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RISK MANAGEMENT IN LOGISTICS NETWORKS: AN OVERVIEW OF THE FIELD AND SOME NOVEL PERSPECTIVES

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Abstract: The publication covers a topic that is gaining more and more significance, namely the area of risk management in logistics networks. This domain became a focus of attention lately for a number of reasons, but most importantly because of the increasing sensitivity of global supply chains to various disturbing effects. Another important reason is the trend of digitalization, which naturally increases the significance of information-based collaboration inside the logistics networks, but it also raises more questions regarding the reliability of the participating elements. Taking into account the previous considerations, the publication tries to provide a comprehensive picture about the current status of the field. Based on the survey of the related literature, it introduces the background and the significance of the topic while also presents the most important trends, the frequently used approaches and a number of related examples. Moreover, partly based upon the conclusions drawn from the literature review, a novel approach for solving the problem is also proposed that could be successfully utilized in the future.
Keywords: *logistics networks, risk management, literature review*

1. THE EVOLUTION AND SIGNIFICANCE OF MODERN LOGISTICS NETWORKS

Logistics networks have been playing an important role in the economy for a long time, though their significance became truly obvious in the last decades. This of course is largely connected to the strengthening of such trends as the expansion of multinational companies, the continuous development of global supply chains or the growing dominance of global markets, as these processes are all largely based on the effective operation of logistics networks. Meanwhile, the continuous emphasis on cost reduction significantly increased the role of logistics outsourcing, which greatly supported the expansion of the logistics service providers as well [1].

It is very important to emphasize that the field of e-commerce also played a crucial role in the evolution of modern logistics networks, especially in the last two decades. While the business sector has been using computer networks for the handling of transactions since the 1970-s and the first EDI applications also appeared during this time, the true advancement was of course came with the spread of the internet and its related technologies. Accordingly, the first e-marketplaces in logistics also appeared in the early 1990-s, first naturally in the area of freight-forwarding (for example NTE or DAT), as it is described in the comprehensive work of Nandiraju and Regan [2]. These were followed in short order by a number of such marketplaces that provided more complex value-added services, thereby giving a glimpse of a future which is dominated by internet-based services (typical examples were FreightMatrix, Transplace or Nistevo, the latter was being also one of the first examples for a collaborative network) [2]. A high-level working schematic of a typical auction-based e-marketplace in the area of freight-forwarding can be found in *Figure 1*.

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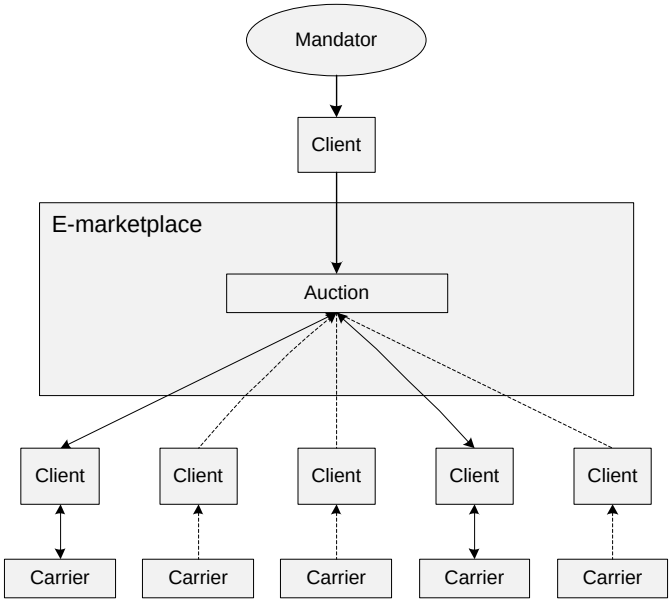

Figure 1. High-level representation of an e-marketplace in the area of freight-forwarding, a typical e-commerce based component of modern logistics networks (Source: own work)

From this point forward the developments followed each other at an even faster pace, which was also fueled by the rapid unfolding of e-commerce. The latter also increased the need for smaller but more frequent shipments (especially for parcel delivery), while the reduction of lead times also became an even more important issue (in many cases, one-day and same-day delivery became a standard practice). All of these developments made it even more necessary to create and maintain effective distribution networks, together with modern e-commerce based supply chains. The description of these processes can be found in a large number of publications. A few examples include the works of Joong-kun, Ozment and Sink [3], Huppertz [4], Foster [5], Harrington [6] and Hill [7]. A good description can also be found in the edited by Gubán [8]. The formation of modern distribution networks further increased the need for the outsourcing of logistics services, thereby supporting the continuous expansion of 3PL („third party logistics") providers. This latter observation can also be found in many sources, like in the already mentioned [3] and [8], or for example in the more economics-oriented publications of Deckmyn [9], Scheraga [10] and Kroll [11]. It is also important to note that in the United States, in parallel with (and partly even before) the previous processes, a deregulation process had also been taken place that allowed the emergence and expansion of 3PL providers in the freight-forwarding industry (this is also described in [2], or for example in the related work of Menon, McGinnis and Ackerman [12]). Therefore, it can be seen that the intensification of the global trends, the increasing role of logistics outsourcing, the spread of 3PL providers, and finally the rapid expansion of e-commerce and the use of internet technologies have all contributed to the rise of modern logistics networks through a mutually strengthening way. Of course, the role of risk manage-

ment in these networks increased in parallel with the previous processes, especially in the supply chains of multinational companies.

The effects of the so called "fourth industrial revolution" on the logistics networks also have to be discussed, as this new paradigm has the potential to cause fundamental changes in the entire industry and economy. Through the widespread application of high level automation, the extensive use of machine to machine communication and real time status monitoring, moreover through the analyzation of the large amounts of information generated by the previous techniques, the fourth industrial revolution could open up entirely new possibilities for the manufacturing companies. For example, it could make it possible to fulfil wide-ranging customer expectations in a flexible way, while at the same time it could also achieve reduced lead times, significantly reduced costs and nearly loss free operation. A detailed description of these possibilities can be found for example in the works of Illés et al [13], [14], in the work of Bányai [15] and in other publications which the latter wrote with his co-authors [16], [17], [18], in the work of Gubán et al [19], and also in the related papers of Tamás [20], [21]. Moreover, the increasingly flexible automation technologies could also increase the role of the holonic manufacturing systems, which are also based on properly organized supply chains [22]. However, the effective organization and operation of logistics networks will have an even greater importance in the more general sense as well, due to the fact that an increased level of transparency and information sharing will be required from the logistics service providers by both the end users and the manufacturing companies. Overall, it can be stated that because of these fundamental changes, the significance of collaborative logistics networks – together with the so-called "virtual enterprises" – will notably increase, which will provide an even greater role for performance measurement and risk management in the related supply chains.

2. RISK MANAGEMENT IN SUPPLY CHAINS

As it was mentioned before, risk management already plays a vital role in one of the most characteristic type of logistics networks, the supply chain. This is very well represented by the fact that the number of related publications between 2000 and 2015 had been tripled based on ScienceDirect, moreover this growth became most intensive since 2010, according to the work of Ziółkowska, Gorzeń-Mitka, Sipa and Skibiński which summarizes some of the main challenges in supply chain management [23]. However, it also has to be noted that while a large number of publications concentrate on the identification of risk sources, a relatively smaller number of them provides quantitative measurement and analytical tools for the precise evaluation of these factors [23]. Besides, it also has to be seen that the field of Supply Chain Risk Management (SCRM) can still be considered relatively new, therefore a large number of different approaches exist both from the perspectives of categorization and analyzation, as it is described in the survey made among the researchers by Sodhi, Son and Tang [24]. What these facts certainly prove however is that there are significant research opportunities in this field.

In general, it can be stated that among the various risk sources in the supply chain, the transportation delays play an outstanding role, together with the changing demand, the asymmetric information flow and inadequate level of supply chain integration (see the already mentioned [23], moreover the SCRM related publication of Wieland and Wallenburg [25], and also that of Wang [26]). However, there are significant differences of opinion regarding the selection of the areas and the main aspects of risk management in the supply

chain. In [24] the authors found the following interpretations for the definition of SCRM: according to 33,3% of the researchers SCRM focuses on the stochastic relationship between supply and demand; 31% of them thinks that it mainly deals with the operational risk factors in the supply chain; 19% of the researchers think that it analyzes the probabilities for rare but significant events; 14,3% of them believe that it deals with yet unknown risk factors; 11,9% of them think that if focuses on the disruptions and catastrophes affecting the supply chain; 7,1% of them believe that it analyzes the risk factors inherent in the supply chain strategy; 4,8% think that it concentrates on developing new probability-based methods; finally, another 4,8% of them believe that it deals with the related financial risks. From the previous, it can be seen that the definition of the field is far from being unified. However, according to [24], the two most widespread approaches are by far the evaluation of the supply risks and the analysis of the operational (logistics related) risk factors in the supply chain.

As in the case of defining the field, there is also a large variation among the utilized techniques as well. A good overview of the latter can be found in the comprehensive work of Ghadge, Dani and Kalawsky [27], which categorizes the majority of methods utilized in SCRM. In this publication, the authors identify three main categories, namely qualitative (54,17% of the examined cases), quantitative (36,66% of the examined cases) and mixed (9,17% of the examined cases) methods. Qualitative methods include case studies, data analysis and conceptual theories, among others. In case of quantitative methods, the majority of them is made up by the modeling techniques used in operations research (OR). According to the authors, these can be further classified into hard (14,17% of the examined cases) and soft (5,83% of the examined cases) methods. Hard OR methods include linear programming, game theory, queuing theory and Markov process [27] [28], while soft OR methods include the use of SWOT/POST analysis, viable systems model, scenario planning and a number of other techniques [27]. Besides the methods of operations research, the use of simulation, probability and statistics, and stochastic programming also belong to the quantitative group, while mixed methods naturally cover those that arise from a combination of techniques [27].

The previously presented works clearly show that plenty of different approaches exist in the field of SCRM. This is also represented by the large number of publications. For example the search engine Google Scholar provides a little more than two million results for the phrase: supply chain risk management. However, it must be noted that this number contains all types of scholarly literature. By using ScienceDirect, which focuses on academic journals and books, the number of results still exceed 73 000 publications. Some notable examples of the papers found through these searches include the publications of Chopra and Sodhi [29], Christopher and Peck [30], Jüttner, Peck and Christopher [31], Tang [32], Manuj and Mentzer [33] and Tang and Musa [34], among many others. Of course, plenty of other publications could be listed here, but it is also important to analyze the field of risk management outside the strictly defined supply chains, covering the area of logistics networks on a wider scale. This is going to be implemented in the following chapter.

3. RISK MANAGEMENT IN LOGISTICS NETWORKS ON A WIDER SCALE

In order to explore the wider topic, it was also necessary to examine the available literature which is related to the risk management of other types of logistics networks. The main goal of the analysis was to find such publications that contain both a detailed operational risk model involving all elements in the given network, and also a (preferably quantitative) mathematical model on which the risk model is based upon. This required a comprehensive

survey which was implemented with the use of the previously mentioned Google Scholar and ScienceDirect academic search engines.

First, the search was implemented with Google Scholar by using the phrase: risk management in logistics networks. This produced a large number (440 000) of results. As previously mentioned, this result contained a wide array of sources, however only the first 990 were shown which were comprised of academic publications. After surveying the listed results, however it became clear that the majority of these concentrate on the supply chains as well, especially on the problem of supply security, which mostly translates into the problem of supplier selection. Of course, some exceptions were found, like for example the work of Goh, Lim and Meng [35], in which there is a greater emphasis on the network model of the supply chain, while the risk factors are also taken into account. However, here the problem is also approached mainly through the analysis of the uncertainties related to supply and demand, and to the various cost elements (for example taxes and exchange rates).

Another example can be the work of Harland, Brenchley and Walker [36], in which a number of different risk sources are taken into account and multiple case studies are also presented. On the other hand, here the described method represents a somewhat more qualitative approach. The search was also repeated in a way that the results were limited to the time period starting from 2013. The final conclusion was the same as in the previous case, with the slight difference that the number of network-oriented publications found this way were somewhat higher than before. Examples for these are the works of Hatefi and Jolai [37], Hearnshaw and Wilson [38], or that of Mari, Lee, Memon, Park and Kim [39], among multiple others. However, it's still true for these cases as well that the risk is primarily taken into account through the stochasticity of supply and demand, while the reliability of the individual components of the logistics network receives somewhat less attention. On the other hand, the latter search showed that the importance of analyzing the effects of unexpected events on the supply chain has clearly grown lately, which is probably related to the growth of global uncertainty in the recent period.

Finally, the search was repeated with the use of other, similar search phrases, such as the following simpler word combination: risk logistics networks. Again, the result was similar to the previous ones in that the found publications mostly dealt with the problems of supply and demand. Among the exceptions was the work of El-Sayed, Afia and El-Kharbotly [40], in which a stochastic forward-reverse logistics network model was presented in great detail, though the related risks were mainly taken into account from a demand perspective. Another, similarly detailed and network-oriented model was described in the paper of Peng, Snyder, Lim, and Liu [41], but the related risks were again mainly discussed from one aspect, which was the occurrence of disruptions at the facilities involved in the supply chain. As it was mentioned, the search was repeated with other word combinations as well, for example with the following phrases: risk in logistics networks; risk assessment in logistics networks; risks in logistics networks. However, the results in these cases remained similar to the previous ones.

The search was also implemented with the use of ScienceDirect. The phrase which was used first was again the following: risk management in logistics networks. The number of results was 15 935, which was less than the number received through Google Scholar, but as it was mentioned before, this is due to the fact that the latter counts with all types of scholarly literature, while ScienceDirect strictly concentrates on academic journals and books. From the results, it was also clear that the number of related publications has constantly grown in every year since 2009, which coincides with the mentioned similar conclusion from [23].

Besides, it could also be seen that a larger number of the publications found this way are focusing more on concrete problems. Altogether, the search implemented in ScienceDirect provided the same result as the ones realized in Google Scholar, in the sense that a relatively small number of publications deal with the comprehensive, reliability oriented risk management of generally defined logistics networks. One found exception was the publication of Govindan and Chaudhuri [42], in which a detailed risk model based on the DEMATEL (Decision Making Trial and Evaluation Laboratory) approach was presented. It's also important to note that the risk factors in this case were specifically analyzed from the perspective of the 3PL providers. With the described method, the authors thoroughly analyze the interrelationships between the various risks, though the description of the related logistics model receives somewhat less attention.

Another good example is the paper made by Choi, Chiu and Chan [43], in which the authors analyze the different areas of the risk management of logistics systems, while they also propose new research directions. In the publication, both of the areas of operational risk control and logistics service risk analysis are discussed, among other important topics. On the other hand, the aim of this work was to provide a comprehensive picture and propose new research directions, rather than to develop a specific new model. A further good example is the case study presented by Tuncel and Alpan [44], in which the authors introduce an FMECA (failure mode, effects and criticality analysis) based, highly detailed risk model, while they also provide a Petri nets based modelling framework for supply chain networks. In this case, both the risk model and the logistics model are highly detailed and quantitative, though the presented framework has to be uniquely applied for each problem.

The search with ScienceDirect was also repeated with the use of other word combinations, for example with the simpler phrase: risk logistics networks. The search with the latter combination produced 18 503 papers, though these were largely similar to the previously found publications, to the point where a majority of the results were exactly the same. On the other hand, it must be noted that a number of such publications were also found this way which were less strictly connected to the actual topic, but nevertheless provided useful and interesting insights. For example, one of these was the paper written by De Rosa, Gebhard, Hartmann and Wollenweber [45], in which the facility location problem in a sustainable bi-directional logistics network was examined in great detail, in order to provide a robust network model for uncertain operational environments. Another interesting publication was the work of Alem, Clark and Moreno [46], in which the authors presented stochastic network models which can be used for logistics planning in disaster situations. Here, it also has to be mentioned that a significant number of other publications were found which also dealt with the role of logistics in disaster situations. Of course, the search was repeated with the previously utilized various other word combinations as well, but the results remained largely the same.

Table I. summarizes and compares the numerical search results in ScienceDirect for the two standard search phrases: supply chain risk management (from the previous chapter); risk management in logistics networks (from the current chapter). It lists the numerical results since 2009 on a yearly basis.

Table I.
Comparison of the numerical search results in ScienceDirect for the two standard search phrases

Number of search results in ScienceDirect		
Year	**"supply chain risk management"**	**"risk management in logistics networks"**
2017	7,595	2,022
2016	6,414	1,709
2015	5,748	1,431
2014	5,518	1,269
2013	4,552	1,049
2012	4,033	946
2011	3,446	740
2010	2,988	679
2009	2,842	562

On the whole, from the searches implemented in Google Scholar and Science Direct it can be concluded that while the field of supply chain risk management already has an extensive literature, the number of publications that concentrate on the risk management of more generally defined logistics networks is significantly smaller, as it can be seen from Table I. as well. Moreover, a significant portion of the found papers were characterized by the use of qualitative techniques, while the utilization of quantitative methods is somewhat less typical. Besides, it can be observed that the analysis of the reliability of the logistics service providers is very rare, which coincides with the fact that the operational risk factors themselves usually receive less attention. Instead, the risk factors are most often taken into account from the perspectives of supply and demand. These observations and the drawn conclusions will be further elaborated in the following chapter.

4. DRAWING CONCLUSIONS AND PROPOSING A NOVEL APPROACH

The survey of the literature verified the statement that the risk management of logistics networks already has a great significance in the field of logistics, especially in relation to supply chains. On the other hand, it also became clear that the number of those approaches which deal with the risk management of generally defined logistics networks is, at present, still significantly smaller compared to that of the supply chain focused methods. Moreover, the existing approaches usually concentrate on certain sides of the problem. Besides, as a general observation it can be also stated that the majority of the methods put a greater focus on qualitative techniques, while the utilization of quantitative tools is rather preferred in such cases when the problem is more constrained, or when a concrete case study is presented. Altogether, it can be seen that the number of such generally applicable quantitative risk management methods which can be used in a wide variety of logistics networks is still very small, while the use of detailed multi-aspect risk models is also less typical.

Based on the previous, it can be easily concluded that there is a significant potential in the development of new risk management methods for logistics networks. An approach that is based on a generally applicable mathematical model while also contains a detailed and multi-lateral risk model could be especially of great value. Of course, there are multiple available ways for the implementation of such a method. One possible solution could be an architecture in which the risk model would be configurable by the users (usually the manufacturing and service companies in the network) in accordance with the specific problem. The results of the risk model then would be applied in the mathematical model through an indirect way, for example as weights in a goal function. This approach would make it possible to utilize the risk model in various types of networks, while the indirect use of the results would allow the inclusion of an arbitrary number of processes and logistics service providers in the goal function.

The risk model itself can be implemented through multiple ways as well. In this regard, one plausible solution could be the utilization of so called multi criteria decision making methods, as these are specifically applied by the users to derive the order of preference of the examined alternatives – in this case, the risk factors – according to their own judgements. Out of these, one possible candidate could be the AHP (Analytic Hierarchy Process) method, as it is one of the most frequently used such technique. It has numerous uses in the field of logistics as well, especially in the cases of supplier and route selection [47], [48]. Besides, it is also very important to note that there are a lot of examples for using the AHP in relation to supply chain risk management as well, both regarding its standard form [49], [50], [51], [52], [53], [54], [55] and its different variations [56], [57], [58], [59]. *Figure 2* shows a possible way for how to implement a detailed risk model of an arbitrary logistics network as a decision hierarchy, by utilizing the AHP method. The proposed model is built around the mandator company which orders the logistics services in the network (the model counts with eight further risk factors which are compared according to the hierarchy below).

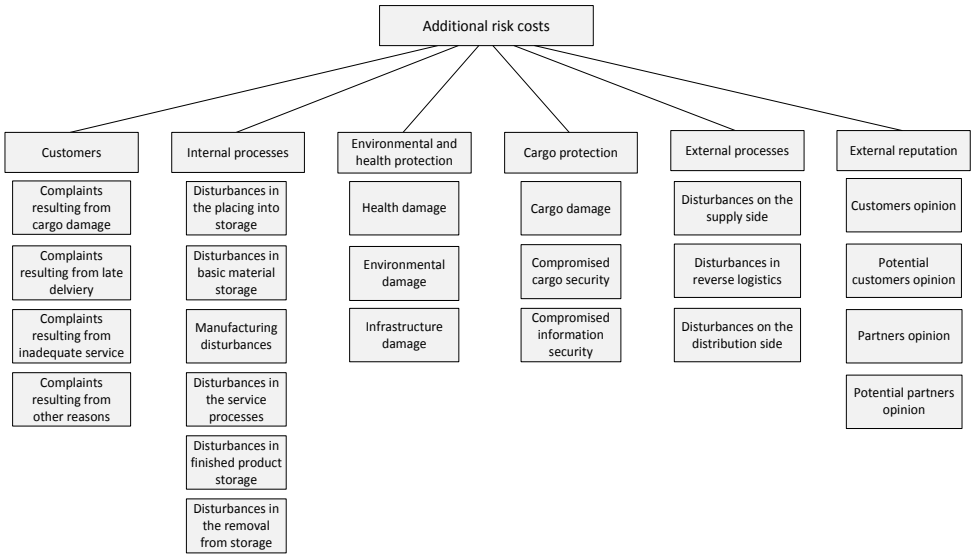

Figure 2. A possible way for implementing a detailed risk model of a logistics network as a decision hierarchy through the use of the AHP, a typical multi criteria decision making method

Of course, besides the AHP, there are plenty of other multi criteria decision making techniques that could be utilized for the creation of the risk model, depending on the way by which the underlying mathematical model of the logistics network is implemented. What is really important from the perspective of the proposed approach, is that the user has to be able to derive the weighted preference order of the risk factors through the application of the elaborated risk model in such a way that makes it possible to utilize the results as weights during the risk-based optimization of the given (but otherwise arbitrary) logistics network. As it became clear from the previous findings, the utilization of such an approach could provide significant benefits, both from a practical and from a research perspective.

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