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Supply chain risk modeling by AHP and Fuzzy AHP methods

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Supply chain management is a discipline dealing with organization, coordination, and optimization of relations within supply chains. Complexity and dynamics of supply chains are not always proportional to their reliability, and supply chain risk management becomes a very important tool in minimizing risk and uncertainties caused by, or impacting on, logistics-related activities or resources in the supply chain. Because risk modeling presents a very important segment of risk management, the paper includes a description of the main characteristics of supply chains and a model for risk assessment based on the Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP) methods. The main intention of the research presented here is to propose approaches based on application of the AHP and FAHP methods which are used as a tool for ranking supply chain risk categories, determining its share in total risk, and as a method for the supply chain risk assessment. The proposed approach is based on the experience and the knowledge of experts from insurance companies which are professionally engaged in the process of risk assessment, and possibility of its application is tested on a numerical example.

Keywords: supply chain; risk modeling; analytic hierarchy process; fuzzy analytic hierarchy process

1. Introduction

Global networks for distribution of products and services and international trade without limits and borders are the cause of existence of complex supply chains. A supply chain presents a set of relationships among suppliers, manufacturers, distributors, and retailers which facilitates the transformation of raw materials into final products (Beamon 1998). Christopher (1992) defines supply chains as a network of organizations that are involved, through upstream (i.e. supply sources) and downstream (i.e. distribution channels) linkages, in different processes and activities that produce value in the form of products and services delivered to the end consumer. Today, delivery time is getting shorter and shorter, idle time is reduced as well as all time losses, and generally the reliability and quality of delivery are increased. The complexity of supply chains depends on their characteristics, dynamics, number of subsystems, relations between them, communication, as well as characteristics of environment.

Supply chain management is a discipline dealing with organization, coordination, and optimization of relations within supply chains. That is, the management of

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upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole (Christopher 1998). The size, complexity, and dynamics of supply chains are not always proportional to their reliability. The reliability is most often directly connected to the system structure and also to the structure, relations, and communications between subsystems. The risk of delay of delivery, failure to meet contracted delivery terms, or cancelation of delivery can be caused by complex structures and communication within a supply chain, influence of external factors and very often by high demands of end users. Completely integrated supply chain and strategic planning provide the opportunity for neutralization of temporary or systematic errors that lead to realization of certain risks.

An important discipline that integrates supply chain management and risk management is the supply chain risk management. Supply chain risk management is where supply chain partners collaborate and apply risk management process tools to deal with risk and uncertainties caused by, or impacting on, logistics-related activities or resources in the supply chain (Norman and Lindroth 2002). In a modern economic context, where companies are more and more interconnected and where competition is greater and greater, it is very important to assess risk factors that are difficult to predict and that could have a negative impact on the profits and survival of the company (Vebrano and Venturini 2011). Due to the fact that supply chains are often very complex, risk management appears as a demanding, comprehensive, and complex process, especially in the segment of risk-level assessment and its minimization. Nowadays, there is a constant need for comprehensive methodologies that do not require companies to invest in information systems and human resources in order to gather a large amount of additional historical data that are usually not available from companies, but they are essential to perform supply chain risk management (Cagliano et al. 2012).

Risk modeling by using various statistical and other methods presents a very important segment of risk management. The paper includes a description of the main characteristics of supply chains and a model for risk assessment based on the AHP and FAHP methods. These methods provide a conversion of descriptive characteristics of certain processes or occurrences into quantitative values. The main idea is in the hierarchical decomposition of the total risk of a certain supply chain into basic risk categories and in the determination of their significance and share in total risk. The main contribution of the research presented here is in proposing an approach based on the application of AHP and FAHP methods which are used as a tool for ranking predefined supply chain risk categories, determining their share in total risk, and as a method for the supply chain risk assessment. The proposed approach is based on the experience and the knowledge of experts from insurance companies which are professionally engaged in the process of risk assessment.

The paper is organized as follows. Basic risk categories in supply chains are presented in Section 2. Application of the AHP and FAHP in supply chain risk modeling is presented in Section 3. Section 4 shows risk modeling process based on the AHP and FAHP methods. A numerical example is presented in Section 5. Finally, the conclusion is given at the end of the paper in Section 6.

2. Basic risk categories in supply chains

Complex systems and processes are not completely predictable and they are usually exposed to potential risks which can be very significant. There are many definitions of risk that describe it depending on the approach, context, and aspect of view. Generally, risk is a complex value that simultaneously describes the probability of occurrence of a loss event and expected consequences within the defined boundaries of a system and during the defined time interval, or during a certain process. Knight (1921) defined risk as complete knowledge of a potential outcome of a given situation, the objective probability of the occurrence of each, and their consequences. In a supply chain, risks are unexpected events that might disrupt the flow of materials on their journey from initial suppliers to the final customer (Waters 2007). Consequences of risk in supply chains can be measured depending on the aspect of view, and are mostly expressed as loss of money (economic loss, costs), number of failures, number of disrupted product units, number of production breaks, level of water, air or land contamination, or in other dimensions. There are many different types of risks that independently or in interaction affect the level of total risk in a supply chain. Supply chain risks can be divided into internal risks, which are either inherent or arise more directly from management decisions, risks within the supply chain, or risks in the external environment (Mason-Jones and Towill 1998). In complex logistic processes and supply chains there are a great number of different types of risk. According to Waters (2007), there are two basic kinds of risk, *internal* (risks that appear in normal operations) and *external* (risks that come outside the supply chain). Also, this author distinguishes *known-in-advance risks*, *unknowable risks* such as *inherently unknowable risks* (hidden risks that only emerge when unexpected events suddenly hit a supply chain), *time-dependant risks* (only emerge with the passing of time), *progress-dependant risks* (depend on the way that operations move forward), and *response-dependant or secondary risks* (only appear when action is taken to respond to an existing identified risk). Complex supply chains can have a framework that includes activities, communication, and flows between senders and receivers that could be at remote distances, even on different continents. Given the characteristics and number of risks present in every supply chain, it is often impossible to simultaneously analyze and evaluate all of them. Therefore, in the process of quantifying it is necessary to define dominant risk categories for assessment, that is, those categories that have the greatest impact on the total risk. Also, every risk category includes a large number of individual risks. This paper presents five main categories of supply chain risks (Table 1).

Operational/Technological (OT) risks are related to realization of main functions in business operations of a company and refer to transport risks, possibility of occurrence of negative effects on business operations as a consequence of failure of employees, inadequate internal procedures and processes, inadequate information management and other systems, and to unpredictable internal or external events. These are the risks that depend on human activities and characteristics, and specific features of a system or a process. They are connected to product development, process management, transportation of products, delivery or services, as well as technological support for all processes. The level of operational and technological risks can be significantly reduced if a proactive approach to risk management is conducted. That means defining standards, methodologies, policies, tools, appropriate

Table 1. Supply chain risk categories with examples (adapted from Deleris and Erhun 2011).

Category	Examples
Operational/ technological	Transportation risks (theft, pilferage and nondelivery risks, accidents, delays, damage from handling/transportation, re-routing, etc.), storage/ warehousing risks (incomplete customer order, insufficient holding space, damage of the goods, etc.), budget overrun, emergence of a disruptive technology, contract terms (minimum and maximum limit on orders), communication/IT forecast errors, component/material shortages, capacity constraints, quality problems, machine failure/ downtime, property losses, software failure, imperfect yields, efficiency, process/product changes, disruptions, etc.
Economy/ competition	Price and incentive wars, bankruptcy of partners, interest rate fluctuation, exchange rate fluctuation, commodity price fluctuation, stock market collapse, global economic recession, etc.
Natural/hazard	Fire, wildfire, flood, monsoon, blizzard, ice storm, severe thunderstorm, drought, heatwave, tornado, hurricane, typhoon, earthquake, tsunami, epidemic, etc.
Social risk	Human errors, organizational errors, labor shortages, loss of key personnel, strikes, absenteeism, union/labor relations, negative media coverage (reputation risk), perceived quality, coincidence of problems with holidays, fraud, sabotage, pillage, acts of terrorism, malfeasance, decreased labor productivity, etc.
Legal/political	New regulations, legal liabilities, law suits, governmental incentives/ restrictions, lobbying from customer groups, customs risks (inspection delay, missing data on documentation) instability overseas, confiscations abroad, war, tax structures, etc.

professional training, and procedures are required for the efficient supply chain risk management.

Economy/Competition (EC) risks are a very important segment that characterizes all national economies, upon which a supply chain depends. Economic risks present a possibility that macroeconomic business terms, such as effective state regulations for business operations, economic and political stability, interest rates and other, affect the efficiency of supply chains, reliability of delivery, safety of investments, and others. Competition presents a possibility that two or more entities offer a similar product or service, which provides the alternative of the most favorable choice to third parties. On the other hand, the presence of unfair competition is a very important segment of risk that can leave direct or indirect consequences on a supply chain. For the supply chain, competition is important in case of temporary or permanent failure of one supplier, when it is necessary to find an alternative supplier as soon as possible.

Natural/Hazard (NH) is a threat of a naturally occurring event that has a negative impact on humankind, human activities, and the environment. This negative impact is usually called a natural disaster. Natural hazard is a characteristic of the relationship between human beings and natural events. The risk from natural hazard and catastrophe in most cases cannot be completely eliminated, but can sometimes be understood in such a way that it can be minimized.

Social risks (SR) also have a great effect on reliability of supply chains. Social policy and social welfare of a country influence the prevention and overcoming of unfavorable situations for individuals or society classes by providing solutions for overcoming economic and SR, such as unemployment, protection of rights at work, protection of rights in case of disability, provision of pensions, etc. As a rule, SR are more dominant in undeveloped or less developed economies. On the other hand, in less developed economies with the highest SR the labor price is lower, which stimulates investors to invest in production in those countries apart from the increased risk.

Legal/Political (LP) risks mean occurrence of a problem in business operations that can be assigned to an unstable legal system, and political decisions or changes that influence realization of business goals. Legal risk most often refers to a situation when legal standards are changing during the validity of a financial agreement between business partners. Political instability generates political risks that can have significant temporary and long-term, direct and indirect consequences. Political risks are analyzed and assessed both on a micro level (e.g. enterprise, distributor, subsystem of a supply chain, and the like) and on a macro level, i.e. the state level (e.g. geopolitical, fiscal, monetary, trade, legal, and other levels of risks).

In practice, individual risks and levels of risk in supply chains are often presented in a diagram in the form of a risk map. It shows individual risks (R_1, R_2, …, R_i ,…, R_n) as points on a graph, which has a vertical axis that shows the probability of events and a horizontal axis that shows the potential consequences (Figure 1).

In the traditional representation, risk R corresponds to the product of a probability of occurrence of a loss event P and it expected consequences C, i.e. $R = P \cdot C$. In the case when total risk R_T is composed of several ($i = 1, 2, \dots, n\}$) partial risks R_i with occurrence probabilities P_i and consequences C_i, total risk can be expressed as a sum:

$$R_T = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} P_i C_i \qquad (1)$$

Knight (1921) distinguished probabilities obtained by two different methods: theoretical or a priori probabilities based on knowledge of a situation, and *statistical*

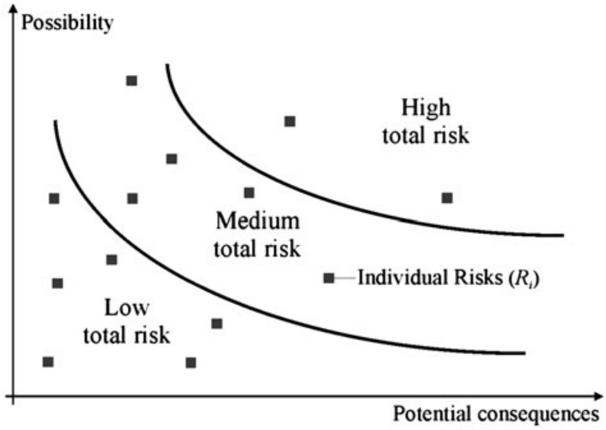

Figure 1. Risk map (Adapted from Waters 2007).

probabilities which are obtained through analysis of historical homogenous data. That means calculation of the statistical probabilities of various negative possible events and assessment of the corresponding expected consequences of such events. In complex systems, total risk should be statistically evaluated as a sum of the statistical parameters of all knowable individual risks, provided that the outcomes are comparable (economic loss, loss of reputation, etc.). Complex supply chains mean the presence of an extremely large number of individual risks in each risk category that are very often difficult to identify, and even more difficult to precisely evaluate.

3. Application of AHP and FAHP in supply chain risk modeling

There are numerous researches in the area of risk management and there are different methods and models that solve a great variety of problems connected to supply chain risk management. The main problem with risk assessment is the provision of representative statistical indicators of frequency and intensity of negative events from the previous period. The problem usually cannot be easily solved due to a great number and diversity of individual risks, nonexistence of required homogeneity of statistical samples, and a small number of identical repetitions of initial events that caused the risk (Gajović and Radivojević 2012). The choice of methods and models for analysis and assessment of risk depends on several factors such as: availability of data on the observed system, reliability and quality of information, complexity and dynamics of the system, number of subsystems, relations between subsystems, length of period for observing the event, expected development of the system in the following period, availability of human resources, level of costs, influence of the environment, and the like. Due to the stated reasons, supply chain risks are usually not assessed on the basis of statistical methods and models but on intuition, experience, knowledge, or prejudice, or certain non-statistical methods that are used for risk assessment. Particularly, the AHP and FAHP methods can be very useful with risk modeling when there are no representative statistical data for risk assessment.

3.1. Analytic Hierarchy Process

Analytic hierarchy process (AHP) is a multicriteria rank method developed by Saaty (1977, 1980). The AHP is a method based on the hierarchical analysis of a certain problem in elements of hierarchy that are structured in levels. The AHP method provides that a certain problem is hierarchically decomposed and partially solved, and then those partial solutions are again combined in order to obtain a solution to the initial problem. According to the AHP method, elements of a problem under analysis are distributed in a hierarchical structure from the total objective on top of a hierarchical structure through criteria and sub-criteria on their respective levels, to alternatives on the lowest level. Alternatives present the final result of a problem analysis, that is, weight values in relation to the set objective. The AHP method enables decision-makers to structure a complex problem in the form of a simple hierarchy and assess big number of quantitative and qualitative factors in a systematic manner.

The application process of the AHP methods is based on the concept proposed by Vinod Kumar and Ganesh (1996):

(1) A hierarchical decomposition of the problem to be solved with the aim at the highest level, the criteria and sub-criteria at lower levels, and the alternatives at the lowest level.
(2) Comparison of pairs of elements in each level of the hierarchy in relation to the elements of the higher level, through application of the Saaty scale from 1 to 9. The decision-maker determines the value a_{ij}, of the elements i and j, where its $a_{ij} = 1/a_{ji}$, $i, j = 1, \ldots n$ and $a_{ij} = 1$, $i = j$.
(3) Setting priorities for each element in relation to a higher authority – w_{ij} is a priority of the alternative i in relation to the criteria j, where it is $i = 1, \ldots, m$, $j = 1, \ldots, n$, m is the number of alternatives, and n is the number of criteria.
(4) Synthesis for all values of priorities so as to obtain the priority of each element in relation to the objective. W_i is the alternative priority i and it is determined as:

$$W_i = \sum_{j=1}^{n} c_j w_{ij} \tag{2}$$

where, c_j is the criteria priority j, and w_{ij} is the alternative priority i in relation to criteria j.

A detailed description and the mathematical formulation of the AHP method are given in the works (Saaty 1977, 1980, 1990).

A great number of authors have applied the AHP method in risk assessment. Saaty applied the AHP method in the papers for assessment of uncertainty and risk (Saaty 2006, 2008). Bochao (2010) gives the AHP and fuzzy comprehensive evaluation for supply chain risk assessment. Mustafa and Al-Bahar (1991) apply the AHP method in the processes of identification, classification, and assessment of risk in civil engineering projects. Wu, Blackhurst, and Chidambaram (2006) propose a model for inbound risk analysis based on the AHP method. Sii, Ruxton, and Wang (2001) used the fuzzy logic and the AHP method for qualitative modeling of marine systems' safety.

3.2. Fuzzy Analytic Hierarchy Process

The Fuzzy Analytic Hierarchy Process (FAHP) method extends the AHP method by combining it with the fuzzy set theory. In some cases, although simple and easy to use, the traditional AHP method is not able to present human cognitive processes. That is specific for situations when problems are not completely defined, their solution includes uncertain data or there are no exact and reliable data on realization of a certain problem. Although Saaty's (1990) discrete scale (from 1 to 9) has an advantage in terms of simplicity and easy use, it does not take into account the uncertainty connected to the perception of a decision-maker. Application of fuzzy numbers in the basic scale can improve accuracy of evaluations, so, the FAHP method is often applied. The FAHP method was proposed by van Laarhoven and Pedrycz (1983). Today, there are different modalities of the FAHP method proposed by various authors. In this paper, we used Chang's (1996) extent analysis method developed on the basis of the classical AHP method.

The FAHP can be described as follows (adapted from Wang, Luo, and Hua 2008):

- Comparison of pairs of elements i and j at every level of the hierarchy in relation to the elements at the higher level, by applying the fuzzy numbers that correspond to the Saaty scale from 1 to 9. The decision-maker determines the value b_{ij}, for elements i and j, where b_{ij} is a triangular fuzzy number (l_{ij}, m_{ij}, u_{ij}).
- Summing of rows of the matrix $B = (b_{ij})_{n \times n}$ so that one gets the values:

$$\mathrm{RS}_i = \sum_{j=1}^{n} b_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \right), i = 1, \cdots, n \tag{3}$$

The normalization of values RS_i according to relation:

$$S_i = \frac{\mathrm{RS}_i}{\sum_{j=1}^{n} \mathrm{RS}_j} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{k=1}^{n} \sum_{j=1}^{n} l_{kj}} \right), \ i = 1, ..., n \tag{4}$$

- Determining the degree of possibility of $S_i \geqslant S_j$ according to relation:

$$V(S_i \geqslant S_j) = \begin{cases} 1, & \mathit{if}\ m_i \geqslant m_j \\ \frac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)}, \quad \mathit{if}\ l_j \leqslant u_i, & i,j = 1, ..., n;\ j \neq i \\ 0, & \mathit{otherwise} \end{cases} \tag{5}$$

where $S_i = (l_i, m_i, u_i)$ and $S_j = (l_j, m_j, u_j)$. Calculate the degree of possibility of S_i over all the other fuzzy numbers by

$$V(S_i \geqslant S_j | j = 1, ..., n;\ j \neq i) = \min_{j \in \{1, \cdots, n\}, j \neq i} V(S_i \geqslant S_j),\ i = 1, \cdots, n \tag{6}$$

- Define the priority vector $W = (w_1, \cdots, w_n)^T$ of the fuzzy comparison matrix B as:

$$w_i = \frac{V(S_i \geqslant S_j | j = 1, \cdots, n; j \neq i)}{\sum_{k=1}^{n} V(S_k \geqslant S_j | j = 1, \cdots, n; j \neq k)}, \quad i = 1, \cdots, n \tag{7}$$

More detailed description and mathematical formulation of the FAHP can be found in Chang (1996).

Most authors use the FAHP method in risk management. Vosooghi, Fazli, and Mavi (2012) use the FAHP method to break down and quantify risks in supply chains of crude oil. Dagdeviren and Yuksel (2008) developed the FAHP model for safety management in production systems. Tuysuz and Kahraman (2006) applied the FAHP method for risk assessment in information technology projects. Nan, Zhen, and Hua (2009) used the FAHP method for supply chain purchasing risk evaluation of manufacturing enterprise. An, Huang, and Baker (2007) applied the FAHP method for risk assessment in railroad transport systems. Numerous authors compare values obtained by using the AHP and FAHP methods. Kabir and Hasin (2011) compare the AHP and FAHP models for multicriteria inventory classification.

4. Risk modeling process based on the AHP and FAHP methods

Risk modeling in supply chains depends on the complexity, the number of participants, and ways of realization of individual processes. In practice, the decisions of managers on risk assessment are based on experience, intuition, and determining whether the adverse events would happen. This paper develops a model for risk assessment based on the application of the AHP and FAHP methods. The application of these methods allows the overall risk of supply chains to be decomposed into individual risks, in order to determine their impact on the overall risk. The developed model consists of three parts: Analytical part, Processing part, and Decision Support part (Figure 2).

Analytical part involves collecting data on the supply chain and potential risks. Data on the risks are usually not available and therefore the experience, knowledge, and intuition of experts in order to assess the importance and impact of various risks to the supply chain are used. The start of modeling the overall risk is a classification of selected elements that make up the overall risk. In this paper, the classification was done according to the main categories of risks in the supply chain, which are described in Table 1.

Processing part starts with defining the hierarchical structure of risk according to the adopted classification. The hierarchical model has three levels (Figure 3). The objective of the model is supply chain risk assessment. On the second level are the criteria – risk categories (OT, EC, NH, SR, and LP), and the third are the alternatives – levels of risk: low total risk, medium total risk and high total risk. The second and third levels of the hierarchy are the comparison of elements i and j, and the formation of matrix $A = (a_{ij})_{n \times n}$ and $B = (b_{ij})_{n \times n}$, which represent the entry data for the application of the AHP and FAHP methods. The values of the matrix elements A and B are an expert evaluation of the importance of the elements i and j, expressed in crisp and fuzzy numbers corresponding to the Saaty scale from 1 to 9 (Saaty 1990). The result is a relative importance of each element and a rank according to their level of risk weights.

Decision Support part includes the analysis of the data on the categories and levels of risk. Ranking risk level indicates the level of overall risk for a particular supply chain. Based on the relative importance of the categories of risk, we can consider their impact on the overall risk. Management decisions are often related to the reduction of the overall risk, risk sharing with other participants in the supply chain, additional insurance for the dominant categories of risk, and others. In the process of making management decisions about the risks, it is necessary to make sure that the effects of measures to reduce the overall risk are greater than the costs associated with the activities in order to reduce the overall risk.

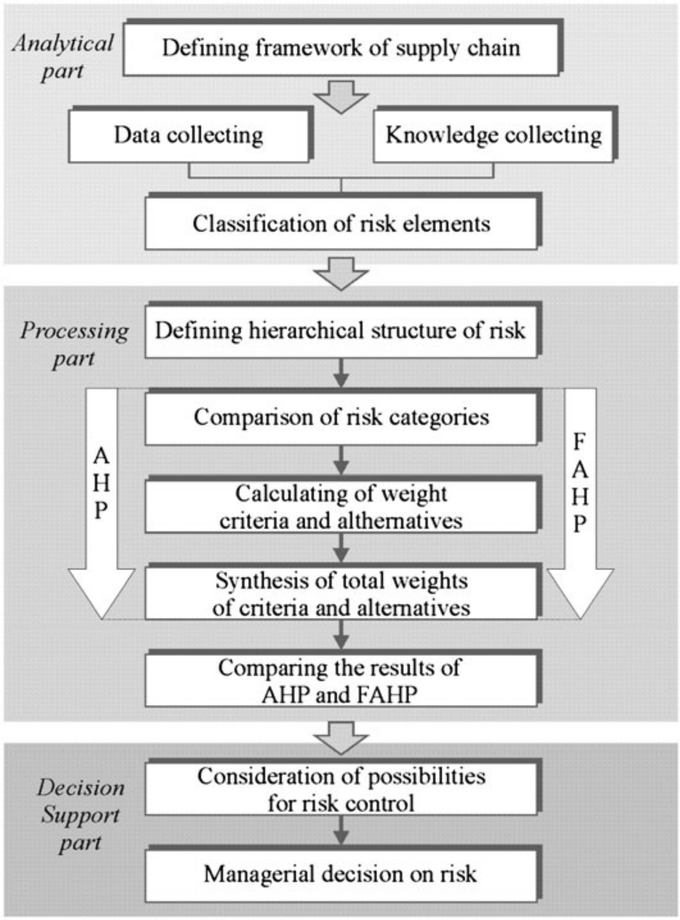

Figure 2. Model for risk assessment using the AHP and FAHP methods.

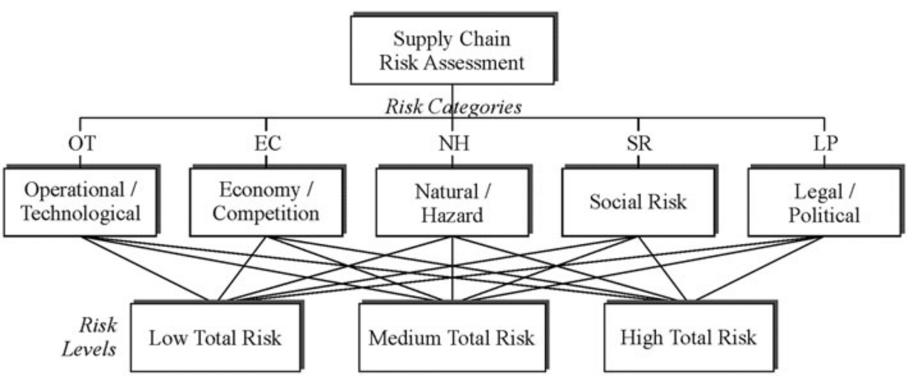

Figure 3. Hierarchical structure of risks and risk levels.

5. Numerical example

To test the proposed approach, let us assume that the problem is to assess risk in an arbitrary supply chain. In accordance to the proposed modeling approach, we consider $n = 5$ criterions – risk categories (OT, EC, NH, SR, and LP) and $m = 3$ alternatives – risk levels (low total risk, medium total risk and high total risk).

To apply the proposed modeling approach based on the AHP and FAHP methods we develop an MS Excel application, while the values of pairwise comparison matrices are based on an expert's estimates.

5.1. The AHP Method

Table 2 shows the values of pairwise comparison matrix, given by experts, and calculated values of the resulting vector of priorities *W*. The vector of priorities is the principal eigenvector of the matrix. It gives the relative priority of the criteria measured on a ratio scale. The table shows the values for λ – the principal eigenvalue of matrix, CI – consistency index, and CR – consistency ratio, which are obtained by applying the AHP method. Considering that CI is less than 10%, we can accept the estimate of the priority vector *W* (Saaty 1990). The highest priority is OT with 35.4% of the influence, and the lowest priority is NH with 7.1% of the influence.

In the next step, experts determine the pairwise comparison matrices for each level of risk in relation to each criterion. Table 3 shows the values of local priorities *w* for each level of risk.

Based on the obtained values of local priorities, global priorities are calculated for each alternative (risk level). Table 4 shows the values of local and global priority of all alternatives. Final priority vector indicates that the observed supply chain has a low total risk (0.608).

5.2. The FAHP Method

Table 5 shows the fuzzy values $b_{ij} = (l_{ij}, m_{ij}, u_{ij})$ matrix pairwise comparison of performance criteria *i* and *j*, given by experts and the calculated crisp values of the resulting vector of priorities *W*. The highest priority is OT with 29.8% of the influence, and the lowest priority is NH with 10.3% of the influence.

After this, the experts determine the elements of pairwise comparison matrix expressed in fuzzy numbers, for each level of risk in relation to each criterion (Table 6). Applying the relation of the FAHP method, the local priorities *w* for each level of risk are calculated.

Table 2. Pairwise comparison matrix for risk categories – AHP approach.

	OT	EC	NH	SR	LP	*W*
OT	1	1	5	3	3	0.354
EC	1	1	5	3	1	0.291
NH	1/5	1/5	1	1	1/3	0.071
SR	1/3	1/3	1	1	1	0.109
LP	1/3	1	3	1	1	0.174
	$\lambda = 5.194$		CI = 0.0485		CR = 0.0433	

Table 3. Comparison matrices and local priorities for risk levels – AHP approach.

	Low total risk	Medium total risk	High total risk	w
OT				
Low total risk	1	3	5	0.633
Medium total risk	1/3	1	3	0.260
High total risk	1/5	1/3	1	0.106
	$\lambda = 3.0390$	CI = 0.0190	CR = 0.0330	
EC				
Low total risk	1	5	3	0.633
Medium total risk	1/5	1	1/3	0.106
High total risk	1/3	3	1	0.260
	$\lambda = 3.0390$	CI = 0.0190	CR = 0.0330	
NH				
Low total risk	1	3	3	0.600
Medium total risk	1/3	1	1	0.200
High total risk	1/3	1	1	0.200
	$\lambda = 3.000$	CI = 0.000	CR = 0.000	
SR				
Low total risk	1	1	3	0.429
Medium total risk	1	1	3	0.429
High total risk	1/3	1/3	1	0.143
	$\lambda = 3.0000$	CI = 0.0000	CR = 0.0000	
LP				
Low total risk	1	3	5	0.633
Medium total risk	1/3	1	3	0.260
High total risk	1/5	1/3	1	0.106
	$\lambda = 3.0390$	CI = 0.0190	CR = 0.0330	

Table 4. Local and global priorities – AHP approach.

	OT 0.354	EC 0.291	NH 0.071	SR 0.109	LP 0.174	Final priority vector W
Low total risk	0.633	0.633	0.600	0.429	0.633	0.608
Medium total risk	0.260	0.106	0.200	0.429	0.260	0.229
High total risk	0.106	0.260	0.200	0.143	0.106	0.161

Table 5. Matrix pairwise comparison of performance criteria – FAHP approach.

	OT	EC	NH	SR	LP	W
OT	(1,1,1)	(1,1,3)	(3,5,7)	(1,3,5)	(1,3,5)	0.298
EC	(1/3,1,1)	(1,1,1)	(3,5,7)	(1,3,5)	(1,1,3)	0.276
NH	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	(1,1,3)	(1/5,1/3,1)	0.103
SR	(1/5,1/3,1)	(1/5,1/3,1)	(1/3,1,1)	(1,1,1)	(1,1,3)	0.136
LP	(1/5,1/3,1)	(1/3,1,1)	(1,3,5)	(1/3,1,1)	(1,1,1)	0.187

Local and global priorities of the risk levels are shown in Table 7. According to these data, the supply chain has a low total risk with priority 0.552.

5.3. Numerical example results and discussion

Comparison of the results using the AHP and FAHP method is shown in Figure 4, and it includes comparison at risk categories and risk levels.

Analysis of the results leads to the following conclusions:

- Both methods rank categories in the same way (OT, EC, LP, SR, and NH) and the levels of risk (low total risk, medium total risk, high total risk).
- The observed supply chain has low total risk and the biggest influence on the risk comes from O/T risks.
- The values of vectors, priority of risk categories and risk levels vary in the AHP and the FAHP methods, but it does not affect the final ranking.

Table 6. Comparison matrix and local priorities – FAHP approach.

	Low total risk	Medium total risk	High total risk	*w*
OT				
Low total risk	(1,1,1)	(1,3,5)	(3,5,7)	0.577
Medium total risk	(1/5,1/3,1)	(1,1,1)	(1,3,5)	0.372
High total risk	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	0.051
EC				
Low total risk	(1,1,1)	(3,5,7)	(1,3,5)	0.574
Medium total risk	(1/7,1/5,1/3)	(1,1,1)	(1/5,1/3,1)	0.051
High total risk	(1/5,1/3,1)	(1,3,5)	(1,1,1)	0.375
NH				
Low total risk	(1,1,1)	(1,3,5)	(1,3,5)	0.497
Medium total risk	(1/5,1/3,1)	(1,1,1)	(1,1,3)	0.295
High total risk	(1/5,1/3,1)	(1/3,1,1)	(1,1,1)	0.208
SR				
Low total risk	(1,1,1)	(1,1,3)	(1,3,5)	0.457
Medium total risk	(1/5,1/3,1)	(1,1,1)	(1,3,5)	0.457
High total risk	(1/5,1/3,1)	(1/5,1/3,1)	(1,1,1)	0.085
LP				
Low total risk	(1,1,1)	(1,3,5)	(3,5,7)	0.577
Medium total risk	(1/5,1/3,1)	(1,1,1)	(1,3,5)	0.372
High total risk	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	0.051

Table 7. Local and global priorities – FAHP approach.

	OT	EC	NH	SR	LP	Final priority vector *W*
	0.298	0.276	0.103	0.136	0.187	
Low total risk	0.577	0.574	0.497	0.457	0.577	0.552
Medium total risk	0.372	0.051	0.295	0.457	0.372	0.287
High total risk	0.051	0.375	0.208	0.085	0.051	0.161

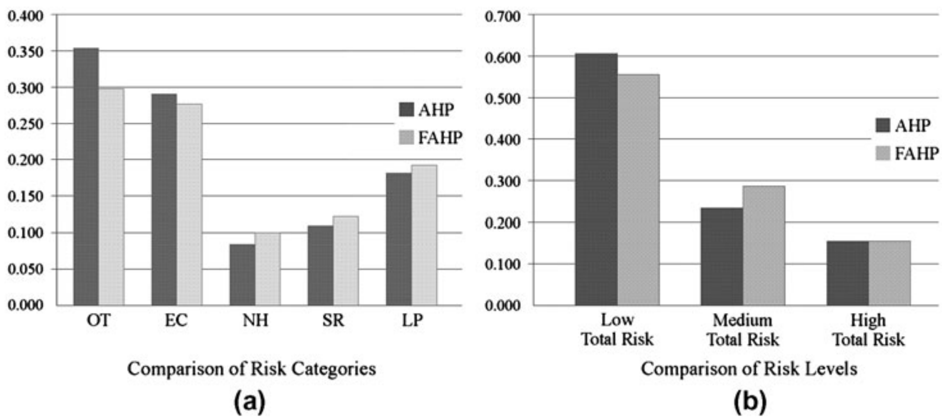

Figure 4. Comparision of the AHP and FAHP methods.

6. Conclusion

The process of modeling and risk assessment in the supply chain can be done in different ways and through different methods. A thing in common to all approaches to this problem is that in practice, there is a lack of relevant statistical data that can provide a risk assessment that is good and reliable enough, so almost the only possible solution, which is acceptable in practice, is the implementation of some of the methods of decision support.

This paper describes a model based on the use of the AHP and FAHP methods, allowing a hierarchical decomposition of risk. In these methods, subjective assessment, the experience, and intuition of experts on the evaluation of selected categories and levels of risk are used. The test results of the developed model are encouraging and suggest the possibility of using this approach in real-world conditions. The results also demonstrate that there are no significant differences in the risk assessment using the AHP and FAHP methods.

A developed model for assessing the risk in the supply chain can be of great benefit to managers in order to make smart decisions to reduce overall risk. In future studies, the described model may be a good basis for the development of decision support systems in the field of risk management in supply chains, with the goal to impose further extensions of the model, primarily in the direction of extension of the set of criteria, and then in the direction of increasing the number of levels in a hierarchical structure, introducing a more structured sub-criteria.

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