters. According to this law, the protection and rescue system is one part of the national security system presenting integrated form of management and organization of subjects of protection and rescue during implementation of preventive and operative measures and execution of tasks of protection and rescue of people and property from the effects of natural disasters and other disasters, including implementation of measures for recovery from these consequences. Actors of protection and rescue system are government bodies, companies, citizens, civil groups, associations, professional and other organizations, and Serbian Army.

A case study is based on a group evaluation of disaster logistics system in Serbia for the needs of the two main types of disasters: sudden-onset disasters and slow-onset disasters. Logistics system has different key indicators if the disaster type is different, since the lead time, the speed of response, as well as the possibility of relocation are different. In sudden-onset disasters, it is not possible to do almost anything during the disaster, and it is difficult to predict it.
In this study, triangular fuzzy numbers are applied, with the value of the fuzzy distance $\delta$; at the borders, (1, 1, 3) is used for fuzzy value 1, and (7, 9, 9) for fuzzy value 9. The fuzzy distance 2 is used for odd values, and the fuzzy distance of 1 is used for even values.
The ranking of the indicators is based according to Group Fuzzy Analytic Hierarchy Process (GFAHP). Four experts were included in the analysis, with the following experience: $B=\{10,9,12,9\}$ and $C=\{5,4,4,5\}$. According to that, the following weight vector of experts is obtained: $\Gamma=\{0.28,0.20,0.27,0.25\}$.
Based on the individual fuzzy judgment matrices for the criteria, the aggregated fuzzy judgment matrix is obtained (Table 2). $DM_i$ is the fuzzy pairwise comparison matrix of the $i$-th expert, and $\gamma_1$ the gamma coefficient for the $i$-th expert. The matrix is consistent, because $CCI$ value is less

than 0.35. Further, the mean aggregated weight (MW) for the criteria is obtained.

**Table 2** The aggregated fuzzy judgment matrix for the criteria. *CCI= 0.01*

| | *a* | *b* | *c* | *MW* |
|---|---|---|---|---|
| *a* | (1,1,1) | (0.4,0.68,1.25) | (0.3,0.52,1) | 0.23 |
| *b* | (0.8,1.46,2.41) | (1,1,1) | (0.3,0.76,1) | 0.30 |
| *c* | (1,1.93,3.41) | (1,1.32,3.41) | (1,1,1) | 0.47 |

The indicators are ranked according to two different types of disasters: slow-onset disasters and fast-onset disasters. Experts concluded that factors have the same value for both types of disasters, but that there are differences between the influences of some indicators. Thus, experts ranked indicators for two types of disasters. The ranks for slow-onset disasters are defined in tables 3 to 5.

**Table 3** The aggregated fuzzy judgment matrix for indicators in relation to the criterion *a* for slow-onset disasters. *CCI*=0.01

| | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | *MW* |
|---|---|---|---|---|---|---|
| $a_1$ | (1,1,1) | (1.1,1.2,1.8) | (1.3,3,4.5) | (1.2,3,4.5) | (1.3,2.5,3.8) | 0.33 |
| $a_2$ | (0.5,0.8,0.9) | (1,1,1) | (0.7,1.8,2.5) | (0.4,2.2,1.3) | (0.8,1,2.4) | 0.21 |
| $a_3$ | (0.2,0.3,0.7) | (0.4,0.5,1.3) | (1,1,1) | (0.4,1,1.3) | (0.4,0.8,1.2) | 0.13 |
| $a_4$ | (0.2,0.3,0.7) | (0.7,0.8,2.2) | (0.7,1,2.2) | (1,1,1) | (0.5,0.8,1.6) | 0.16 |
| $a_5$ | (0.3,0.4,0.7) | (0.4,1,1.2) | (0.8,1.2,2.4) | (0.6,1.2,1.8) | (1,1,1) | 0.16 |

As the most important indicators for slow-onset disasters in this group, experts selected planning (criteria $a_1$) and funds (criteria $a_2$).

The aggregated fuzzy judgment matrices based on the comparison of indicators in relation to other criteria are presented in Tables 4 and 5.

**Table 4** The aggregated fuzzy judgment matrix for indicators in relation to the criterion *b* for slow-onset disasters. *CCI*=0.01

| | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | *MW* |
|---|---|---|---|---|---|---|
| $b_1$ | (1,1,1) | (0.4,0.7,1.2) | (1.3,3,4.4) | (1,1.9,3.5) | (1.3,2.9,4.3) | 0.28 |
| $b_2$ | (0.8,1.4,2.1) | (1,1,1) | (2.4,4,5.4) | (1.3,2.7,3.9) | (2.4,4,5.4) | 0.36 |
| $b_3$ | (0.2,0.3,0.7) | (0.2,0.3,0.4) | (1,1,1) | (0.4,0.5,1) | (0.4,1,1.2) | 0.09 |
| $b_4$ | (0.3,0.5,1) | (0.3,0.4,0.8) | (1,2,2.7) | (1,1,1) | (0.6,1.1,1.8) | 0.15 |
| $b_5$ | (0.2,0.3,0.7) | (0.2,0.3,0.4) | (0.8,1,2.4) | (0.6,0.9,1.6) | (1,1,1) | 0.12 |

**Table 5** The aggregated fuzzy judgment matrix for indicators in relation to the criterion *c* for slow-onset disasters. *CCI*= 0.01

| | $c_1$ | $c_2$ | $c_3$ | $c_4$ | $c_5$ | *MW* |
|---|---|---|---|---|---|---|
| $c_1$ | (1,1,1) | (0.6,1.2,1.8) | (1.3,2.1,3.8) | (0.7,2,2.8) | (1.5,3.2,4.7) | 0.30 |
| $c_2$ | (0.6,0.8,1.7) | (1,1,1) | (0.9,1.9,2.5) | (0.7,1.2,2.5) | (1.3,2.7,4) | 0.26 |
| $c_3$ | (0.3,0.5,0.8) | (0.4,0.5,1.1) | (1,1,1) | (0.6,0.9,1.8) | (0.8,1.5,2.3) | 0.15 |
| $c_4$ | (0.4,0.5,1.3) | (0.4,0.8,1.3) | (0.6,1.2,1.7) | (1,1,1) | (0.8,1.7,2.3) | 0.18 |
| $c_5$ | (0.2,0.3,0.7) | (0.3,0.4,0.8) | (0.4,0.7,1.3) | (0.4,0.6,1.3) | (1,1,1) | 0.11 |

The most important indicators in these two groups, for slow-onset disasters, are analysis of available resources ($b_1$), critical infrastructure assessment ($b_2$), information-communication system ($c_1$), and transportation and storage diversification ($c_2$). The same procedure for ranking the indicators is done for fast-onset disasters. The results are presented in the following tables (6 to 8). The following most important indicators are identified for fast-onset disasters: critical infrastructure assessment ($b_2$), information-communication system ($c_1$), transportation and storage diversification ($c_2$), analysis of available resources ($b_1$),

**Table 6** The aggregated fuzzy judgment matrix for indicators in relation to the criterion *a* for fast-onset disasters. *CCI*=0.02

| | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | *MW* |
|---|---|---|---|---|---|---|
| $a_1$ | (1,1,1) | (0.6,1,1.8) | (1.3,2.7,3.9) | (1.3,2.7,3.9) | (1.1,2.2,3) | 0.31 |
| $a_2$ | (0.6,1,1.7) | (1,1,1) | (0.7,1.5,2.5) | (0.3,1,1) | (0.6,1,1.8) | 0.19 |
| $a_3$ | (0.3,0.4,0.7) | (0.4,0.7,1.3) | (1,1,1) | (0.5,1,1.3) | (0.4,0.9,1.4) | 0.14 |
| $a_4$ | (0.3,0.4,0.7) | (1,1,3) | (0.7,1,2.2) | (1,1,1) | (0.5,0.9,1.3) | 0.17 |
| $a_5$ | (0.3,0.5,0.9) | (0.6,1,1.7) | (0.7,1.1,2.2) | (0.8,1.1,2.3) | (1,1,1) | 0.18 |

**Table 7** The aggregated fuzzy judgment matrix for indicators in relation to the criterion *b* for fast-onset disasters. *CCI*=0.01

| | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | *MW* |
|---|---|---|---|---|---|---|
| $b_1$ | (1,1,1) | (0.6,0.7,1.7) | (1.4,3,4.5) | (1.8,3.1,4.3) | (0.4,0.9,1.3) | 0.24 |
| $b_2$ | (0.6,1.4,1.8) | (1,1,1) | (1.8,3.6,5.4) | (2.4,3.9,5.4) | (0.6,0.9,1.8) | 0.29 |
| $b_3$ | (0.2,0.3,0.7) | (0.2,0.3,0.6) | (1,1,1) | (0.6,1,1.7) | (0.2,0.3,0.7) | 0.10 |
| $b_4$ | (0.2,0.3,0.6) | (0.2,0.3,0.4) | (0.6,1,1.8) | (1,1,1) | (0.2,0.3,0.6) | 0.09 |
| $b_5$ | (0.7,1.2,2.2) | (0.6,1.2,1.7) | (1.4,3.2,5) | (1.8,3.4,4.8) | (1,1,1) | 0.28 |

**Table 8** The aggregated fuzzy judgment matrix for indicators in relation to the criterion *c* for fast-onset disasters. *CCI*= 0.01

| | $c_1$ | $c_2$ | $c_3$ | $c_4$ | $c_5$ | *MW* |
|---|---|---|---|---|---|---|
| $c_1$ | (1,1,1) | (0.8,1,2.4) | (0.7,1.4,2.2) | (0.8,1.2,2.3) | (0.6,1.2,1.7) | 0.23 |
| $c_2$ | (0.4,1,1.2) | (1,1,1) | (0.7,1.4,2.2) | (0.8,1.2,2.3) | (0.7,1.2,2) | 0.22 |
| $c_3$ | (0.4,0.7,1.3) | (0.4,0.7,1.3) | (1,1,1) | (0.5,0.9,1.3) | (0.4,0.8,1.4) | 0.16 |
| $c_4$ | (0.4,0.8,1.3) | (0.4,0.8,1.3) | (0.7,1.1,2.2) | (1,1,1) | (1,1.4,3) | 0.21 |
| $c_5$ | (0.6,0.9,1.8) | (0.5,0.9,1.3) | (0.7,1.2,2.2) | (0.3,0.7,1) | (1,1,1) | 0.18 |

logistics inventory management ($c_4$), active participation of the community and individuals ($b_5$), and planning ($a_1$).

Final results are presented in Table 9. It presents the comparison of obtained results of ranking the indicators in the strategic analysis of disaster logistics at local level for slow-onset and fast-onset disasters.

Although the most of indicators are evaluated in the same way, experts made some differences during the selection of the key indicators for slow-onset and quick-onset disasters.

For fast-onset disasters, the most important indicators are, in addition to information-communication systems and monitoring the efficiency of transportation and storage, also management of critical infrastructures, local availability of resources, planning and operationalization of plans, and coordination of activities.

However, fast-onset disasters appear almost instantaneously, and response time is almost zero, so it is important that, in addition to information and monitoring primarily take care of the logistics inventory, to have active participation of individuals, save critical infrastructure objects, and analyse available resources. Reallocation of resources is possible before the occurrence of slow-onset disasters, because the effect is expected in a shorter or longer period of time (for example, a tidal wave on the river or the arrival of a tropical storm). However, fast-onset disasters, such as a major earthquake, do not allow such tactical moves before a disaster.

In both analyzes, dominat are the indicators from the group Logistics system organization (*c*). The worst ranked indicators are from the group related to institutional basis. However, experts believe that these indicators are also very important in the process of efficient creation and organization of the disaster logistics system.

Particularly interesting is low ranking of knowledge management. Knowledge is very important in the preliminary phase of system organization, and it is contained in plans, risk maps, ways of system implementation, and laws. The process of response to a disaster and disaster control does not give enough time to properly manage the knowledge. After a disaster, someone must initiate the analysis of outcomes, consequences and effects, the analysis of disaster logistics system performance according to the control algorithm, and, at the end, propose some improvement measures. This is where knowledge management takes place.

**Table 9** The ranking of key indicators in the strategic analysis of the disaster logistics

| | Indicator | Slow-onset disasters | | Fast-onset disasters | |
|---|---|---|---|---|---|
| | | Indicator weight | Rank | Indicator weight | Rank |
| $a_1$ | Planning | 0.077 | 6 | 0.071 | 9 |
| $a_2$ | Funds | 0.047 | 9 | 0.044 | 10 |
| $a_3$ | Politics | 0.030 | 14 | 0.032 | 13 |
| $a_4$ | Laws | 0.038 | 11 | 0.040 | 12 |
| $a_5$ | Partnership institutionalization | 0.037 | 12 | 0.042 | 11 |
| $b_1$ | Analysis of available resources | 0.083 | 5 | 0.073 | 8 |
| $b_2$ | Critical infrastructure assessment | 0.109 | 3 | 0.087 | 4 |
| $b_3$ | Logistics system monitoring and control | 0.028 | 15 | 0.029 | 14 |
| $b_4$ | Knowledge management | 0.044 | 10 | 0.026 | 15 |
| $b_5$ | Active participation of the community and individuals | 0.035 | 13 | 0.085 | 5 |
| $c_1$ | Information-communication system | 0.142 | 1 | 0.109 | 1 |
| $c_2$ | Monitoring transportation and storage efficiency | 0.120 | 2 | 0.103 | 2 |
| $c_3$ | Plans operationalization | 0.072 | 7 | 0.077 | 7 |
| $c_4$ | Logistics inventory management | 0.083 | 4 | 0.097 | 3 |
| $c_5$ | Activity coordination | 0.053 | 8 | 0.084 | 6 |

## 4 CONCLUSION

This paper presents multi-criteria model for disaster logistics performance assessment at strategic level. Proposed group evaluation model defines disaster logistics performance at strategic level more objective than personal estimates based on individual indicators. The model is based on defined disaster logistics management algorithm, which emphasizes the importance of performance assessment, based on decision hierarchy describing institutional basis of disaster logistics, local community ability and coping capacity, and logistics system organization. Dynamic character, increased coping capacity of a local community and active participation of individuals and organisations, dynamic character of disaster logistics and continuous monitoring, control and improvement, are the most important indicators for efficient disaster logistics.

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