EVALUATION OF DISRUPTION RISK IN LARGE SCALE COMPLEX SYSTEMS WITH EXPERT'S KNOWLEDGE

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Abstract

In the times of market-economy, all decision making processes play the key role in managing a company or organization. The more and more complicated level of production, logistics processes and logistics supply chains and networks, the growing competition or budget restrictions are some of the factors forcing the managements of companies to conduct continuous, dynamic and rational planning. Providing the continuity of the supply in logistic chain is a difficult challenge at the present time, with insights into the increasingly difficult to predict global threats such as floods, earthquakes and so on.The objective of this paper is to propose a universal concept of quantitative risk assessment related to the occurrence of different treats and hazards, and resulting in disrupting process continuity on a large scale. This problem is particularly important for the large scale complex systems, for instance, global supply chains.

Keywords: Supply Chain Management Fuzzy Logics; Experts Knowledge

1. INTRODUCTION

Dynamical market situation, growing competition for customers urge businesses to look for newer and more efficient management methods, which are designed to assist in maintaining or winning competitive edge, and sometimes in an organisation's surviving in the market. Contemporary enterprises have to operate in a highly complex, dynamic and competitive environment. In order to survive in such circumstances, they have to monitor the developments in the environment and plan their activity flexibly, but also creatively. Pressure from international organisations, increasing global communications and, quite recently, the technological leap all contribute to growth of international competition. Each enterprise has to continuously improve a customer's satisfaction and look for new ways to reduce its cost of activity. In recent years, logistics has been playing a key role in the rationalisation of operations and processes ongoing at enterprises, as it proposes systemic organisational and technical solutions for processes along the entire chain from suppliers to production, to customers. When the increase in economic performance and maintenance of an enterprise's market position can no longer be supported with production cost reduction, the efficiency of chains and networks, as well as logistics processes may prove a decisive factor of successful competition. 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 is risk at every point, so it's not enough just to focus on the internal threats facing your own enterprise. It's equally critical that you have a handle on vulnerabilities among your suppliers and your distributors - and also in the markets where you find your consumers …" [1]. 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 [2, 3, 4, 5, 10]. Some of these works use artificial intelligence methods such as fuzzy reasoning and artificial neural networks to support decision-making [2, 6, 7, 8, 9]. 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].

2. DISRUPTION RISK CONCEPT

The concept of risk is very broad and covers many areas of human activity, and therefore, it has a social character [12]. In the most general terms, it is understood as a situation involving exposure to danger [13]. In applied sciences, it was adopted at the beginning of the 20th century that the risk is objectively dependent on subjective uncertainty, and a little later F.H. Knight [14] published his uncertainty theory, dividing uncertainty into measurable one (i.e. risk), and non-measurable one (uncertainty sensu stricto). Based on these assumptions, in the following years a number of definitions of the concept of risk and their modifications appeared and were successfully used to model risk when making decisions in specific areas of activity.

The object of our interest is the operational risk occurring in the large scale complex systems, such as global supply chains. One of the major operational problems in these systems is risk of loss of business continuity. We define the continuity as a system capability to deliver products and/or services at acceptable predefined performance level under the real work conditions. The continuity can be interrupted by disruptive events such as system failures, natural catastrophes and man-made faults. This type of risk is called disruption risk [15].

The search for an universal definition of disruption risk can be based on the works of T. Aven [16, 17, 18], where he proposes a critical review of the literature on risk and a classification of the definition of risk, dividing these definitions into 9 groups.

- Risk = expected value (loss)
- Risk = probability of an undesirable event
- Risk = objective uncertainty
- Risk = uncertainty
- Risk = potential (possibility) of a loss
- Risk = probability and scenarios of consequences
- Risk = event or consequence
- Risk = consequences/damage/severity of these uncertainty
- Risk = effect of uncertainty on objectives

Based on the above discussions and taking into account the current possibilities of modelling uncertainty, the following definitions of disruption risk are proposed, from both the quantitative and qualitative perspective:

Disruption risk - potential for realization of unwanted scenario leading to a disruptive event with possibility of negative consequences.

$$RD = (\{si\}, \{pi\}, \{ci\}) \qquad \text{for } i = 1, 2, 3, \ldots, n \qquad (1)$$

Disruptive risk metric - the triplet (si, pi, ci), where {si} is the i-th unwanted disruption scenario, {pi} is the uncertainty metric (probability or possibility) of that scenario, and {ci} is the consequence of the i-th scenario, for i = 1, 2, 3, …. n.

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. A free hand in choose of suppliers means that the currently exist supply chain or supply network has a complex structure. Therefore they are exposed to unpredictable or difficult predictable factors such as natural disasters, terrorist attacks, etc. These types of events and their incidence are difficult to estimate by statistical methods. The expert estimate of risk as a probability of occurrence of this type of event was proposed in the work and universal algorithm of quantitative risk assessment related to the occurrence of different treats and hazards, and resulting in disrupting process continuity on a large scale. This problem is particularly important for the large scale complex systems, for instance, global supply chains [19, 20, 21].

The disruption risk evaluation of a whole investigated complex system is a process that can be represented in the form of the general algorithm (**Figure 1**) implemented in seven steps [21].

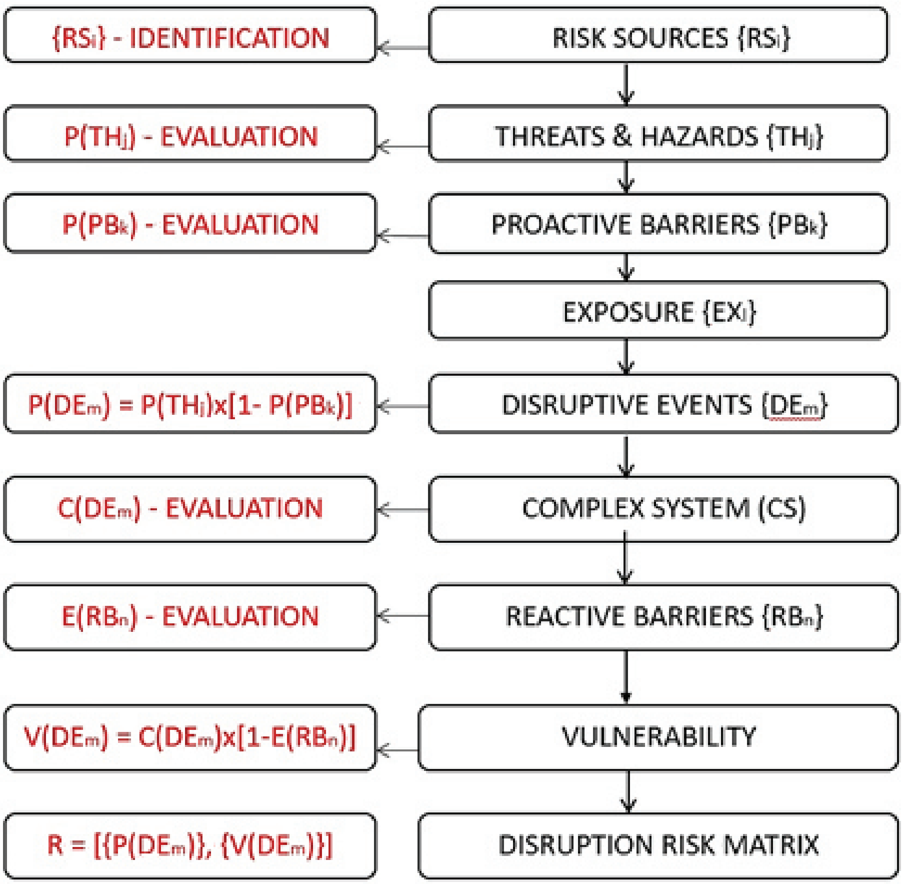

Figure 1 Algorithm of the framework for evaluation of complex system disruption risk [21].

Step 1 - Expert, or a group of experts selects potential sources of risk {RSi},

Step 2 - The set {RSi} is the basis for generating a set of threats and hazards {THj}, which actually may occur within the analysed system. Experts estimate the probability of occur of each event.

A properly designed complex system, should be equipped with a security subsystem consisting of a number of proactive barriers {PBk}, which are designed to prevent direct exposure of the system to a loss of its ability to perform the function.

Step 3 - Assess by the experts the effectiveness of barriers in case of each of the potential threats and hazards - P(PBk).

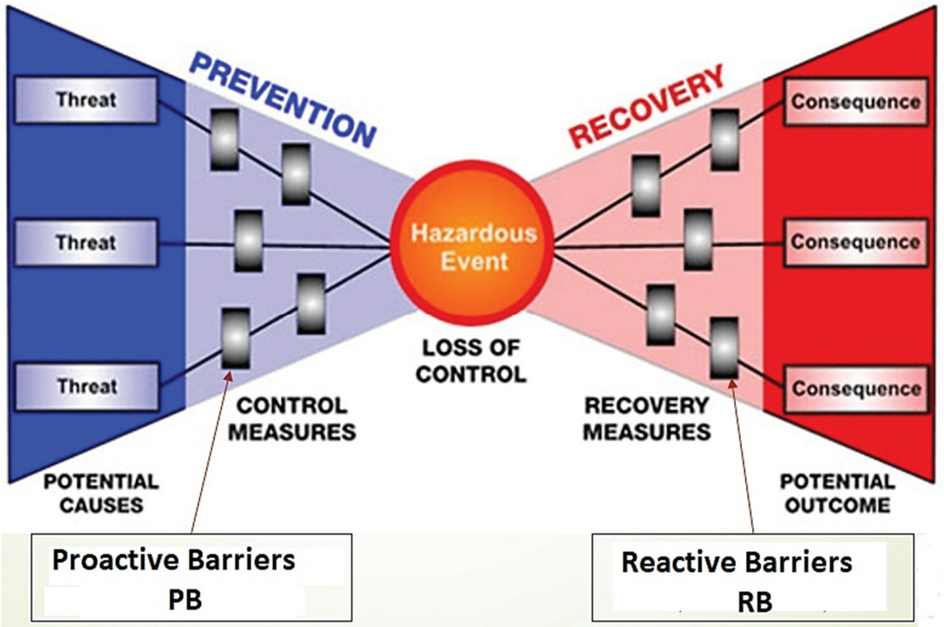

Figure 2 Bow tie diagram [22]

These risks, which are not effectively blocked by proactive barriers (left part of **Figure 2**), become direct system exposures {EXl} and are defined as the initiating events that can interrupt the continuity of process {DEm} (disruptive events).

Step 4 - lose control of the system (middle part of **Figure 2**). To these events we should prescribe the measures of uncertainty of their occurrence, e.g. in the form of probabilities {P(DEm)}.

Step 5 - The next stage of the process is a comprehensive evaluation of resilience of the system to the exposure (resilience - ability of a system to absorb and withstand the disruption impact, and still continue to deliver products and/or services at acceptable predefined performance level). The estimation of the susceptibility of the analysed system to individual exposure and the prediction of the effects of events {DEm} in the form of losses caused by these events {C(DEm)} (consequences).

Step 6 - The next step is to assess the effectiveness of reactive barriers {E(RBn)} (safety subsystem), which are designed to protect the complex system and its environment against the effects of disruptive events. Then, we can evaluate the vulnerability of the entire complex system to the particular disruptive events - {V(DEm)}.

Step 7 - The final step of the proposed procedure is to assess the overall risk of a disruption, taking into consideration all possible scenarios {si} and their consequences {cl}. The entire disruption risk will be expressed as a m-dimensional vector R = [{P(DEm)}, {V(DEm)}], where m is the number of a possible disruptive scenarios.

In above procedure steps we suggest use of expert knowledge for the evaluation of numerical indicators Xi (e.g. P(.), C(.) and E(.)). For evaluation of each parameters we suggest use not a crisp numbers but fuzzy numbers. For example the team of experts evaluated each of the parameters by the three numbers corresponding to the maximum value, the most likely value and the minimum 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 fuzzy sets theory introduced by Zadeh in 1965 [23] is suitable for expressing uncertainty and subjective judgments in estimating probability using less precise formulations: high risk, low probability, significant impact.

These formulas can be defined mathematically and are subjected to arithmetic and logical operations. Below we presents the basic fuzzy operations that can be used in evaluation of risk procedure.

The fuzzy set A in the space X is defined by the membership function μ_A (x) assigning each element x in the space X a real value from the interval [0, 1].

The fuzzy number is called the fuzzy set A = {x, μ_A (x)}, where x∈R and μ_A: R → [0, 1] and the membership function has the following properties:

- is a continuous mapping;
- assumes the constant value μ_A (x) = 0 ∀x∈ (-∞, a) and ∀x∈ (d, ∞);
- is a function strictly increasing for x ∈ [a, b];
- assumes the constant value μ_A (x) = 1 ∀x∈ [b, c];
- is a strictly decreasing function for x ∈ [c, d];

where a, b, c, d are real numbers.

For fuzzy numbers representing the probability P, x belongs to the interval [0, 1] (X = [0, 1]).

Trapezoidal fuzzy number A is a fuzzy number A = (a, b, c, d), whose membership function is described by the relation:

$$\mu_A(x) = \begin{cases} \frac{(x-a)}{(b-a)} & a \le x \le b \\ 1 & b \le x \le c \\ \frac{(d-x)}{(d-c)} & c \le x \le d \\ 0 & x < a \; lub \; x > d \end{cases}, \tag{2}$$

where a, b, c, d are real numbers such that a <b <c <d. The trapezoidal function of belonging is a generalization of the triangular function for which b = c can also represent the interval and the singleton number.

The arithmetic operations of two trapezoidal fuzzy numbers can be represented by formulas [23]:

1. Add

$$A_1 \oplus A_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2) \tag{3}$$

2. Subtract

$$A_1 \Theta A_2 = (a_1 - d_2, b_1 - c_2, c_1 - b_2, d_1 - a_2) \tag{4}$$

3. Multiply

$$A_1 \otimes A_2 \approx (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2, d_1 \times d_2) \tag{5}$$

4. Divide

$$A_1 \emptyset A_2 \approx (a_1/d_2, b_1/c_2, c_1/b_2, d_1/a_2) \tag{6}$$

The result of adding and subtracting two trapezoidal numbers is also a trapezoid number, while the result of multiplying and dividing two trapezoidal numbers is only approximately trapezoidal number.

The concept of α-cuts [25] is used to determine the membership function for multiplication and division operations. Let A^α denote the α-cut of the set A being a closed compartment:

$$A^\alpha = \{x | \mu(x) \ge \alpha, 0 \le \alpha \le 1\}, A^\alpha = [A_l^\alpha, A_r^\alpha] \tag{7}$$

Multiplying and dividing two sections $[{A_1}_l^\alpha, {A_1}_r^\alpha]$ i $[{A_2}_l^\alpha, {A_2}_r^\alpha]$ is defined by [24]:

$$(A_1 \times A_2)^\alpha = [{A_1}_l^\alpha \times {A_2}_l^\alpha, {A_1}_r^\alpha \times {A_2}_r^\alpha] \tag{8}$$

$$(A \div B)^\alpha = [{A_1}_l^\alpha / {A_2}_r^\alpha, {A_1}_r^\alpha / {A_2}_l^\alpha] \tag{9}$$

The fuzzy set can be represented by α-cuts as:

$$A = \bigcup_{\alpha\in[0,1]} \alpha A^{\alpha}(x) \quad (10)$$

where U is the sum of fuzzy sets, and αA^{α} is a special fuzzy set with the membership function such that: $\mu_{\alpha A^{\alpha}}(x) = \begin{cases} \alpha & \text{for } x \in A^{\alpha} \\ 0 & \text{for others } x \end{cases}$

Based on the concept of α-cuts, the multiplication and division of fuzzy numbers is defined as::

$$A_1 \otimes A_2 = \bigcup_{\alpha\in[0,1]} \alpha(A \times B)^{\alpha}(x) \quad (11)$$

$$A_1 \emptyset A_2 = \bigcup_{\alpha\in[0,1]} \alpha(A/B)^{\alpha}(x) \quad (12)$$

The use of fuzzy sets in expert evaluation allows more option in assessing of the probabilities. Determining the probability as a precise number could be a problem for experts, but application of fuzziness should help in the estimation of individual probabilities. An example of the application of the presented procedure with the use of fuzzy sets with triangular membership functions to the estimation of probability done by three experts can be found in work [21], and the framework for the risk and resilience analysis of steel mill logistic supplying systems can be found in work [25].

3. CONCLUSION

The concept of risk is very broad and covers many areas of human activity. The object of our interest is the operational risk occurring in the large scale complex systems, such as global supply chains. One of the major operational problems in these systems is risk of loss of business continuity. We define the continuity as a system capability to deliver products and/or services at acceptable predefined performance level under the real work conditions. The continuity can be interrupted by disruptive events such as system failures, natural catastrophes and man-made faults. There are many ways to assess the incidence of this type of threat. In the paper we propose the use of probability as a measure of risk assessment and use expert's assessments. Also we propose the use of fuzzy sets for probability estimation and calculation. This type of approach will help the analysis of imprecise expert's assessments, which we should take into consideration when we want analyze complex systems such as global supply chains.

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