FUZZY APPROACH TO SUPPLY CHAIN RISK ASSESSMENT. CASE STUDY

Sylwia WERBIŃSKA-WOJCIECHOWSKA, Maciej CHLEBUS

Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Wroclaw, Poland, EU,
sylwia.werbinska@pwr.edu.pl, maciej.chlebus@pwr.edu.pl

Abstract

The paper discusses a problem of risk assessment in supply chains. The need to adapt the operation of supply chains in today's uncertain and volatile environment has caused the need to develop a well-adjusted asset management and risk management systems. Following this, the authors analyze a risk management system implemented in a case company from automotive industry. Based on the analysis results, the authors propose fuzzy FMEA method use in order to ensure the possibility of achieving the company's set goals. The short comparative analysis of the new approach and a classic FMEA method implementation is provided. The work ends up with summary and directions for further research.

Keywords: Fuzzy approach, supply chain, risk assessment, uncertainty

1. INTRODUCTION

In today's time of intense global competition, every industry is constantly looking to enhance their production levels and performance efficiency [1,2]. On the other hand, there is a groving awareness of the necessity of developing a risk management systems, which will allow the identification and management of hazardous events [3,4].

According to [5], FMEA is a videly used approach for identification, evaluation and effective management of risks in production systems. However, the input parameters in this approach (called probability of occurrence, severity and detection of failurem mode) may be difficult to estimate by experts due to many uncertainies (internal/external ones) in such production systems performance. Thus, fuzzy logic can be implemented to overcome such problems.

Currently, the Fuzzy FMEA is videly used in practice [6]. A comprehensive review on fuzzy FMEA applications is given e.g. in [7]. In this study, we proposed the application of the Fuzzy FMEA method, aiming to develop the prioritization and assesment of risk events that likely occur in the production systems of the analysed case company. Thus, the remaining of this article is as follows. Section 2 pesents the results of the application of conventional FMEA (currently used in the case company). Later, the Fuzzy FMEA approach is proposed in order to overcome some drawbacks connected with the performed risk analyses. The paper ends with summary and recommendations of research.

2. CASE STUDY

The analyzed international company, on the example of which research was conducted, is located in Poland in Lower Silesia region. The investigated company is a global manufacturer of compressors for automotive air conditioning. In Poland, the company was established in 2005 and nowadays employs about 1,100 people and has over 40,000,000 square meters of production area for holding manufacturing processes, including: production of bodies by high-pressure aluminum casting, mechanical treatment and assembly of complete compressors. Each year it produces about 3 million compressors, which are delivered to European assembly plants of the biggest car manufacturers. Currently, the investigated company manufactures products for world famous brands such as Volkswagen, Volvo, or Ford. Moreover, the company has assembly lines for HVAC systems (automotive heating, ventilation and air conditioning systems) for SCANIA and DAF manufacturers,

with a production capacity of 140 thousand units per year. In the production plant operate 26 production lines, which include processes such as: high-precision machining, grinding, electron welding, friction welding and coating.

The main goal of the company is to respond to the customers' demand for appropriate technologies, products and services. World's success is based on the three strategic pillars: quality, cost and delivery on time, as well as continuous product development with constant care for the environment. The company's motto is "Delivering Excellence" and the company's policy is to achieve the trust and satisfaction of its customers and an essential position on the market.

In order to achieve the policy goals, some priority actions are defined. One of them is connected with ensuring the highest quality supply components for air conditioning systems and ventilation. This is mainly achieved by implementation of rigorous quality control, continuous control of the assembly parameters as well as meeting the ISO and IATF standards. The second covers risk-based thinking and continuous improvement of integrated management system.

The main goals of risk management system is to ensure proper performance of company's goals and tasks and create company's resilience system. The risk is defined as the effect of uncertainty on objectives. The currently implemented risk management system is focused on 13 main areas (e.g. Business risk management, Legal risk management, Occupational risk management, Environmental risk management, Operational (production/logistic) processes risk management, Supply risk management). In the given paper the authors focus on operational risk management system (for production system performance), which bases on five main steps implementation (according to **Figure 1**) and is compatible with ISO standard. The selection of production system area for risk analyses is mainly connected with the company set goals. This operational area has the best structured approach for risk management and analyzes are carried out on an ongoing basis and the results continuously monitored. The introduced risk management approach bases on simplified FMEA (Failure Mode and Effect Analysis) method use. The detailed description is given in the Section 2.1.

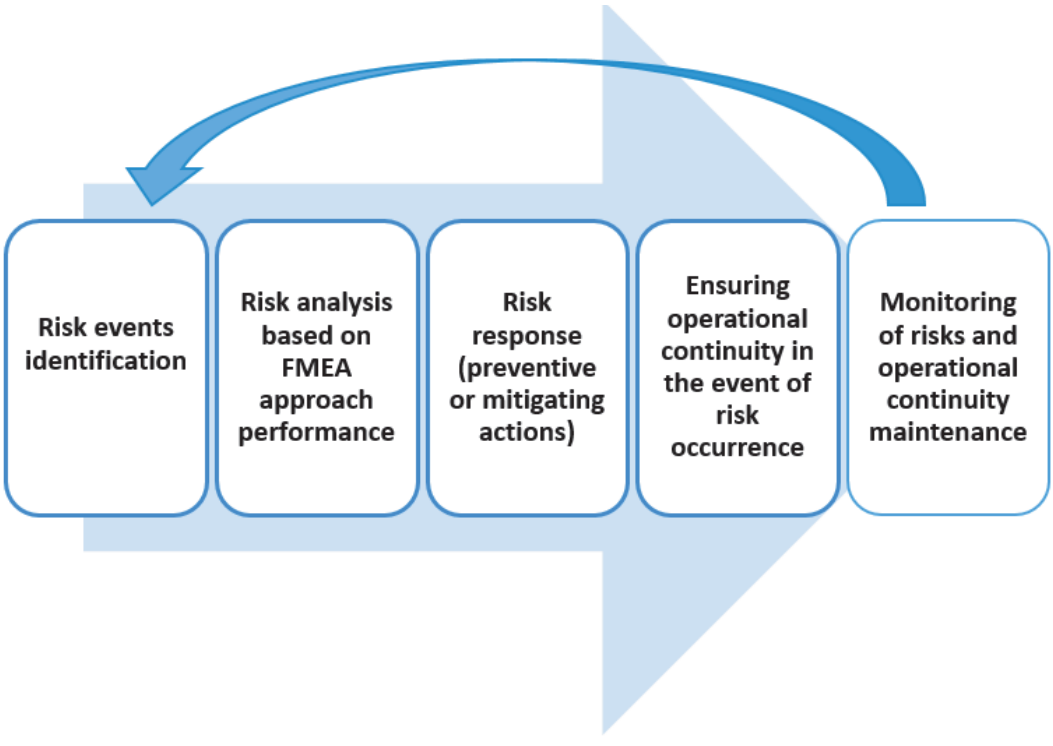

Figure 1 The main steps of risk management method used in the analyzed company (source: case company documents)

2.1. Conventional FMEA implementation

The first step of the investigated risk management system is risk events identification. For the considered case, in the carried out research the results of performed in 2017 FMEA analysis are considered. The managers defined 14 main hazard events that may occur. The defined risk events are strictly connected with production processes performance (internal risks). Moreover, two external risks connected with danger of power supply failure and natural disaster occurrence were also identified. On this basis, the simplified FMEA procedure was implemented. The assessment of risk indexed parameters bases on the very limited point scale (see **Table 1**). The investigated company analyzes the main risk parameters only in the 3-point scale, what limited its usefulness and may lead to wrong decision-making. The results of the performed FMEA analysis are presented in the **Table 2**. The obtained results are later analyzed according to the defined risk management activities (**Table 3**).

Table 1 Risk indexed parameters rankings for RPN estimation (source: case company documents)

Occurrence of risk event		Severity of risk event for an organization		Detection of risk event by a customer	
Description	**Scale**	**Description**	**Scale**	**Description**	**Scale**
Low probability of occurrence	**1**	Low impact on organization performance	**1**	No influence on a customer	**1**
Medium probability of occurrence	**2**	Medium impact on organization performance	**2**	Medium influence on a customer	**2**
Very high (almost certain) probability of occurrence	**3**	Very high impact on organization performance	**3**	Very high influence on a customer	**3**

Table 2 Risk assessment for the case company operational performance using FMEA analysis (source: based on case company documents)

Risk event	Risk analysis			
	Probability of occurrence	**Severity of risk event for an organization**	**Detection of risk event by a customer**	**RPN index**
The product does not meet the specification	2	1	2	4
Oil leak into the ground	1	2	2	4
Aliphatic hydrocarbons emissions exceeded	1	2	1	2
VOCs (Volatile Organic Compounds) emissions exceeded	2	3	2	**12**
NO2, SO2, CO emissions exceeded	2	2	1	4
Production equipment/plants fire	1	2	2	4
No staff to complete production plans	2	3	2	**12**
Serious, fatal or collective accident occurrence	1	2	2	4
Spare parts not available	2	2	1	4
No machining tools	1	2	2	4
Insufficient production support	2	2	2	**8**
Incorrect waste management (throwing waste to wrong containers)	2	2	1	4
No power supply	2	2	2	**8**
Local flooding	1	2	2	4

Table 3 Company's risk management activities according to the estimated RPN (source: based on case company documents)

RPN index values	Description of risk management activities
1-3	risk event significance is assumed to be low, which means: a small impact on the achievement of the objectives and tasks and no impact on the key activities of the organization; the risk assessed as acceptable, should be monitored, the decision to counteract is taken by the owner of the process, except for those risks where detection parameter is equal to 3 points, then risk prevention is always undertaken
4-8	risk event significance is assumed to be medium, which means: average impact on the objectives and tasks performance and potential impact on the key activities of the organization; the risk assessed as medium, should be counteracted and monitored, can be tolerated only if the costs of counteracting are too high, then the risk should be only monitored, but the decision is made by the process owner
>8	risk event significance is assumed to be very high, which means: in the event of a risk occurrence, it is very difficult or impossible to implement the organization's tasks and goals - very high negative impact on the implementation of the key activities of the organization or the inability to implement them, may cause significant financial losses; the risk is assessed as high, it should be constantly monitored, it cannot be tolerated, it must be immediately counteracted

The main limitation of the used method is a very general risk event assessment based on the three-point scale. This causes that many events receive the same rating, which would mean that the same emphasis should be placed on the so-called management and monitoring activities. For example, two events *VOCs emissions exceeded* and *No staff to complete production plans* achieved the same number of points in every risk assessment parameter (the highest rank in the given analysis). However, taking into account the possible negative consequences, which are defined by the risk managers, in case of the risk event *VOCs emissions exceeded*, one should take into account not only the organizational problems (e.g. failure to implement production plans, no shipments to the customer, stopping the customer's production line) there should be also taken into account environmental issues (environmental pollution, penalties imposed on the organization). Thus, these two risk events should not be quantified in the same way.

Following this, and taking into account the main drawbacks of the conventional FMEA method (investigated also e.g. in [3]), the authors propose fuzzy FMEA implementation in the company's risk management system.

2.2. Fuzzy FMEA implementation

Implementation of fuzzy FMEA model bases on two main steps: choosing a fuzzy membership function and defuzzification of membership function [3,8]. In this research triangular fuzzy numbers (FN) are used. A triangular FN is presented by a triplet $A_z = (a, b, c)$, and its member function is given by:

$$\mu_z(x) = \begin{cases} \frac{x-a}{b-a} & for\ a \le x \le b \\ \frac{c-x}{c-b} & for\ b \le x \le c \end{cases} \quad (1)$$

The FN parameters meaning is straightforward: *a* and *c* are the lower and upper bounds of fuzzy number A_z, respectively, and *b* denotes the modal value of fuzzy number A_z. Based on this, the risk assessment parameters ratings for the case company are presented in **Tables 4-6**.

Table 4 Fuzzy ratings for occurrence of risk event (source: own contribution)

Rating	Probability of occurrence	Fuzzy number
Absolutely Certain (AC)	Risk event is almost inevitable	(9, 10, 10)
Very High (VH)	Risk event is very likely to occur	(8, 9, 10)
High (H)	Repeatable risk event	(7, 8, 9)
Moderate High (MH)	Occasional occurrence of risk event	(6, 7, 8)
Moderate (M)	Rare occurrence of risk event	(5, 6, 7)
Low (L)	Relatively low probability of occurrence	(4, 5, 6)
Very Low (L)	Very low probability of occurrence	(3, 4, 5)
Remote (R)	Risk event is remote	(2, 3, 4)
Very Remote (VR)	Risk event is very remote	(1, 2, 3)
Absolutely Uncertain (AU)	Risk event is almost unlikely	(0, 1, 2)

Table 5 Fuzzy ratings for severity of risk event for an organization (source: own contribution)

Rating	Probability of occurrence	Fuzzy number
Hazardous Without Warning (HWoW)	Very high severity ranking without warning	(9, 10, 10)
Hazardous With Warning (HWW)	Very high severity ranking with warning	(8, 9, 10)
Very High (VH)	System inoperable with very high negative consequences (e.g. cost, time)	(7, 8, 9)
High (H)	System inoperable with high negative consequences (e.g. cost, time)	(6, 7, 8)
Moderate (M)	System inoperable with minor negative consequences (e.g. cost, time)	(5, 6, 7)
Low (L)	System inoperable without noticeable negative consequences (e.g. cost, time)	(4, 5, 6)
Very Low (VL)	System operable with significant interference	(3, 4, 5)
Minor (MR)	System operable with some interference	(2, 3, 4)
Very Minor (VMR)	System operable with minimal interference	(1, 2, 3)
None (N)	No effect	(0, 1, 2)

Table 6 Fuzzy ratings for detection of risk event by a customer (internal/external) (source: own contribution)

Rating	Probability of occurrence	Fuzzy number
Absolutely Uncertain (AU)	No effect for customer	(0, 1, 2)
Very Remote (VR)	Very remote chance to negatively influence a customer	(1, 2, 3)
Remote (R)	Remote chance to negatively influence a customer	(2, 3, 4)
Very Low (L)	Very low chance to negatively influence a customer	(3, 4 ,5)
Low (L)	Low chance to negatively influence a customer	(4, 5, 6)
Moderate (M)	moderate chance to negatively influence a customer	(5, 6, 7)
Moderate High (MH)	Moderately high chance to negatively influence a customer	(6, 7, 8)
High (H)	High chance to negatively influence a customer	(7, 8, 9)
Very High (VH)	Very high chance to negatively influence a customer	(8, 9, 10)
Absolutely Certain (AC)	Almost certainty	(9, 10, 10)

Later, linguistic variables are allocated to each of the factors of risk number by experts. The next step regards fuzzy RPN index calculation based on multiplying the risk factors as fuzzy numbers. To convert a fuzzy number to a concrete value, there are several methods that can be implemented [6,8]. In this research center of gravity method is used [7]. The obtained analysis results are presented in **Table 7**.

Table 7 Risk assessment for the case company operational performance using fuzzy FMEA analysis

Risk event	Risk analysis					
	Probability of occurrence	Severity of risk event for an organization	Detection of risk event by a customer	Fuzzy RPN index	Deffuzified RPN index	**Rank**
The product does not meet the specification	(8, 9, 10)	(4, 5, 6)	(8, 9, 10)	(256, 405, 600)	420.33	**2**
Oil leak into the ground	(2, 3, 4)	(7, 8, 9)	(6, 7, 8)	(84, 168, 288)	180.00	**8**
Aliphatic hydrocarbons emissions exceeded	(1, 2, 3)	(7, 8, 9)	(5, 6, 7)	(35, 96, 189)	106.67	**13**
VOCs (Volatile Organic Compounds) emissions exceeded	(6, 7, 8)	(8, 9, 10)	(5, 6, 7)	(240, 378, 560)	392.67	**3**
NO2, SO2, CO emissions exceeded	(6, 7, 8)	(7, 8, 9)	(5, 6, 7)	(210, 336, 504)	350.00	**5**
Production equipment/plants fire	(1, 2, 3)	(8, 9, 10)	(8, 9, 10)	(64, 162, 300)	175.33	**10**
No staff to complete production plans	(7, 8, 9)	(9, 10, 10)	(9, 10, 10)	(567, 800, 900)	755.67	**1**
Serious, fatal or collective accident	(1, 2, 3)	(7, 8, 9)	(4, 5, 6)	(28, 80, 162)	90.00	**14**
Spare parts not available	(6, 7, 8)	(6, 7, 8)	(5, 6, 7)	(180, 294, 448)	307.33	**6**
No machining tools	(3, 4, 5)	(6, 7, 8)	(5, 6, 7)	(90, 168, 280)	179.33	**9**
Insufficient production support	(7, 8, 9)	(4, 5, 6)	(6, 7, 8)	(168, 280, 432)	293.33	**7**
Incorrect waste management (throwing waste to wrong containers)	(7, 8, 9)	(7, 8, 9)	(1, 2, 3)	(49, 128, 243)	140.00	**11**
No power supply	(6, 7, 8)	(8, 9, 10)	(5, 6, 7)	(240, 378, 560)	392.67	**3**
Local flooding	(1, 2, 3)	(6, 7, 8)	(7, 8, 9)	(42, 112, 216)	123.33	**12**

The obtained results give the possibility to compare both the modeling approaches. In the analysis that bases on the fuzzy FMEA approach the highest ranks are given to the three events: *Serious, fatal or collective accident, Aliphatic hydrocarbons emissions exceeded and Local flooding*. However, based on the conventional approach use, e.g. the local flooding risk index was estimated only to 4 points. This may result from more diverse assessment scales for risk parameters that are now better adjusted to the company's operating conditions.

3. CONCLUSIONS

On the basis of literature research (among others in the fields of practical used risk analysis methods, resilience engineering, supply chain risk management, as well as in the field of quantitative and qualitative analyses using, for example, key evaluation indicators) and case studies from enterprises representing various sectors of the economy, authors will develop a new measure of the level of production process reliability that will take into account the performance results in the main areas of operation and will be consistent with the proposed definition of reliability of the production process, given e.g. in [9]. Thanks to this, managers could use the developed solutions that would adapt flexibly to the needs of the processes they manage.

The development of such a system, taking into account the specificity of the industry and production processes, will be the subject of further research carried out by the authors.

REFERENCES

[1] DĄBROWSKA, A., GIEL, R., PLEWA, M.The Picking Process Model in e-Commerce Industry. In: ZAMOJSKI, W., MAZURKIEWICZ, J., SUGIER, J., WALKOWIAK, T., KACPRZYK, J. (eds). *Engineering in Dependability of Computer Systems and Networks. DepCoS-RELCOMEX 2019. Advances in Intelligent Systems and Computing* 2020, vol 987. Springer, Cham.

[2] KIERZKOWSKI, A., KISIEL, T. Simulation Model of Logistic Support for Functioning of Ground Handling Agent, Taking into Account a Random Time of Aircrafts Arrival. In: *5th International Conference on Military Technologies, ICMT 2015,* Brno, Czech Republic, 19-25 May 2015, doi:10.1109/MILTECHS.2015.7153694.

[3] TUBIS, A. Process assessment of risks in the production company with the use of linguistic variables and the FMEA analysis. In: *Intelligent Systems in Production Engineering and Maintenance - ISPEM 2017: proceedings of the First International Conference on Intelligent Systems in Production Engineering and Maintenance ISPEM 2017*, BURDUK, A., MAZURKIEWICZ, D. (ed.), Springer, 2018, 368-379, https://doi.org/10.1007/978-3-319-64465-3_38.

[4] FRIEDRICH, J., RESTEL, F. A fuzzy approach for evaluation of reconfiguration actions after unwanted events in the railway system. In: *Engineering in dependability of computer systems and networks: proceedings of the Fourteenth International Conference on Dependability of Computer Systems DepCoS-RELCOMEX*, July 1-5, 2019, Brunów, Poland, Springer, 2020, 195-204.

[5] TUBIS, A. 2-dimensional decision space in the risk assessment process in road transport.In: *8th Carpathian Logistics Congress, CLC'2018: conference proceedings*, December 3rd-5th 2018, Prague, Czech Republic. Ostrava: Tanger, cop. 2019, 885-889.

[6] CHANAMOOL, N., NEANNA, T. Fuzzy FMEA application to improve decision-making process in an emergency department. Appplied Soft Computing. 2016. 43, pp. 441-453.

[7] WANG, Y-M., CHIN, K-S., KWAI POON, G. K., YANG, J-B. Risk evaluaiton in failure mode and effects analysis using fuzzy weighted geometric mean. *Expert Systems with Applications*. 2009. 36, pp. 1195-1207.

[8] HAYATI, M., ABROSHAN, M., R. Risk assessment using Fuzzy FMEA (Case Study: Tehran Subway Tunneling Operations). *Indian Journal of Science and Technology*. 2017. vol. 10(9), pp. 1-9.

[9] WERBIŃSKA-WOJCIECHOWSKA, S., CHLEBUS, M. Issues on supply chain reliability measurement - review and a case study. In: *Proceedings of the 29th European Safety and Reliability Conference (ESREL)*, 22-26 September 2019, Hannover. Singapore: Research Publishing Services, 2019, 4188-4196.