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PROCESS-ORIENTED RISK ASSESSMENT IN INTEGRATED LOGISTICS NETWORKS: AN AHP APPROACH

RÓBERT SKAPINYECZ[1] - BÉLA ILLÉS[2]

Abstract: As the importance of integrated logistics networks increases together with the advancements in information technology, the proper evaluation and selection of third-party logistics services becomes a core issue for the participants of these networks. The paper describes a proposed risk assessment approach that can help the customers in the proper evaluation of the mentioned services. The concept employs the analytic hierarchy process (AHP), a well known and widely applied multi-criteria decision making method, for the structured evaluation of the primary operational risk factors which are relevant to the customers. In the proposed approach, the quantification of these risk factors at the side of the service providers is realized through the utilization of process capability indices, the latter are well known and widely applied in the fields of quality management and statistical process control. The aim is to provide a relatively straight-forward and easily applicable way for the risk-based evaluation of third-party logistics services in integrated logistics networks. Another advantage of the concept is that it could be utilized in different fields of the logistics industry, regardless of the concrete field of application.
Keywords: risk assessment, AHP**,** process capability, third-party logistics, logistics networks

1. Introduction

The significance of collaborative networks, in which the individual units and organizations develop a certain level of collaboration as a result of their increasingly connected activities and mutual challenges, is continuously on the rise both in general terms and in the field of logistics [1]. In many ways, this is a result of the rapidly advancing information technologies, which enable the formation of such flexible systems on an ever wider scale. In the field of logistics, these advances led to a higher level of integration in the already complex logistics networks, therefore providing an even greater role to third-party logistics services. Examples of this trend can be seen in almost every field of the industry, involving freight-forwarding, supply-chain management, city-logistics, reverse logistics, maintenance logistics, etc. A common characteristic of the majority of the these logistics systems is that in order to be able to effectively fulfill the rapidly changing logistics requirements, their standard operation is to a large extent based on the utilization of modern IT networks and applications. Another feature of these networks is that their composition could easily and frequently change over time, while the opportunities for personal contact are sometimes limited. Overall, these attributes generally provide new possibilities, like the precise quantification of the performance of the various processes related to a logistics service, while they also represent a new environment for the customers, one in which the latter could sometimes face new questions as well.

The general conclusion is that while the outsourcing of logistics services is more plausible than ever, the quickly changing information-based operational environment, combined with the time-constraints that usually characterize the decision making process in

[1] assistant lecturer, University of Miskolc
altskapi@uni-miskolc.hu
[2] university professor, University of Miskolc
altilles@uni-miskolc.hu
3515 Miskolc, Egyetemváros, Hungary

the logistics industry, certainly makes room for the utilization of properly adapted risk-management solutions on the side of the customers. In the followings, the conceptual model of such an approach is going to be presented, one which is based on some well proven methods from the fields of decision science and quality management.

2. Determination and quantification of the main risk factors

There are a number of well-known risk factors that are associated with the logistics industry, mainly resulting from the comprehensive nature of the field. Here we can think of operational risks, economic and business risks, environmental and societal factors, etc. Out of these, the proposed concept mainly focuses on how to evaluate the operational risks related to a logistics service or activity, as these are the ones which directly affect the operation of the customer at the first place (of course, the inclusion of other types of risk factors is also possible later). Among the different elements of a logistics network, the following operational risks usually have the highest importance:

- **late delivery (RF 1):** determined by deviation of the actual delivery times from the pre-determined values during a given time period at a given service provider, related to the delivery process,
- **cargo damage (RF 2):** determined by the percentage of the damaged cargo delivered during a given time period at a given service provider, mainly related to the cargo handling process,
- **quantity problems (RF 3):** determined by the deviation of the delivered quantities from the ordered ones during a given time period at a given service provider, mainly related to the cargo registering process,
- **loss of shipment (RF 4):** determined by the percentage of the cargo that is lost by the service provider during a given time period, related to the cargo tracking and tracing process,
- **cancellation of shipment (RF 5):** determined by the percentage of the cargo that is ordered by the customer, but later canceled by the service provider during a given time period, mainly related to the delivery process,
- **incorrect shipment (RF 6):** determined by the percentage of the cargo that is differed from the order during a given time period at a given service provider, related to the cargo registering process,
- **faulty packaging (RF 7):** determined by the percentage of the cargo that arrived with faulty packaging during a given time period from a given service provider, related to the cargo handling process.

In an integrated logistics network, where most of the operations are carried out with the support of information networks and software applications, such operational risks are not always visible for the average customer, which could unnecessarily complicate the process of service provider selection. The latter is especially true considering that the same type of technologies should make the processes related to a logistics service more transparent than ever. Thanks to real-time sensors, all-around connectivity and big-data techniques, in fact the quantification of the performance of a given process at a given service provider could be realized almost automatically, which would greatly simplify the process of service provider selection for the customers.

However, in order to utilize the potential of the above mentioned technologies, first proper modes of risk-based evaluation of the different processes has to be employed. The proposed concept uses a two-way approach: on one hand, the customer identifies the most critical risk factor(s) from the point of its own processes and other criteria groups, using an AHP model that will be described later, while the actual values of the risk factors at a given service provider are quantified through the continuous measurement of process performance (at the service provider). The first problem is the proper implementation of this latter quantification, based on the measured data. As the operational risk factors basically emerge from the failures in the respective logistics processes (like delivery, cargo handling, cargo tracking and tracing, etc.), therefore it is plausible to utilize a well proven concept from quality management for the task, namely the process capability indices.

The concept of process capability itself has its roots in the 1920s/1930s, when it primarily appeared in the field of manufacturing. Today, it has become one of the most widely used tools in quality management, forming the basis of numerous other methods. In fact, one simple reason behind its usage is exactly this wide-scale adaptation, supplemented by the fact that it is also becoming a common tool in the different service industries as well, usually as a part of broader philosophies like „lean-management” or „lean six sigma” (this trend also can be seen in the case of other lean-management methods, see for example value stream mapping) [2] [3] [4] [5]. The most important indicators related to the process capability concept are the following: c_p – process capability, which effectively shows the relation between the predefined tolerances and the statistical distribution that characterizes the process; c_{pk} – critical process capability, which mainly differs from the previous in that it also takes into account the long term shift of the mean value (usually calculating with a 1,5 multiplier); DPMO – Defects Per Million Opportunities, which is the number of defects appearing during a million opportunities, as the name implies; sigma levels – distinctive quality levels associated with the well-known six sigma methodology. In general it can be stated that though the task of maintaining the indices at a given level requires a significant amount of practical and theoretical knowledge, yet for the task of process evaluation, relatively simple charts and expressions are available (see Table I.) [2].

Table I.
Values of the most important process capability indices together with the related sigma levels [2]

Main indices at 1,5 shift of the mean			
c_p	c_{pk}	six sigma	DPMO
1,00	0,50	3	66 810,6
1,33	0,83	4	6 209,7
1,67	1,17	5	232,7
2,00	1,50	6	3,4

The practicality of the process capability concept makes it an ideal tool for the quantification of process performance. In the proposed concept, with proper implementation the latter can be translated into operational risk factors, as it was previously seen.

However, for complex systems (and most logistics systems fall into this category), determining the level of contribution of the individual sub-processes to the overall performance is usually a hard problem. This also applies to the opposite direction, where the significance of the individual risk factors has to be determined from the perspective of the customer. This is the point where different decision-making tools can be applied for the prioritization of the different factors. Among the many available choices, the proposed concept utilizes the analytic hierarchy process (AHP), a well refined and widely utilized multi-criteria decision making method.

3. A summary of the AHP method

The AHP is a widely applied multi-criteria decision-making technique that was originally developed by Thomas L. Saaty in the 1970s. Since then, it has become one of the most popular methods with a wide range of applications, including the field of logistics [6] [7] [8] [9] [10] [11].

The AHP essentially builds upon the pairwise comparisons of the different decision criteria in a problem. It is a structured technique, where the different criteria are organized into a decision hierarchy that is uniquely constructed for each problem (the hierarchy always descends from the goal of the analysis). The criteria are pairwise compared with each other according to the hierarchy and in respect to the goal of the analysis. The comparisons are represented in a "comparison matrix". It is important to note that the goal varies from problem to problem and is usually formulated with the use of questions. Answering these questions during the pairwise comparisons help in determining the relative importance of the compared elements from the point of the analysis. The results of the comparisons are chosen from a 1 to 9 scale proposed by Saaty, which is explained in Table 2. [12]. Reciprocals are used to represent the comparisons in the reverse direction. For example, if the result of comparing criterion A to criterion B is 9, then comparing criterion B to criterion A will have the result of 1/9. Ratios arising from the scale could be used in certain cases. Based on the results of the pairwise comparisons, the priorities of the compared criteria are calculated, forming a "priority vector". The sum of the elements (the individual priorities) of the priority vector always equals to 1, while the goal on the highest level of the hierarchy also naturally has a priority of 1. For the mathematical background of the pairwise comparisons and the calculation of the priority vector, see [12] and [13].

If the criteria are organized into multiple groups (this is the case in more complex hierarchies with multiple levels of criteria under the level of the goal), then the pairwise comparisons have to be implemented in each group separately (a group is formed by the direct child nodes of a parent node in the hierarchy). This means that a priority vector (in this case also called a "local priority vector") is separately calculated for each group. These will provide the "local priorities" of the criteria in their respective groups. In order to get the "global priorities" for the criteria, their local priorities have to be multiplied by the global priority of the corresponding parent node in the hierarchy. Again, the global priority of the goal equals to 1, while the sum of the global priorities on a single level is also 1 (in a simple hierarchy, where the goal is followed by only a single level of criteria, there is no difference between the local and global priorities of these criteria). The calculation of the global priorities of the criteria essentially gives the weights of the latter in the hierarchy.

The decision alternatives themselves are pairwise compared at the lowest level of the hierarchy against the criteria which are one level above the level of the alternatives. The comparisons of the alternatives are repeated against each of the mentioned criteria separately. Through this process, a separate local priority vector of the alternatives for each of the previous criteria will be calculated. Multiplying each vector by the weight of the corresponding criterion and adding the results together provides the "global priority vector" of the decision alternatives, in other words the final ranking of these alternatives in the problem. The consistency of the result is measured through the calculation of the "consistency ratio (CR)". The detailed description of the entire AHP method with examples for multiple applications can be found in [12] and [13].

Table II.
The explanation of the 1 to 9 scale for the pairwise comparisons based on [12]

Comparison scale	Explanation
1	The two criteria are equally important.
3	One of the criteria is moderately important compared to the other.
5	One of the criteria is strongly important compared to the other.
7	One of the criteria is very strongly important compared to the other.
9	One of the criteria is extremely important compared to the other.
2,4,6,8	Intermediate values in between the above judgements.

4. The description of the proposed decision hierarchy and the mode of utilization

In the proposed risk-assessment approach, the aim of using the AHP is to provide an objective basis for the ranking and evaluation of the introduced risk factors, based on the preferences of the customer. The goal of the analysis, and therefore the basis of the comparisons, is to examine which criteria affect more the accumulation of the additional risk related costs for the given customer. In other words, the risk factors (which are the decision alternatives in the problem) will eventually be ranked by the amount of additional costs they are generally responsible for at the given customer, determined through the use of the decision hierarchy. In general, the more additional cost a risk factor is responsible for, the higher its priority should be at the end of the analysis.

As the proposed concept identifies the customers of the network (in this context, the buyers of the logistics services) as the main users, therefore the "inner processes" main criterion refers to the importance of those additional costs which emerge from the negative effects of the risk-factors on the inner processes of these customers. Naturally, for most customers this criteria group has a higher priority than the other groups in the hierarchy. Of course, the definition of who is considered a customer is relative and it also depends on the perspectives and the actual operational environment. In an integrated logistics network, naturally most of the parties can fulfill the role of the customer and the service provider at the same time.

The proposed decision hierarchy has four levels, where the first node on the first level is the “Risk related cost” (the goal of the analysis), the main criteria level (second level) is composed of the “Inner processes”, the “Environment”, the “Managed cargo” and the “Partners” nodes, while the third level is constructed from the different sub-criteria related to the main criteria (the fourth level is composed of the decision alternatives, which in this case are the risk factors). Of the four main criteria, the “Inner processes” are already described before. The “Environment” represents the importance of the additional externalized costs which are the result of the damage to the environment, in relation to the identified risk factors. Here it is important to note that in the current application, the environment consists both the natural and man-made environments. The “Managed cargo” criterion refers to the importance of the additional risk related costs that emerge from the improper treatment of the cargo managed by the service provider (of course, the cargo in question here is the property of the customer). Finally, the “Partners” main criteria refer to the importance of the additional risk related costs that could affect the partners of the given user (the buyer of the logistics services), due to the collateral effect of the failures in the procured logistics services.

It is a distinctive characteristic of the proposed model that it is highly customizable by the user. This means that in each of the four criteria groups, the user can define an arbitrary number of sub-criteria relevant for the actual analysis and operational environment. In the “Environment” criteria group, the subject of the sub-criteria can also be freely chosen, while in the other groups, it is supposed to be either an inner process (in the “Inner processes” criteria group), a cargo category (in the “Managed cargo” group) or a partner (in the “Partners” group). Overall, the number of the applied sub-criteria in the model is dependent on the user and on the concrete implementation (for a meaningful comparison, naturally at least two sub-criteria are needed in each criteria group).

At the fourth level, the evaluation of the risk-factors, which in this application fulfill the role of the decision alternatives, is realized according to the different sub-criteria of the third level. For clarification, these risk factors are the “late delivery”, “cargo damage”, “quantity problems”, “loss of shipment”, “cancellation of shipment”, “incorrect shipment” and “faulty packaging”, as they were introduced before. The general decision hierarchy of the model is represented in Figure 1.

The concept of implementation is based on a network-structure, where each participant of the network has access to the cloud-based application that utilizes the described risk model. During a given evaluation, in theory all of the results of the pairwise comparisons could be customized by the user. However, in practice the customer would be also able to choose from partially predetermined hierarchies with set results in certain groups, for example in case of the “Environment” and “Managed cargo” criteria groups, as these can have similar importance for a larger number of customers who operate in the same region and/or industry. The values for these partially pre-determined hierarchies could be determined and maintained by experts, while access to them could be provided through the application.

As it was described before, a core element of the concept of utilization would be the possibility for the user to have direct access to process capability indices describing the available services in the network. Naturally, this capability would also be built upon a cloud-based service, in which the service providers would be motivated to share reliable data about the performance of their selected processes, in return of other benefits. In order to reliably determine the process capability indices for the risk-factors in relation to a given service, multiple types of historical data are needed regarding the processes to which these risk-factors are connected. For an overview of the necessary parameters, see the appropriate chapter in [2]. If these parameters are unavailable for a given service, then an appropriate estimation of the sigma levels or the DPMO values for the related processes can also serve as a starting point. Regarding the utilization of the results, multiple approaches are available.

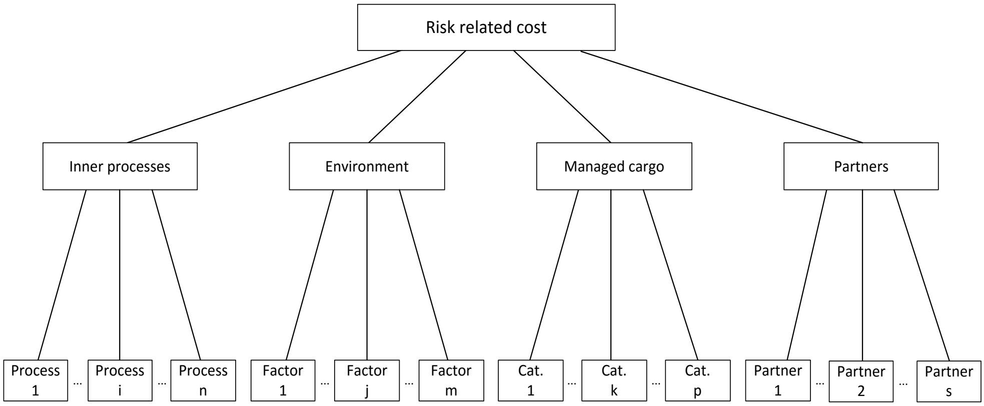

Figure 1. Decision hierarchy of the proposed risk-assessment model

The clearest way to utilize the results of the AHP analysis is to select the logistics service that has the best (highest) process capability indices for the highest ranking risk-factor. For example, if the cargo damage (RF 4) received the highest global priority at the end of the analysis, than it is an obvious choice for the customer to select the logistics service that has the best indices, in other words the lowest occurrences for cargo damage incidents. A similar logic can be applied for any case, where a given risk factor received clearly higher global priorities from the others.

Other types of evaluation might be needed, if a number of risk factors received relatively similar priorities. A plausible solution in that case could be to look for those services in the network which have the best overall combination of the prioritized indices. In this case, the global priorities might be used as weighing factors in the decision and the service with the highest weighted sum of the indices could be selected.

5. Example for a possible application in reverse logistics

A typical example for an integrated logistics network is the field of reverse logistics, where a large number of individual participants have to coordinate their activities in a usually widespread geographical area. The transported cargo can often carry additional risks (like contamination, health effects, etc.), while serious regulations are in place regarding the handling of these waste materials, which makes the importance of the field especially clear. Also, if an event does occur during the handling of a dangerous shipment, then the associated external costs could be really significant. These circumstances made the field extensively studied in the related literature as well [14] [15].

Because of the risk-sensitive nature of the field, the monitoring technologies of reverse logistics services are often better developed than in ordinary processes. These include various cargo-tracking and tracing technologies like RFID, real-time cargo monitoring, fleet-management systems, different safety technologies for reducing the occurrence of various incidents, etc. These certainly are in favor of the implementation of the proposed concept. In relation to the following example, again it is important to clarify that the criteria are evaluated from the perspective of the organization that relies on the reverse logistics services. This means that during the pairwise comparisons, the criteria which receive the highest values are usually those which are the most relevant for the inner waste management processes of the given organization (the customer). While these are often the same criteria which are prioritized from the perspective of the entire reverse logistics network, differences are also possible. In general, the highest concern for the customer in this setting is to hand over the waste materials to the service provider without incident and as effectively as possible (as the material flow is realized in the “reverse” direction), while the overall network might have higher level goals as well. Figure 2 shows a customized form of the introduced risk model applied for the given problem (again, the customization would be implemented by the given user).

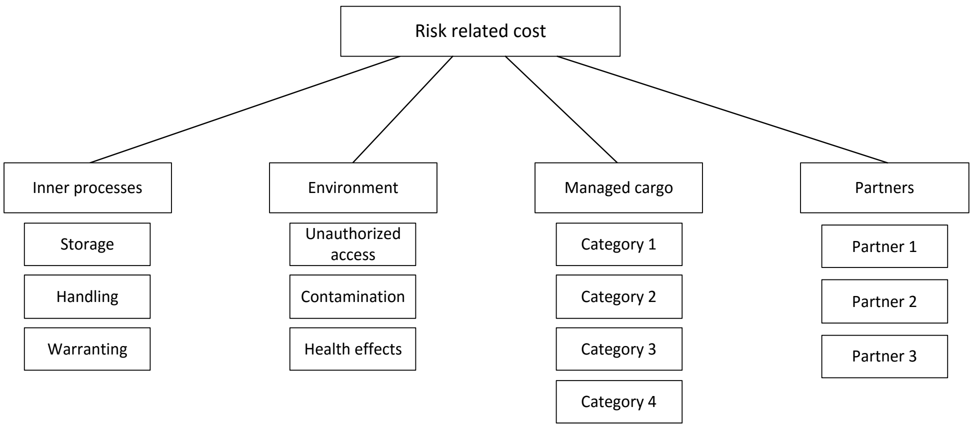

Figure 2. Decision hierarchy of the risk model applied for a reverse logistics environment

In the example, the prime activity of the reverse logistics system is the gathering and recycling (or neutralizing) of the accumulated food waste at the different participants of the network (mainly supermarkets and other vendors) [16] [17]. As it was described above, the risk assessment therefore is done from the perspective of these latter participants, who order the logistics services from the dedicated reverse-logistics companies (the service providers). Therefore, the most important inner processes will be those which are directly connected to the management of the waste materials at the sites of these customers. In the example, these inner processes are determined as the storage, handling and warranting of the waste materials. The environment criteria group naturally composes those criteria which are the most important from the point of environmental damage, while the managed cargo group contains four cargo categories (these will be explained later). Finally, the partners in this setting are those waste processing companies which have direct contracts with the customers, while the transportation of the cargo between the two parties is solved by the reverse logistics service providers.

As mentioned before, the comparison of the main criteria (Table III.) reflects the priorities of the customers, which is the reason of why the inner process criteria received a distinctively higher priority. It can be argued that the environment is also a key factor in this setting. However, according to most of the regulations, once the waste material is handed over to the service provider, the responsibility (in most cases) also passes with it. Therefore, the customers themselves usually rarely face directly the external costs of the environmental risks (instead, these are usually charged on the service provider), which explains the previous prioritization.

Table III.

Comparison of the main criteria in the problem

	InnerProcesses	**Environment**	**Managed cargo**	**Partners**	**Priority vector**
InnerProcesses	1	3	5	5	0,5596
Environment	1/3	1	3	3	0,2495
Managed cargo	1/5	1/3	1	1	0,0955
Partners	1/5	1/3	1	1	0,0955

The comparison of the main criteria is followed by the comparisons of the different sub-criteria in the main groups. An example for this can be seen in Table IV., where the four cargo categories, distinguished from a logistics perspective, are compared. Regarding this, it needs to be said that in the particular problem, the cargo types grouped in "Category 3" fall in the waste categories 1 or 2 of the relevant regulatory framework, while all the other "managed cargo categories" are composed of cargo types belonging into the 3rd waste category. This means that "Category 3" should be the most important on absolute terms, as it is composed of cargo types associated with higher environmental risks.

Table IV.

Comparison of the cargo categories in the "Managed cargo" criteria group

	Category 1	**Category 2**	**Category 3**	**Category 4**	**Priority vector**
Category 1	1	1	2	5	0,3683
Category 2	1	1	2	5	0,3683
Category 3	1/2	½	1	3	0,1929
Category 4	1/5	1/5	1/3	1	0,0704

However, the cargo groups “Category 1” and “Category 2” are far more numerous in the network, therefore their overall importance is also higher. For the same reason, “Category 4” will have the lowest importance, as it is associated with the same waste category as the previous two groups, combined with a lower presence in the system. The ranking is again clearly shown by the priority vector in Table IV.

After calculating all the local priorities in every criteria group, the global priorities of the sub-criteria can also be determined. Figure 3 shows the given decision hierarchy with the global priorities.

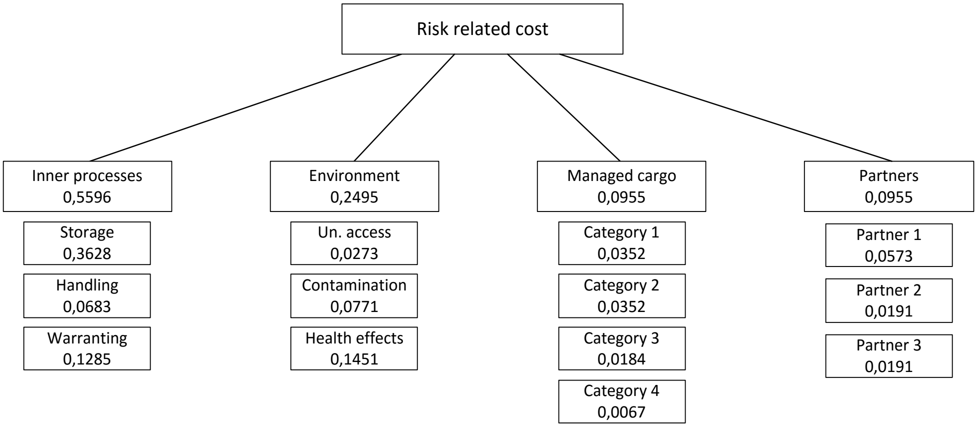

Figure 3. The given decision hierarchy with the weights of the criteria

Finally, the seven risk factors are pairwise compared against all the thirteen sub-criteria, in the same way as it is shown in the previous examples (the question that has to be examined during the comparisons is that in respect to a given sub-criteria, which risk-factor affects the customer the most, based on a cost perspective). The results of the comparisons (the local priority vectors for the risk factors) are represented in Table V., together with the final result, which is the global priority vector of the risk factors.

The results are generally in line with the expectations, as it can be clearly seen that both the “cargo damage” (RF 2) and “loss of shipment” (RF 4) factors have outstanding global importance, together with “faulty packaging” (RF 7). However, it can be also seen why the “cancellation of shipment” (RF 5) factor received the highest priority, as the frequent occurrence of such events can significantly increase the waste management costs of the customer, while RF 2, RF 4 and RF 7 represent greater concern for the service providers (due to the previously mentioned regulations).

By having the global priorities, a customer is able to select the reverse logistics service that has the most suitable combination of process capability indices of the prioritized risk factors. As the field of hazardous waste management requires higher than average quality standards and the consequent implementation of cargo tracking and tracing technologies, it can be assumed that such information could be already gathered and available in many reverse logistics systems.

Table V.

Determining the global priorities of the risk factors

Risk factors	**Risk related cost**													**Final result**
	Inner processes 0,5596			**Environment** 0,2495			**Managed cargo** 0,0955				**Partners** 0,0955			
	Stor. 0,3628	**Hand.** 0,0683	**Warr.** 0,1285	**Una.** 0,0273	**Cont.** 0,0771	**Health** 0,1451	**Cat. 1** 0,0352	**Cat. 2** 0,0352	**Cat. 3** 0,0184	**Cat. 4** 0,0067	**Part. 1** 0,0573	**Part. 2** 0,0191	**Part. 3** 0,0191	
RF 1	0,1765	0,1579	0,0303	0,0400	0,0337	0,0323	0,0667	0,0667	0,0345	0,0667	0,0286	0,0256	0,0286	**0,0955**
RF 2	0,0588	0,0526	0,2121	0,2000	0,3036	0,2258	0,2000	0,2000	0,2414	0,2000	0,2000	0,1795	0,2000	**0,1524**
RF 3	0,1765	0,2632	0,0303	0,0400	0,0337	0,0323	0,0667	0,0667	0,0345	0,0667	0,0857	0,0769	0,0857	**0,1080**
RF 4	0,0588	0,0526	0,2727	0,3600	0,2361	0,2903	0,3333	0,3333	0,3103	0,3333	0,2571	0,2308	0,2571	**0,1856**
RF 5	0,4118	0,2632	0,0303	0,0400	0,1012	0,0968	0,0667	0,0667	0,1034	0,0667	0,1429	0,1795	0,1429	**0,2156**
RF 6	0,0588	0,0526	0,2727	0,1200	0,0337	0,0968	0,0667	0,0667	0,1034	0,0667	0,1429	0,1795	0,1429	**0,1013**
RF 7	0,0588	0,1579	0,1515	0,2000	0,2579	0,2258	0,2000	0,2000	0,1724	0,2000	0,1429	0,1282	0,1429	**0,1416**

6. Conclusions

The paper introduced a process-oriented risk assessment approach for the evaluation of third-party logistics services, building primarily on the utilization of the AHP method. The concept is primarily proposed for integrated logistics networks, with the aim to provide the basis for an easily applicable risk assessment tool that could be used by the participants of these systems. A practical example was also presented from the area of reverse logistics, in which quality management and process-monitoring play a distinctive role, therefore the field could be an ideal candidate for the application of the concept.

In the future, a number of non-operational risk factors could also be introduced, together with the further elaboration of the proposed decision model, which would help the customers even more in the precise risk assessment of the outsourcing of logistics services. The long-term goal of the research would be to integrate the different results from the individual users into a single model that could be used for the process-based risk assessment of the entire logistics system in a comprehensive way. This would provide the possibility for the customers to gain valuable information about the overall performance of a given logistics network.

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