ASSESSMENT OF SUPPLIER'S RISK IN LOGISTICS NETWORKS

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Abstract

The aim of this paper is to propose a new methodology of supplier's risk assessment. Based on the classic method of FMEA and its modifications we have developed a new method of supplier's risk assessment. This modification is closely linked with the concept of risk-based thinking as well as fuzzy reasoning, and therefore seems to be appropriate for assessment of supplier's risk in logistics networks. The method is applied iteratively in seven main steps. Firstly, a team of experts selects potential risk categories, based on the literature, data and their own experience. The set of risk categories is the basis for generating of possible threats and hazards, which may occur within the analysed system. These risks become system exposures, and can interrupt the supply process continuity. To these events we prescribe the measures of uncertainty of their occurrence in the form of fuzzy probabilities. The next step of the process is an evaluation of the exposure frequency, which represents a rating of how often a supplier performs the activity where risk exposure occurs. The last step is to assess the impact severity in the form of losses caused by these events, and to calculate the risk priority number as a product of fuzzy numbers.

Keywords: Risk, logistics networks, FMEA, fuzzy

1. INTRODUCTION

The issue of risk in supply chains, and particular in those with global scale, becomes recently more and more important. ISO 9001:2015 [14] recommends to use the concept of *risk-based thinking* for "carrying out preventive action to eliminate potential nonconformities, analysing any nonconformities that do occur, and taking action to prevent recurrence that is appropriate for the effects of the nonconformity". To conform to the requirements of this Standard, each organization needs to plan and implement actions to address all possible risks as well as opportunities. "Addressing both risks and opportunities establishes a basis for increasing the effectiveness of the quality management system, achieving improved results and preventing negative effects." Based on these assumptions the Automotive Quality Management System Standard - IATF 16949 [13] introduces a requirement that each organization shall have a documented supplier selection process, which shall include "an assessment of the selected supplier's risk to product conformity and uninterrupted supply of the organization's product to their customers". IATF 16949 requires that "organizations shall ensure conformance of all products and processes, including service parts and those that are outsourced." This use of the term "ensure" implies that the organization needs to establish and maintain a system that mitigates the risk of non-conformance throughout the whole supply chain. The organization is ultimately responsible for all conformity and must cascade all applicable requirements down the supply chain to the point of manufacture. Manufacturing processes have the same output requirements as those specified for the product, and often require the use of specific method, such as capturing and analysing risk via a FMEA (Failure Mode and Effect Analysis).

2. SUPPLIER SELECTION METHODS

The basic criteria typically utilized for supplier selection are: costs, delivery time, product quality, and service level. Traditionally most buyers consider cost as the primary decision factor, but recently more and more various criteria for the supplier selection are taken into account: performance history, warranties & claims policies, production facilities and capacity, financial position, procedural compliance, reputation and position in industry, desire for business, repair service, attitude, packaging ability, geographical location, amount of past business, and reciprocal arrangement. With economic globalization, companies can choose suppliers from anywhere in the world, and developing countries are becoming more competitive because of their low labour and operating costs.

Different supplier selection methods observed in the literature can be classified as follows:

- Categorical Methods (CM). CM are qualitative models. Based on historical data and experience, current suppliers are evaluated on a set of criteria. After a supplier has been rated on all criteria, the buyer gives an overall rating. The primary advantage of the categorical approach is that the evaluation process is clear and systematic [1].
- Data Envelopment Analysis (DEA). DEA is a classification system that splits suppliers between two categories, ‘efficient’ or ‘inefficient’. Suppliers are judged on two sets of criteria, i.e. outputs and inputs. Weber et al. have discussed the application of DEA in supplier selection in several publications [25].
- Cluster Analysis (CA). CA is a method based on statistics which uses a classification algorithm to group a number of items described by a set of numerical attribute scores into a number of clusters. This classification is used to reduce a larger set of suppliers into smaller more manageable subsets (Hinkle et al. [12]).
- Analytical Hierarchical Process (AHP). AHP is a decision-making method developed for prioritizing alternatives when multiple criteria have to be considered and allows the decision maker to structure complex problems in the form of a hierarchy. This method incorporates qualitative and quantitative criteria. The hierarchy usually consists of three different levels, which include goals, criteria, and alternatives. Because AHP utilizes a ratio scale for human judgments, the alternatives weights reflect the relative importance of the criteria in achieving the goal of the hierarchy [11, 16, 22].
- Analytic Network Process (ANP). ANP [18] is a comprehensive decision-making technique that captures the outcome of the dependence and feedback within and between the clusters of elements. ANP is a more general then AHP, incorporating feedback and interdependent relationships among decision attributes and alternatives. ANP is a coupling of two parts, where the first consists of a control hierarchy or network of criteria and subcriteria that controls the interactions, while the second part is a network of influences among the elements and clusters [19, 20].
- Total Cost of Ownership (TCO). TCO-based models for supplier choice consists of summarization and quantification of several costs associated with the choice of vendors and subsequently adjusting or penalizing the unit price quoted by the supplier. TCO is a methodology and philosophy, which looks beyond the price of a purchase to include many other purchase-related costs (Ellram [8]).
- Technique for the Order Performance by Similarity to Ideal Solution (TOPSIS). According to the concept of the TOPSIS, a closeness coefficient is defined to determine the ranking order of all suppliers and linguistic values are used to assess the ratings and weights of the factors. TOPSIS is based on the concept that the optimal alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS) [22].
- Multiple Attribute Utility Theory (MAUT). The MAUT proposed by Min, H. [17] is considered a linear weighting technique. The MAUT method has the advantage that it enables purchasing professionals to formulate feasible sourcing strategies and is capable of handling multiple conflicting attributes. However, this method is mostly used for international supplier selection, where the environment is more complicated and risky [23].
- Outranking Methods (OM). OM are useful decision tool to solve multi-criteria problems. These methods are capable of dealing with situations in which imprecision is present. Lot of attention has been paid to

outranking models, however, so far, in the literature there is no evidence of applications of outranking models in purchasing decisions [1].

- Mathematical programming models (MPM). MPM often consider only the quantitative criteria. Mathematical programming models allow decision makers to consider different constraints in selecting the best set of suppliers. MPM are particularly useful for solving the supplier selection problem because they can optimize results using either single objective models or multiple objective models [6, 26].
- Case-Based-Reasoning (CBR). CBR systems fall in the category of the artificial intelligence (AI) approach. Basically, a CBR system is a software-driven database which provides a decision-maker with useful information and experiences from similar, previous decision situations. CBR is still very new and only few systems have been developed for purchasing decision making [15].
- Artificial Neural Network (ANN). The ANN models are very efficient when we have a large number of credible data. The weakness of this model is that it demands specialized software and requires qualified personnel who are expert [15].
- Fuzzy logic approach (FLA). In this method, linguistic values are used to assess the ratings and weights for various factors. Usually these linguistic ratings can be expressed in trapezoidal or triangular fuzzy numbers. Since human judgments including preferences are often vague and cannot estimate his preference with an exact numerical value, the ratings and weights of the criteria in the problem are assessed by means of linguistic variables [2, 6, 9, 24]. .
- Hybrid methods (HM). Some authors have combined different decision models into a supplier selection process. Degraeve and Roodhoft [7] developed a model combining Mathematical Programming Model with Total Cost of Ownership methodology. Ghodsupour and O'Brien [10] had integrated AHP and Linear Programming to consider both tangible and intangible factors in choosing the best suppliers. Sanayei et al. [21] presented an effective model using both MAUT and LP for solving the supplier selection problem. Boran [2] has proposed a multi-criteria group decision making approach using fuzzy TOPSIS, to deal with uncertainty.

None of the above methods meet the requirements of the IATF 16949 regarding risk-based thinking. Thus there is a need to develop a new method, which is focused on "an assessment of the selected supplier's risk to product conformity and uninterrupted supply of the organization's product to their customers".

3. SUPPLIER'S RISK ASSESSMENT METHOD BASED ON THE MODIFIED FMEA METHODOLOGY

Based on the classic method of FMEA and its modifications proposed in papers [3, 4, 5 and 27] we have developed a new methodology of supplier's risk assessment. This modification is closely linked with the concept of risk-based thinking, and therefore seems to be an appropriate method for assessment of supplier's risk in logistics networks. The process of evaluation of supplier's risk can be represented in the form of the general algorithm presented in **Figure 1**. The method is applied iteratively in seven main steps. Firstly, a team of experts selects potential risk categories $\{RC_i\}$, based on their own experience. The set $\{RC_i\}$ is the basis for generating a set of threats and hazards $\{TH_j\}$, which may occur within the analysed system. These risks become system exposures and are defined as the initiating events that can interrupt the continuity of supply process. To these events we should prescribe the measures of uncertainty of their occurrence, e.g. in the form of probabilities $P(TH_j)$. The next step of the process is the evaluation of the exposure frequency $F(TH_j)$, which represents a rating of how often a supplier performs the activity where risk exposure occurs. The next step is to assess the impact severity in the form of losses caused by these events $S(TH_j)\}$ (e.g. consequences of a delivery delay). Having evaluated parameters - $P(TH_j)$, $F(TH_j)$ and $S(TH_j)$ we can calculate the risk priority number as the product of fuzzy numbers:

$$RPN(TH_j) = P(TH_j) * F(TH_j) * S(TH_j) \quad (1)$$

If the value of RPN exceeds the acceptable level of risk it should proceed to planning of risk mitigation actions, and recalculation of the RPN **(Figure 1)**.

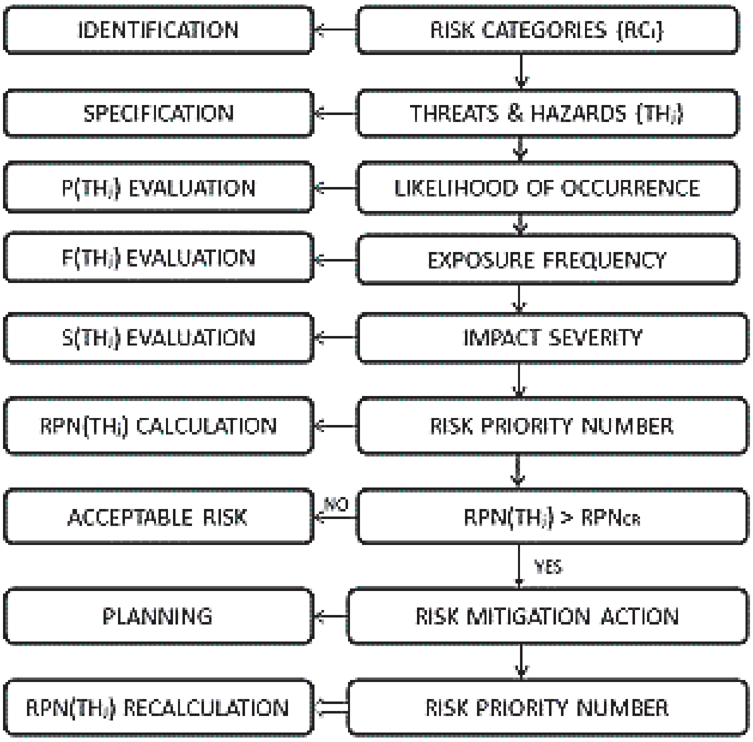

Figure 1 General algorithm of the framework for evaluation of supplier's risk
(Source: Own elaboration)

The method has been verified on the example of a real supply chain. Due to the lack of statistical data on the occurrence of threats and their possible consequences in the past, we used the expert knowledge for the evaluation of numerical indicators X_i , e.g. $P(TH_j)$, $F(TH_j)$ and $S(TH_j)$. The team of three experts evaluated each of the above parameters by the three numbers corresponding to the minimum value, the most likely value and the maximum value of the indicators. These numbers were the basis for describing a triangular membership function of a random variable X in terms of the fuzzy sets theory. The result of the evaluation are therefore triangular membership functions in a number equal to the amount of the experts involved in the assessment process. Aggregation of expert assessments can be done by building a collective triangular membership function with the parameters:

$$X_i=f(x_i-a_i,\ x_{im},\ x_i+b_i),\ for\ i=1\ldots n \tag{2}$$

where: $x_{im} = 0.5\ (x_{imax} + x_{imin})$

and the parameters "a" and "b" are calculated from the Hartley's formula (Hartley 1928) as a function of two standard deviation of the all three experts evaluations.

In the first step the team of three experts selected potential sources of risk $\{RS_i\}$, based on the literature, data and their own experience. The set $\{RS_i\}$ was the basis for describing a most dangerous scenario of the threats and hazards $\{TH_j\}$, which potentially may occur within the analysed supply system. The probability of occurrence for this scenario was assessed by each of three experts, and **Table 1** shows an example of the threat likelihood assessment. The graphic interpretation of these assessments is presented in the left side of

Figure 2, and the result of aggregation of all three expert evaluations is shown in **Figure 2** (right side). The parameters of the function P (TH_j) after aggregation are [0.27, 0.4, 0.57].

Table 1 An example of the threat likelihood assessment

	P(TH min)	P(TH m)	P(TH max)
Expert 1	0.25	0.35	0.45
Expert 2	0.3	0.4	0.5
Expert 3	0.25	0.45	0.6

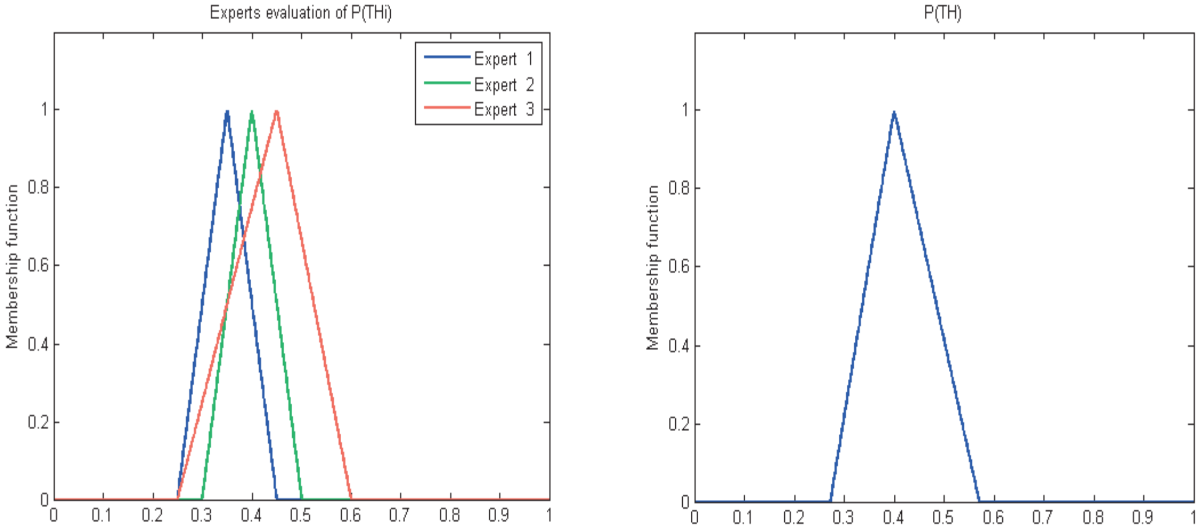

Figure 2 The graphic interpretation of the threat likelihood assessment and the P(TH) function after aggregation
(Source: Own elaboration)

The second step of the assessment process is an evaluation of the exposure frequency $F(TH_j)$. **Table 1** shows an example of the exposure frequency rating by the experts, a graphic interpretation of these assessments is presented in **Figure 3** (left side), and the result of aggregation of all three expert evaluations is shown in **Figure 3** (right side). The parameters of the function $F(TH_j)$ after aggregation are [0.58, 0.73, 0.83].

The next step of the process involves the evaluation of robustness and resilience of the system to given exposure, and the prediction of the effects of the dangerous scenario in the form of impact severity $S(DE_j)$. **Table 3** shows an example of the impact severity rating by the experts, a graphic interpretation of these assessments is presented in **Figure 4** (left side), and the result of aggregation of all three expert opinions is shown in **Figure 4** (right side). The parameters of the function $S(TH_j)$ after aggregation are [0.32, 0.43, 0.53].

Table 2 An example of the exposure frequency assessment

	F(TH min)	F(TH m)	F(TH max)
Expert 1	0.7	0.75	0.8
Expert 2	0.6	0.7	0.8
Expert 3	0.55	0.75	0.85

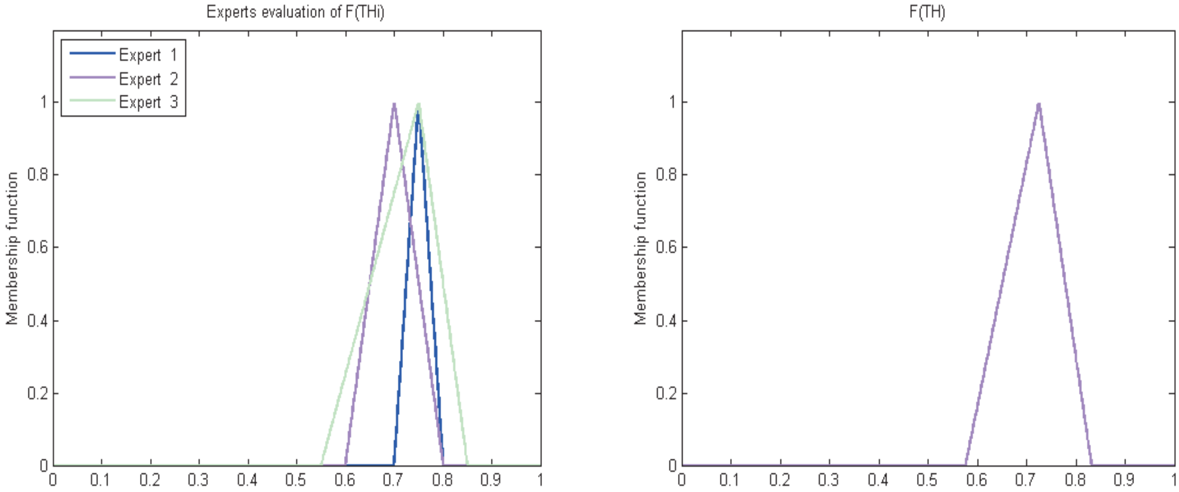

Figure 3 The graphic interpretation of the exposure frequency assessment and the F(TH) function after aggregation (Source: Own elaboration)

Table 3 An example of the severity impact assessment

	F(TH min)	F(TH m)	F(TH max)
Expert 1	0.4	0.45	0.55
Expert 2	0.3	0.4	0.5
Expert 3	0.35	0.45	0.55

The last step of the procedure is risk priority number calculation using the equation (1). The result of the multiplication of three fuzzy numbers [0.050, 0.124, 0.252] is shown in **Figure 5**. After defuzzyfication process we achieve the crisp number for RPN(TH_j) = 0.138. In case of the analysed systems, the maximum acceptable RPN value was set at 0.2, so the scenario meet this requirement.

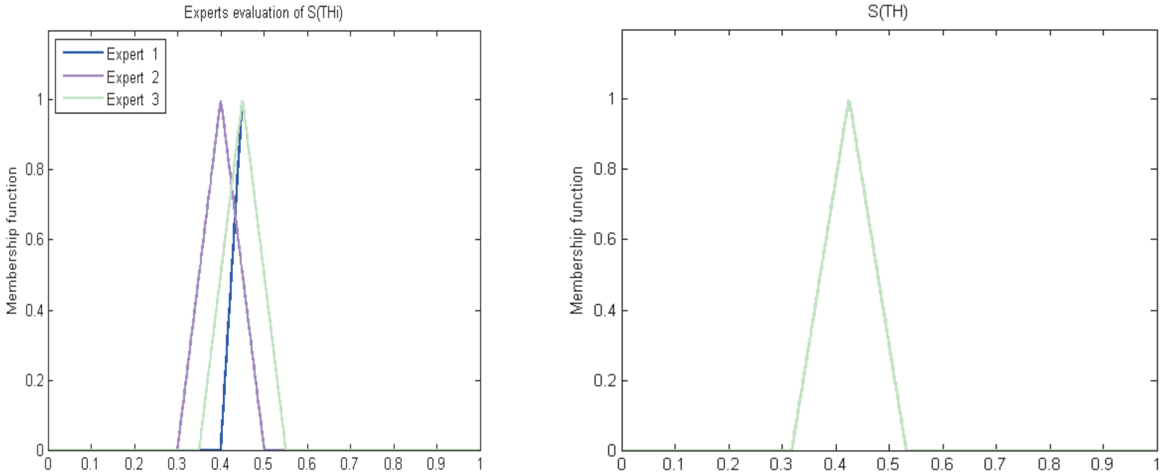

Figure 4 The graphic interpretation of the impact severity assessment and the S(TH) function after aggregation

(Source: Own elaboration)

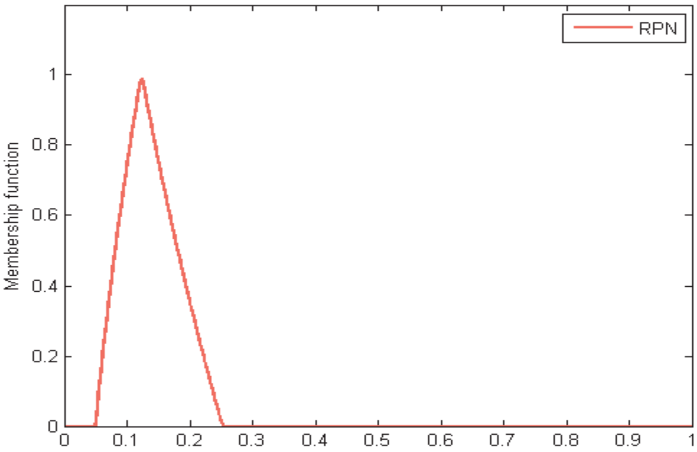

Figure 5 The graphic interpretation of RPN fuzzy number for the analysed scenario
(Source: Own elaboration)

4. CONCLUSION

Supplier's risk assessment for logistics networks is a process that can be represented in the form of the framework presented in the section 3. This method is based on the modified FMEA methodology, and can be implemented iteratively. The procedure for the risk assessment was based on the assumption of incomplete information about the possible sources of risk, threats and hazards, as well as their probabilities and consequences for the system. Therefore, as a knowledge base we accepted expert evaluation procedure and fuzzy inference process.

The applicability of the presented method has been verified on the example of a real logistics system. As a practical measure of risk we have chosen the product of three fuzzy numbers: probability of threats occurrence, exposure frequency and impact severity, for each of the possible scenarios. The maximum acceptable risk value was set and for the scenarios which do not meet this requirement the appropriate risk mitigation actions have to be planned. This procedure should be iteratively repeated as long as all scenarios reach a satisfactory result.

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