SUPPLY RISK ASSESSMENT FRAMEWORK BASED ON FAULT TREE ANALYSIS METHOD

[1]Jerzy FELIKS, [2]Marek KARKULA, [3]Katarzyna MAJEWSKA

[1,2,3] *AGH University of Science and Technology, Krakow, Poland, EU,*
[1]*jfeliks@zarz.agh.edu.pl*, [2]*mkarkula@zarz.agh.edu.pl*, [3]*kmajewsk@zarz.agh.edu.pl*

Abstract

The problem of ensuring the continuity of the product's flow across whole supply chains and networks become more and more important. Quality standards recommends to use founded on the concept of risk-based thinking 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. Therefore, each organization must cascade all applicable requirements down the whole supply chain, which requires the use of special methods. The aim of this paper is to propose a method of supply risk assessment, based on expert knowledge and the FTA methodology. The most important difference between this concept and existing solutions is that the uncertainty of the risk assessment is taken into account, with the use of possibility measures and fuzzy reasoning.

Keywords: Risk, supply chains, FTA method

1. INTRODUCTION

Modern organizations are developing enterprise risk management (ERM) frameworks in response to an increasingly unpredictable global business environment. It allows companies to take corporate risk management to actively anticipate, track and manage customer and supplier risks. More and more companies are turning to predictive methods to gain a better and more complete view of long, complex supply chain and distribution networks. Risk at any point on the supply chain become the risk at every point, so it's not enough just to focus on the internal threats facing one enterprise, but we have to handle vulnerabilities among each supplier and distributor - and also in the markets of our consumers. The biggest problem is related to integrating and consolidating risk management throughout complex global supply chains and assessing individual suppliers, manufacturer, distributors, vendors and consumers in a more and more complicated logistical environment.

Professional literature devoted a great deal of attention to the problems of suppliers evaluation and selection [1-9] Some of these works use artificial intelligence methods such as fuzzy reasoning and artificial neural networks to support decision-making [10]. On the other hand, relatively little attention is paid to the problem of risk on a holistic basis, namely the risk of ensuring the continuity of the product's flow across whole supply chains and networks [11]. Quality standards ISO 9000:2015 and ISO 9001:2015 recommends to use the concept of risk-based thinking for "… carrying out preventive action to eliminate potential non-conformities, analyzing any nonconformities that do occur, and taking action to prevent recurrence that is appropriate for the effects of the nonconformity …". To conform to this requirements each organization needs to plan and implement actions to address all possible risks and opportunities, to "… establish a basis for increasing the effectiveness of the quality management system, achieving improved results and preventing negative effects …".. chapter titles for a clear structuring and an easy understanding of the text.

The aim of this paper is to propose a universal method of supply risk assessment, based on expert knowledge and the FTA (Failure Tree Analysis) methodology. The most important difference between this concept and existing solutions is, that the uncertainty of the risk assessment is taken into account, with the use of possibility measures and fuzzy reasoning. The advantage of this approach is the ability to make decisions about the future with the uncertainty awareness of the obtained analytical evaluation.

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 labor 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. The primary advantage of the categorical approach is that the evaluation process is easy, clear and systematic.

Data Envelopment Analysis (DEA). DEA is a classification system that splits suppliers between two categories, namely '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 [12].

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 [13].

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 [14], [15].

Analytic Network Process (ANP). ANP 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 [16].

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 be-yond the price of a purchase to include many other purchase-related costs [17]

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) [18]

Multiple Attribute Utility Theory (MAUT). The MAUT proposed by Min, H. [15] 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 at-tributes. However, this method is mostly used for international supplier selection, where the environment is more complicated and risky [9]

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.

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.

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 [6].

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 [6]

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 [1].

Hybrid methods (HM). Some authors have combined different decision models into a supplier selection process. Degraeve and Roodhoft [9] developed a model combining Mathematical Programming Model with Total Cost of Ownership methodology. Ghodsupour and O'Brien [3] had integrated AHP and Linear Programming to consider both tangible and intangible factors in choosing the best suppliers. Sanayei et al. [18] presented an effective model using both MAUT and LP for solving the supplier selection problem. Boran [1] has proposed a multi-criteria group decision making approach using fuzzy TOP-SIS, to deal with uncertainty.

None of the above methods meet the requirements of the IATF 16949 regarding risk based thinking [19]. 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. FAULT TREE ANALYSIS (FTA AND FFTA)

Fault Tree Analysis is a technique used to identify the chain of events leading to failure . A separate tree is drawn for every service, using Boolean symbols. The tree is traversed from the bottom up. FTA distinguishes the following events:

- Basic Events: inputs in the diagram such as power outages and operator errors. These events are not investigated.
- Resulting Events- resulting from a combination of earlier events.
- Conditional Events: events that only occur under certain conditions, such as an air conditioning failure.
- Trigger Events: events that cause other events, such as an automatic shutdown initiated by a UPS.

Events can be combined with logical operations, such as:

- AND operation: the Resulting Event will occur if all inputs occur simultaneously.
- OR operation: the Resulting Event will occur if one or more of the inputs occur.
- XOR operation: the Resulting Event will occur if only one of the inputs occurs.
- Inhibit operation: the Resulting Event will occur if the input conditions are not fulfilled.

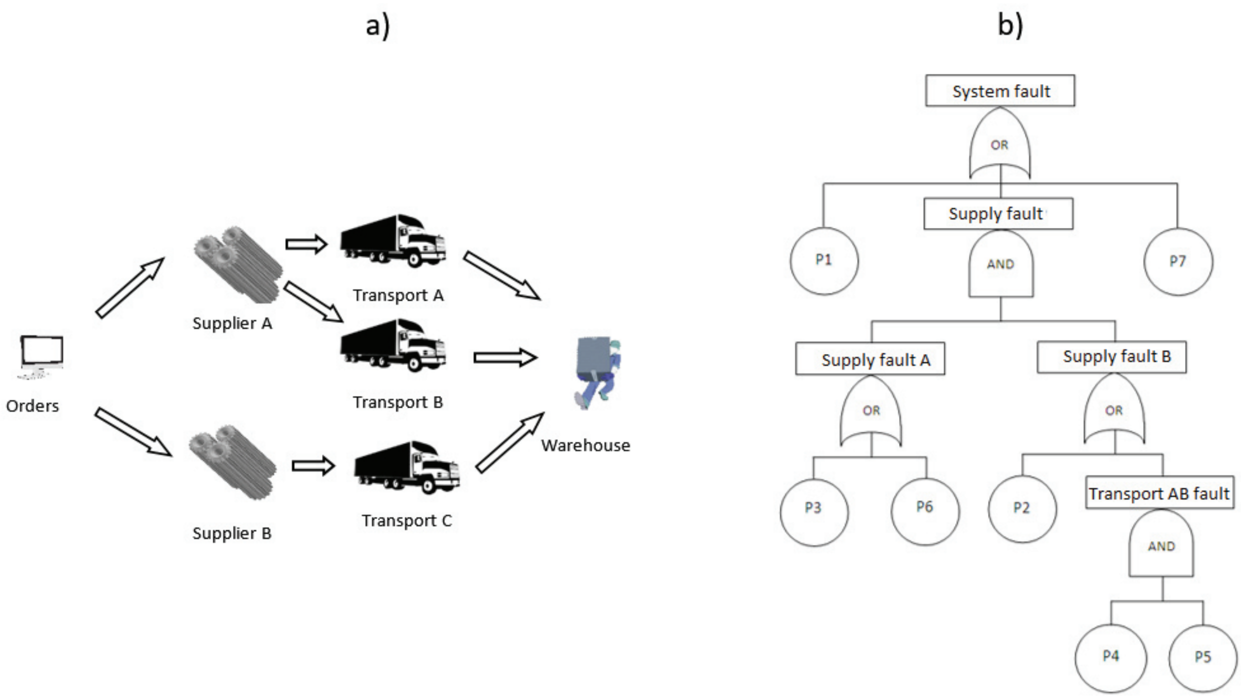

Figure 1 Functional structure a) sample supply system, b) fault tree

On the basis of formula no. 1, we can determine the conditions for the fault of the system from **Figure 1**.

$$F = (1 - P1)(1 - P7)(P2 + P4 \cdot P5 - P2 \cdot P4 \cdot P5) \cdot (P3 + P6 - P3 \cdot P6) \quad (1)$$

The use of the formula (1) requires estimation (for example by experts) of the likelihood of occurrence of particular events from P1 to P7. More information about this estimation can be find in the article [11, 20]. Many approaches to reliability assessment are based on the use of linguistic terms instead of numerical values. Most often, experts, based on their knowledge and experience, assign appropriate word definitions to the reliability parameters of individual system components. Then the evaluations of individual experts are subjected to aggregation, as a result of which the resultant values of the reliability parameters of the elements are determined. In the final phase, fuzzy values are converted to sharp values by one of the defuzzification methods. The following steps to be taken when determining the reliability of the logistics system using the Fuzzy Fault Tree are [21, 22]:

1) Selection of experts. Experts should be people with considerable experience, representing various departments, and even various companies that are part of the logistics network.
2) Define the framework of the system under examination and the level of detail of the analysis. Experts decide what elements are part of the tested system and how they will be analyzed in detail, eg whether individual transport means, infrastructure and drivers will be considered separately in the transport subsystem, eg a car with a driver will be treated as one element. Decisions are also made as to whether all components of the 8R principle will be taken into account in the assessment of reliability, or whether some will be separated.
3) Variable selection of fuzzy to determine the unreliability of system components. An example of this is a set of terms - reliability: small, medium, large, very large, certain, which are represented for example by triangular membership function.
4) Determination of the unreliability of individual elements of the system by experts. In this step, each expert evaluates the veracity of each element of the system under examination.
5) Select potential sources of risk, based on the literature, data and their own experience (as a probability and fuzzy number).

6) Obtain threats and hazards, which actually (although sometimes with a very low probability) may occur within the analysed system
7) Evaluate effectiveness of barriers (if any) in case of each of the potential threats and hazards. These risks, which are not effectively blocked by security barriers, become direct system exposures and are defined as the initiating events that can interrupt the continuity of process [11].
8) Determination of the average fuzzy number for the failure of individual system components. Aggregation of expert assessments for the resultant fuzzy number.
9) Calculation of the fuzzy number for the failure of the entire system by the FTA method. In this step, the tree of inability is built and using operations on fuzzy numbers determines the unreliability of the system.
10) Presentation of the final result.

The fuzzy number representing the unreliability of the system is not necessarily a trapezoidal or triangular number and does not coincide with the fuzzy numbers defined in step 3 which determine the unreliability of the elements. In order to obtain a linguistic term for the failure of the system, the maximum intersection of the fuzzy number determining the unreliability of the system with the fuzzy numbers defined in step 3 is determined. Visual information can help in the interpretation of the result. If there is a need to provide uncertainty in the form of a single value, one of the methods of defuzzification it can be used.

4. CONCLUSION

Organizations needs to plan and implement actions to address all possible risks and opportunities, to establish a basis for improved their results and preventing negative effects. One of the biggest problems by achieving this goal is related to integrating and consolidating risk management throughout complex global supply chains and assessing individual suppliers, manufacturer, distributors, vendors and consumers in a complicated logistical environment. In the paper we propose method of supply risk assessment, based on expert knowledge and the of FFTA methodology for risk analyses. The use of FFTA methodology is very valuable for supply chains since it helps to understand the system’s behavior and how failures can happen, and it can be also used as a complementary method to simulation methods using in the design of large-scale logistic systems [23].

ACKNOWLEDGEMENTS

Subject subsidy for maintaining research potential AGH University of Science and Technology, Krakow.

REFERENCES

[1] BORAN, F.E., GENC, S., KURT, M. and AKAY, D. A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method, *Expert Systems with Applications,* 36 (2009) pp. 11363-11368.

[2] BROSS, M.E. and ZHAO, G. *Supplier selection process in emerging markets - The Case Study of Volvo Bus Corporation in China*, Master Thesis. School of Economics and Commercial Law, Göteborg University (2004).

[3] GHODSYPOUR S. H. and O'BRIAN C. A decision support system for supplier selection using an integrated analytic hierarchy approach and linear programming. *International Journal of Production Economics*, 56/57(1998) pp.199-212.

[4] HINKLE, C.L., ROBINSON, P. J. and GREEN, P. E. Vendor evaluation using cluster analysis, *Journal of Purchasing* 5 (3) (1969) pp.49-58.

[5] HO, W., XU, X., and DEY, P.K. Multi Criteria Decision Making Approaches for Supplier Evaluation and Selection: A Literature Review, *European Journal of Operational Research*, 2010, 202 (1), pp.16-24

[6] KUO, R. J., WANG, Y. C. and TIEN, F. C. Integration of artificial neural network and MADA methods for green supplier selection. *Journal of Cleaner Production*, 18(12)(2010), pp.1161-1170.

[7] LEE, E.K., HA, S. and KIM, S.K. Supplier Selection and Management System Considering Relationships in Supply Chain Management. *IEEE Transactions on Engineering Management*, 47(4) (2001) pp. 307-318.

[8] SHYUR, H.J. and SHIH, H.S. A hybrid MCDM model for strategic vendor selection, *Mathematical and Computer Modeling*, 44(2006), pp. 749-761.

[9] SVENSSON, G. Supplier segmentation in the automotive industry: A dyadic approach of a managerial model, *International Journal of Physical Distribution & Logistics Management,* 34(1/2) (2004), pp.12-38.

[10] CHEN-TUNG, C. and CHING-TORNG, L. A fuzzy approach for supplier evaluation and selection in supply chain management, *International Journal of Production Economics,* 102 (2006) pp. 289-301

[11] BUKOWSKI L.A. , FELIKS J. Imperfect knowledge based prediction of disruption risk in large scale complex systems *In Safety and reliability - theory and applications : proceedings of the 27 European Safety and Reliability conference* (ESREL 2017) : Portorož, Slovenia, 18-22 June 2017 pp. 191-198.

[12] VERMA, R. and PULLMAN, M. E. An Analysis of the Supplier Selection Process, *OMEGA- International Journal of Management Science,* 26(6) (1998), pp.739-750.

[13] HILL, R.P. and NYDICK, R.L. Using the Analytic Hierarchy Process to structure the supplier selection procedure, *International Journal of Purchasing and Materials Management* 28 (2) (1992), pp.31-36.

[14] HARTLEY R. V. L. Transmission of information, *The Bell System Technical Journal* (Volume: 7 , Issue: 3 , July 1928), pp.535 - 563

[15] MIN, H. International Supplier Selection: a Multi-attribute Utility Approach, *International Journal of Physical Distribution & Logistics Management*, 24(5) (1994), pp. 24-33.

[16] SAATY, T.L. and VARGAS, L.G. *Decision-Making with the Analytic Network Process Economic, Political, Social and Technological Applications with Benefits, Opportunities, Costs and Risks*, Springer, New York, 2006.

[17] MAGGIE C.Y.T. and TUMMALA, V.M.R. An application of the AHP in vendor selection of a telecommunications system, *Omega International Journal of Management Science,*, 29 (2001) pp.171-182.

[18] SANAYEI, A., MOUSAVI, S.F. ABDI, M.R. and MOHAGHAR, A. An integrated group decision-making process for supplier selection and order allocation using multi-attribute utility theory and linear programming, *Journal of the Franklin Institute,* 345(2008) pp.731-747.

[19] IATF 16949, *Automotive Quality Management System Standard*, IATF, 2016

[20] BUKOWSKI L., FELIKS J. and MAJEWSKA K. Modelling and simulation of disruption risk in the complex logistic networks - a multimethod approach, *Safety and Reliability of Complex Engineered Systems*, 2015 Taylor & Francis Group, A Balkema Book, London, pp. 3911-3918

[21] BUKOWSKI L. and FELIKS J. Application of Fuzzy Sets in Evaluation of Failure Likelihood, *Proceedings. 18th International Conference on Systems Engineering(ICSENG)*, Las Vegas, NV, USA, 2005, pp. 170-175.doi:10.1109/ICSENG.2005.16

[22] FELIKS J, LICHOTA A, MAJEWSKA K. Fuzzy Fault Tree Analysis FFTA for reliability assessment of logistics systems. *Selected aspects of logistics management*, Vol. 4 Wydawnictwa AGH, 2016, pp. 321-332

[23] STRAKA, M; LENORT, R; KHOURI, S; FELIKS, J. Design Of Large Scale Logistics Systems using Computer Simulation Hierarchic Structure. *International Journal of Simulation Modelling* Volume: 17 Issue: 1 pp.105-118.