INTRODUCTION

Risk exists in all companies. In a business environment which is characterized by high complexity and uncertainty, all companies are forced to manage their supply chains effectively in order to increase efficiency and reactivity [41]. Supply chain (SC) can be defined as the network of organisations that are involved through upstream and downstream relationships in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer [5]. The goal for all involved organisations is to provide the ultimate customer with the right product and the right time, the right volume and place [9, 33]. The emergence of the extended manufacturing enterprise, a globally dispersed collection of strategically aligned operations, has brought new attention to how organizations coordinate the flow of materials, information, money and knowledge across their supply chains. Recent trends in global production have both increased supply chain complexity and reinforced the notion that logistics strategies and practices are essential elements of business strategy. [35]. The area of supply chain risk management (SCRM) has recently received vast attention in the discipline. Supply chain risk management is very important because of problems such as supplier losses or quality problems. Additionally catastrophes such hurricane Katrina, or the Tsunami have raised the attention on this issue [41].

The paper treats about risk management in supply chain. The shortcomings of current supply chain risk management processes, tools and techniques, are identified and the case for the application of supply chain risk management especially an approach to supply chain risk identification and assessment is made. The authors propose a hierarchical-risk breakdown structure and an approach to risk management aided decision makers in risk assessment of supply chain process. The approach dedicated to supply chain risk assessment base on fuzzy sets and can be easily used to supply chain risk management.

1. RISK DEFINITION

The concept of risk has been extensively studied in various business contexts in many papers by many researchers. We present two notable studies providing insights to the meaning of risk. One of them is developed by Baird and Thomas [1]. These researchers have defined risk from eight different perspectives. Their arguments incorporate views from finance, marketing, management, strategy, and psychology. Table 1 presents the eight risk definitions and a brief description of each. The first three definitions – variability of returns, variance, and market risk – focus on the organization’s financial return. The last two definitions of risk as disaster and as accounting risk measures relate to the risk of a company going bankrupt. These definitions of risk provide evidence that risk is a multi-dimensional construct and differs according to business function [45].

Another approach to risk issue is done by Shapira [21]. An often-cited definition of risk in literature is “the variance of the probability distribution of outcomes”. However, Shapira found that very few managers define risk in those terms. Instead, managers identify (1) the downside of risk, (2) its magnitude of possible losses, (3) the act of risk taking involving the use of skills, judgment and control, and (4) risk as a concept that cannot be captured with a single number. A list of these four risk aspects and brief definitions is also presented in tab. 2. These findings also suggest that the term “risk” can be perceived in different ways, and no single definition of risk may be appropriate in all circumstances.
Tab. 1. The risk characteristics and definition by Baird and Thomas. Source [45]

<table>
<thead>
<tr>
<th>Risks characteristics</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variability of returns</td>
<td>Firm performance evaluated in terms of return and growth criteria</td>
</tr>
<tr>
<td>Variance</td>
<td>Variability of the probability distribution of returns</td>
</tr>
<tr>
<td>Market risk</td>
<td>The use of the capital asset pricing model to measure risk</td>
</tr>
<tr>
<td>Risk as innovation</td>
<td>Risk conditions equated with conditions characterized by newness, uncertainty, and lack of information</td>
</tr>
<tr>
<td>Risk as lack of information</td>
<td>Information scarcity as a key facet of uncertainty in terms of the existence of important resources and commitment duration</td>
</tr>
<tr>
<td>Risk as entrepreneurship</td>
<td>Independence of action in venturing into the unknown</td>
</tr>
<tr>
<td>Risk as disaster</td>
<td>Strategies that could result in corporate disaster, bankruptcy or ruin</td>
</tr>
<tr>
<td>Accounting risk measures</td>
<td>Accounting ratios related to risk of ruin, default or bankruptcy</td>
</tr>
</tbody>
</table>

Tab. 2. The risk characteristics and definition by Shapira. Source: [21]

<table>
<thead>
<tr>
<th>Risks characteristics</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downside of risk</td>
<td>Risk being associated with a negative outcome</td>
</tr>
<tr>
<td>Magnitude of possible losses compared to its probabilities</td>
<td>At least one possible outcome of an uncertain situation having a bad outcome</td>
</tr>
<tr>
<td>Distinction between risk taking and gambling</td>
<td>Risk taking is associated with using skills, judgment, and control, while gambling is not</td>
</tr>
<tr>
<td>Risk as a multi-faceted construct</td>
<td>Risk cannot be captured with a single number, since multiple facets such as financial, technical, marketing, production and other risk aspects exist</td>
</tr>
</tbody>
</table>

2. CHARACTERISTIC OF SUPPLY CHAIN RISK MANAGEMENT

Supply chain management (SCM) is a business term that has emerged in the last few decades and has been gaining in popularity ever since [2]. The objective of supply chain management is the strategic and operative planning and controlling of materials and service flows, including the associated information and money flows along the entire supply chain. In supply chain management, not only the first tier suppliers, but also second and third tier suppliers, along with the second and third tier customers-up to the final consumer—all have to be integrated [4] (fig. 1).

![Fig. 1. An example of designed strategic supply chain network. Source [42]](image-url)
Company growth and development gathered in supply chain are based on the introduction of intermittent, major changes, typically initiated by external and internal risks [31]. Risk is the potential for complications and problems with respect to completion of a company task and the achievement of a company goal. Risk is inherent in all tasks undertaken by companies, as such it can never be fully eliminated, although can be effectively management to mitigate the impacts to the achievement of companies goals [23]. We can find in the literature another definitions of risk such as “the exposure to the possibility of economic or financial loss or gain, physical damage or injury, or delay, as a consequence of uncertainty associated with pursuing a particular course of action” [25], “a barrier to success” [14]. Recent research of risk management tens to emphasize the two-edged nature of risk. The risk can be treated as “a threat and challenge” [11], “the chance of something happening that will have an impact on objectives; may have a positive or negative impact” [32], “combination of the probability or frequency of occurrence of a defined threat or opportunity and the magnitude of the consequences of the occurrence” [22]. This in turn has provoked vigorous debate among the community of risk practitioners, with individuals and groups taking and defending strong opposing positions. The issue is whether the term risk should encompass both opportunities and threats, or whether risk is exclusively negative with opportunity being qualitatively distinct [15].

Generally, risk management is described as the identification and analysis of risks as well as their control. A main particularity of Supply Chain Risk Management (SCRM) contrary to traditional risk management is that it is characterized by a cross-company orientation aiming at the identification and reduction of risks not only on the company level, but rather focusing on entire supply chains [41]. Numerous papers demonstrate the importance of managing supply chain risks. One of the major characteristics of supply chains is their high level of risk. In practice, it means that too many undesirable events may cause delivery delays, unsatisfactory customer service level, high stocks level, and another failures in the supply chain. Suppliers are expected to reduce manufacturing firms supply chain risks by minimizing supply failures and by resolving supply problems, even those ones resulting from firm’s actions. Integration mechanism may enhance interaction and collaboration in the firm supply chain, especially in the buyer-supplier interface, to reach these goals [29]. The changes in the global market have inevitably increased the importance of supply chain risk management. Nature disaster, terrorist attack, labor strike, accidents can all be causes for supply chain disruption and delay [40].

Tang and Musa presented an overview of literature survey relevant to supply chain risk management. Based on the literature survey we can say that main issues discussed during the year 1995 until 1999 included financial risk management and operations strategies such as adoption of lean concept and early supplier involvement. The number of papers in area of supply chain risk management slowly increased between year 2000 and 2003. Main issues vary from operation plans to relationship of supply chain partners. In the same time period, the authors of survey noted the emerging of studies on information technology and information flow. Meantime, Tang and Musa noted a rising discussion on globalization risk associating with political and cultural practices. A dramatic increase of publications relevant to supply chain risk management started in 2004 [40].

Based on developed definition by March and Shapira [20] Gaonkar and Viswandaham we can define supply chain risks as distribution of the loss resulting from the variation in possible supply chain outcomes, their likelihood, and their subjective values [12]. Jüttner, Peck and Christopher define supply chain risks relative to the integrity of the flow of the supply chain and conceive them accordingly, “...any risks for the information, material and product flows from original supplier to the delivery of the final product for the end user” [16]. Tang and Musa follow the supply chain risk management definition from [39]. The definition should refer to (i) events with small probability but may occur abruptly and (ii) these events bring substantial negative consequences to the system. The management of these events through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity can be named supply chain risk management [38, 40].

Christopher and Peck [6] distinguished risks in supply chain. They proposed external and internal supply chain risks. In terms of internal supply chain risks, cross-company-based risks and internal company risks can be differ-entiated. Internal company risks deal with disruptions caused by problems
within the organizational boundaries of the company such as machine breaks downs or IT problems, human resource absence. These risks can be influenced by a company directly. In the context of cross-company-based supply chain risks it can be distinguished between purchasing risks and demand risks. Purchasing risks are concerned with “upstream” activities in the supply chain. Here, companies are faced with the risks related to suppliers, e.g. quality problems of delivered parts. Furthermore, the financial instability of a supplier can lead to its insolvency and therefore can result in the total loss of a supplier. Technological changes or innovation in terms of the product design might over strain a supplier’s capabilities and therefore lead to disturbances at the supply site. Demand risks are based on “downstream” activities in the supply chain. These risks can be related to the distribution of products or can be based on uncertainties in terms of demand forecasts which might result in delivery bottlenecks, high inventories, or in efficient capacity utilization. Finally, external supply chain risks deal with environmental causes that can barely be influenced and lead directly or indirectly to disturbances within the supply chain. They can be caused by sociopolitical, economical, technological or geographical reasons. Examples are earthquakes or hurricanes as well as terrorist attacks or political instabilities [6, 40].

3. APPROACHES IN SUPPLY CHAIN RISK MANAGEMENT

The current literature on risk management consists of empirical researches on risk management of project in the construction industry, supply chain and conceptual and applied frameworks of risk management using various models and methods [7]. There are many perspectives and views on risk management. Risk management is the systematic process of identifying, analyzing and responding to supply chain risk, or to enterprise risk, or to supply chain risk. The main aims of risk management is to identify and assess risk in the given project, or in given enterprise, or in given supply chain.

Within the last decade supply chain risk management emerges as one of very important tools within supply chain management. The reason is admittedly the increased vulnerability of today's, global supply chains [16, 24, 34, 30, 26], continuously growing variety of threats resulting in supply chain disruptions [17, 13, 19, 38] but also development and practice of business strategies resulting in new or increased risk [39] as a result of enhanced demand for solutions aiming in greater resilience, agility and competitiveness of supply networks [17, 6, 37, 28]. A more comprehensive review of the wide spectrum of supply chain risk management problems represented in the literature may be found in the publications of [36, 18] and others.

The current literature in the field of risk management incorporates four core steps in the process of risk management. These are [30]:
1. Risk identification and classification.
2. Risk assessment.
3. Risk response.
4. Risk monitoring.

The first step in process of risk management is risk identification and classification. In the phase all of potential risks sources are identified. All potential risk factors are determined which may affect the enterprise, supply chain, respectively. The characteristics of risks sources, risks factors are documented. A large number of techniques exist for risk identification. In order to determine the potential risks of the supply chain the brainstorming and workshops, checklist and prompt lists, questionnaires and interviews, Delphi groups or nominal group technique (NGT), and various diagramming approaches such as cause-effect diagrams, systems dynamics, influence diagrams are used [22]. There is no single “best method” for risk identification of supply chain, an appropriate combination for techniques should be used for risk identification of supply chain.

We propose a risk identification method based on Breakdown Supply Chain Structure. Potential risks are grouped in Risk Supply Chain Breakdown Structure (RSCBS) in order to easy study potential risks in the different levels of considered supply chain. Some of risks will be immediately identifiable, others may be less recognizable. This stage is handled by experts, persons that can have knowledge about process of the given supply chain. In order to identify the supply chain risk it is
suggested that experts take part in the process. Experts’s opinions may be useful in determining each risk sources and factors of supply chain. On the basis of their knowledge and experience, the experts define respectively: risk, risk source, risk factors. The relations between risk – risk source and risk factor is presented in fig. 2. Risk can be defined as the potential for complications and problems with respect to the completion of an activity in supply chain and the achievement of a given supply chain goal. The aim of identifying the risk source is to prevent the events that can go wrong and lead to breaches of safety.

We assume, each activity in the Supply Chain Breakdown Structure is affected by numerous factors including suppliers, weather, human errors, manufacturers, machines etc. Risk factors are events, which can occur with a certain probability, and will impact on the supply chain. Because an activity can be affected by many different risks, all potential risks (R) and their sources (RS) with identified factors (RF) are described and linked with the appropriate activity in Supply Chain Breakdown Structure. Based on the main ideas from [3] the risk assessment approach can be built up as a hierarchical system, like RSCBS. The risk factors are sorted into m risk sources on the basis of the types of an activity risk. All the potential risks factors and their consequences on activities of the supply chain are developed (fig. 3).

In this approach we define the set of risk, risk sources and risk factors. The following input data are developed:

- identifying risks (R_i, i = 1, 2, ..., K) – level 1,
- identifying risk sources (RS_i, i = 1, 2, ..., M) – level 2,
- identitying risk factors (RF_i, i = 1, 2, ..., P) – level 3.

The risk factors are grouped to the risk sources. They affected an activity in the Supply Chain Breakdown Structure.

![Fig. 2. The relation risk-risk source-risk factor. Source: own elaboration](image)

Risk assessment is the second phase of the risk management. It is a complex subject shrouded in vagueness and uncertainty. Vague terms are unavoidable since individuals often find it easier to describe risks in qualitative linguistic terms [3]. The main goal of risk assessment is to measure the impact of the identified risks on the given supply chain. The risk assessment is a process of prioritizing risks for further analysis by assessing and combining, generally, their probability of occurrence and impact [23]. The following methods are used in risk assessment: Fault Tree Analysis, Event Tree Analysis, Monte Carlo Analysis, Scenario Planning, Sensitivity Analysis, Failure Mode and Effects Analysis, Expected Monetary Value, Expected Net Present Value, Decision Tree, Program Evaluation and Review Technique (PERT), and fuzzy sets theory [10]. Identified risks are assessed to determine their likelihood and potential effect on objectives, allowing risks to be prioritized for further attention [44]. The primary technique for risk assessment is the Probability-Impact Matrix, where the probability and impacts of each risk are assessed against defined scales, and plotted on two-dimensional grid. Position on the matrix represents the relative significance of the risk, and very high/high/medium/low/very low zones may be defined, allowing risks to be ranked. This kind of technique can be used for assessing threats and opportunities, although it is hard to visualize how
A single Probability-Impact Matrix can clearly show both, since the “Impact” scale would need to reflect both positive and negative effects of risks on objectives of supply chain. One modification of the double Probability-Impact Matrix might be useful, involving rotating the opportunity half as shown in fig. 4. This kind of matrix allows key threats and opportunities to be visualized by focusing on the so-called “Arrow of Attention” [15].

The next stage is evaluation and the measure of the identified risks. Because, it may be extremely difficult to assess the risks associated with a supply chain due to the great uncertainty involved, we propose using fuzzy sets theory. Fuzzy sets theory is a branch of modern mathematics used to model the vagueness intrinsic to human cognitive processes [10]. The fuzzy sets theory was first proposed by Lukasiewicz in 1920s in an attempt to produce systems which were able to represent a range of truth values covering all real numbers from 0 to 1. Zadeh [43] extended the work on possibility theory into a formal system of mathematical logic for representing and manipulating “fuzzy” term, called fuzzy logic [3].

According to fuzzy sets theory we can define a fuzzy set. A fuzzy set $\tilde{a}$ in a universe of discourse $x$ is defined by a membership function $\mu_\tilde{a}(x)$ which associates with each element $x$ in $X$, a real number in the interval $[0,1]$. The function value $\mu_\tilde{a}(x)$ is termed the grade of membership of $x$ in $\tilde{a}$ [10, 23, 43]. When $\mu_\tilde{a}(x)$ is large, its grade of membership of $x$ in $\tilde{a}$ is strong [23].
The relations between risk factors, risk sources and risks and their consequences are represented as fuzzy sets. The risk assessment is viewed as process based on principles of fuzzy logic decision making system.

The experts, members of risk assessment group, are required to provide their judgement on the basis of their knowledge and personal experience in order to assess the supply chain risks. Because of the complex character of the supply chain executing in the uncertainty environment the judgement of the experts can be inexact, imprecise. It is very difficult to estimate the supply chain risk with an exact numerical crisp value. The experts judgment can be expressed with linguistic terms represented by fuzzy sets.

In this paper, for practicality and ease of the supply chain risk assessment, triangular and trapezoidal fuzzy sets for the estimations are proposed. Membership functions are developed using experts’s knowledge and experience.

The supply chain risk is driven on Supply Chain Risk Breakdown Structure. The experts are required to identify and assess the risks associated with the each element of SCRBS. The input data of each risk factor, by which the risks associated with a supply chain activity are assessed. The risk assessment requires calculations of two components of risk: the probability (RP), the impact (RI). In the stage experts definite the important parameters of risk. The probability and impact of the risk factors are defined using linguistics terms. Linguistic variables play an important role in the risk assessment approach. The risk probability indicates the likelihood that each type of risk will occur. The probability for each risk factors is estimated based on the proposed scale. An example of linguistic scale dedicated for expressing probability of risk factor occur is presented in tab. 3.

<table>
<thead>
<tr>
<th>Linguistic variable</th>
<th>Scale</th>
<th>Fuzzy scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>VL</td>
<td>(0, 0, 0.1, 0.3)</td>
</tr>
<tr>
<td>Low</td>
<td>L</td>
<td>(0.1, 0.3, 0.5)</td>
</tr>
<tr>
<td>Medium</td>
<td>M</td>
<td>(0.3, 0.5, 0.7)</td>
</tr>
<tr>
<td>High</td>
<td>H</td>
<td>(0.5, 0.7, 0.9)</td>
</tr>
<tr>
<td>Very High</td>
<td>VH</td>
<td>(0.7, 0.9, 1, 1)</td>
</tr>
</tbody>
</table>

The impact of the risks factors depicts potential effect on the supply chain objectives, i.e. cost, time, scope. We selected to use the following fuzzy sets to fuzzify the input variable impact of the risk factors: Very Low (VL), Low (L), Medium (M), High (H), Very High (VH). The linguistic performance scale is described in Tab. 4. The membership functions are shown in fig. 5.

The linguistics terms are transformed into appropriate fuzzy sets by experts. The values correspond to fuzzy numbers on the proposed numeric scale 0–1. In this phase the fuzzy sets and membership functions for each variables are developed by the experts. The linguistics scale is described in tab. 3. The input data are transformed into several membership grades by membership functions. In the paper, the trapezoidal and triangular membership function is adopted. Figure 5 presents five membership functions of probability and impact.

<table>
<thead>
<tr>
<th>Linguistic variable</th>
<th>Scale</th>
<th>Fuzzy scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>VL</td>
<td>(0, 0, 1, 3)</td>
</tr>
<tr>
<td>Low</td>
<td>L</td>
<td>(1, 3, 5)</td>
</tr>
<tr>
<td>Medium</td>
<td>M</td>
<td>(3, 5, 7)</td>
</tr>
<tr>
<td>High</td>
<td>H</td>
<td>(5, 7, 9)</td>
</tr>
<tr>
<td>Very High</td>
<td>VH</td>
<td>(7, 9, 10, 10)</td>
</tr>
</tbody>
</table>
The risk level is determined by the “IF-THEN” rules. In the first step the risk level of risk sources is estimated based on single fuzzy rule “IF-THEN”. In the case when more than one risk factor is detected in PRBS the fuzzy logic intersection operator (t-norm) is used to join the fuzzy sets, thus [43]:

\[
\mu_{A \cap B}(x) = \mu_A(x) \land \mu_B(x) = \min(\mu_A(x), \mu_B(x))
\]

Fuzzy rules are implemented with AND operator. The total risk level of a supply chain is assessment based on fuzzy rules with AND operator.

The relations between input parameters (i.e. risk probability, risk impact) and output parameter (i.e. risk level) are defined by experts (fig. 5, fig. 6). The decision rules are determined as a set of fuzzy rules. The experience and expert’s knowledge is used for development of “IF-THEN” rules (tab. 5). The risk level (RL) is determined by risk probability and impact. In order to determine risk level the set of rules is performed. The table presents the relations between risk probability, impact and risk level. Some examples of these IF-THEN rules are presented below:

**IF** risk impact is **H AND** risk probability is **H THEN** risk level is **H**

**IF** risk impact is **M AND** risk probability is **H THEN** risk level is **H**

**IF** risk impact is **L AND** risk probability is **M THEN** risk level is **M**

![Fig. 5. The membership functions of the linguistics impact scale. Source: own elaboration](image)

The evaluation of a fuzzy rule is based on computing the truth value of its antecedent and applying it to its consequent. This results in assigning one fuzzy subset to each output variable true. In Min Interferencing where parts of fuzzy rules are labelled with AND logical operation then the fuzzy AND is obtained as the minimum of the membership values of the input variables’ membership values.

**Tab. 5.** The set of rules to determine risk level. Source: own elaboration

<table>
<thead>
<tr>
<th>Risk impact</th>
<th>VH</th>
<th>M</th>
<th>H</th>
<th>H</th>
<th>VH</th>
<th>VH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>VH</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>VL</td>
<td>VL</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk level</th>
<th>VL</th>
<th>L</th>
<th>M</th>
<th>H</th>
<th>VH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk probability</td>
<td>VH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tab. 6. Linguistic terms of risk level. Source: own elaboration

<table>
<thead>
<tr>
<th>Risk level</th>
<th>Description</th>
<th>Fuzzy scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>VL</td>
<td>Very low</td>
<td>(0, 0, 0.2, 0.35)</td>
</tr>
<tr>
<td>L</td>
<td>Low risk</td>
<td>(0.2, 0.35, 0.5)</td>
</tr>
<tr>
<td>M</td>
<td>Medium risk</td>
<td>(0.35, 0.5, 0.65)</td>
</tr>
<tr>
<td>H</td>
<td>High risk</td>
<td>(0.5, 0.65, 0.8)</td>
</tr>
<tr>
<td>VH</td>
<td>Vey high</td>
<td>(0.65, 0.8, 1, 1)</td>
</tr>
</tbody>
</table>

Fig. 6. Fuzzy membership triangular and trapezoidal functions of risk level. Source: own elaboration

The last phase of the approach is defuzzification process. In order to make the calculated fuzzy values useful the fuzzy result (i.e. fuzzy level of risk) should be converted into an exact numerical value (i.e. crisp value) that can adequately represent it. In the paper, the defuzzification process is driven on the center of gravity method [8]:

\[ y^* = \frac{\sum_{i=1}^{m} y_i \cdot \mu_i}{\sum_{i=1}^{m} \mu_i} \]  

where:
- \( y^* \) – defuzzified value,
- \( y_i \) – \( i \)-th value of output variable,
- \( \mu_i \) – value of obtained membership function for \( i \)-th value of output variable,
- \( m \) – a number of discrete values of output variable.

Risk response is the next phase of risk management. The aim of the phase is to develop options and actions to enhance opportunities and to reduce threats to the given supply chain objectives. Risk responses are usually grouped according to their intended effect on the risk being treated. It is common to use for such groupings, or risk strategies [15]:

1. Avoid – seeking to eliminate the uncertainty by making it impossible for risk to occur (i.e. reduce probability to zero), or by executing the project/supply chain in a different way which will achieve the same objectives but which insulates the supply chain from the effect of the risk (i.e. reduce impact to zero).
2. Transfer – identifying another stakeholder better able to manage the risk, to whom the liability and responsibility for action can be passed.
3. Mitigate – reducing the size of the risk in order to make it more acceptable to the supply chain, by reducing the probability and/or the impact.

Based on previous phase of risk management we obtain information of risk ranking. We identify and assessment and then prioritize risks of a given supply chain. We can classify all potential risks on the probability-impact matrix. The fig. 7 presents a general matrix dedicated to risk classification.

![Probability-Impact Matrix](image)

**Fig. 7.** The probability-impact matrix. Source: own elaboration

Risk monitoring and control on the supply chain are the last phases of the risk management process. It can be described as the process of implementing a risk response plan, tracking identified risks, monitoring residual risks, identifying new risks, and evaluating the risks process effectiveness throughout the supply chain [23].

**SUMMARY**

Pfohl and Köhler [26] defined a set of 17 Supply Chain Risk Management principles as below:

1. The focus of risk management is across company boundaries and on the supply chain.
2. The company has a thorough knowledge of all interfaces within the supply chain.
3. Supply Chain Management and Supply Chain Risk Management are seen integrated and not independent on each other.
4. Internal risk management and Supply Chain Risk Management are coordinated and integrated.
5. Supply Chain Risk Management is part of the corporate strategy.
6. Top management supports Supply Chain Risk Management and is responsible for it.
7. All actors within the supply chain have a mutual comprehension of potential risks.
8. Risk information in the supply chain is available for a company.
9. Supply chain companies have a close, cooperative, and fair relationship.
10. Supply chain companies mutually trust strongly.
11. Information asymmetries between companies do not exist.
12. Companies have mutual goals and planning processes for the supply chain.
13. Risk information is exchanged in the supply chain.
14. Direct supply chain partners cooperate with regard to risk management.
15. Risks as well as rewards of risk management are achieved and shared together.
16. All actors of the supply chain (from suppliers to customers, from employees to top management) are involved in risk management activities.
17. All actors of the supply chain aim at the same goals with regard to Supply Chain Risk Management.
Supply chains tend to increase in complexity, as the previous discussion showed. The fact that numerous suppliers, service providers, and end consumers may be involved in a network of relationships causes risks and vulnerability for everyone. It is not sufficient to just analyse the risks with regard to one focal company, but potential domino effects upon all partners and relations have to be examined.

Companies in the supply chain differ in risk attendance and risk acceptance level. It is therefore necessary to aim for mutual goal setting and planning across the entire supply chain network. With regard to Supply Chain Risk Management, this means mutually identifying and communicating problems in order to abolish information asymmetries and prevent negative effects on firm performance. Systematic risk management may be conceptualized as a process that consists of risk identification, risk assessment, risk mitigation strategies and risk control [26].

In the paper we consider supply chain risk management problem. Supply chain risk management is very complex problem. The above background of supply chain risk management based on existing literature provides the motivation to investigate the current trend and issues in supply chain risk management. Because, it may be extremely difficult to assess the risks associated with a given supply chain due to the great uncertainty involved, we propose an approach based on fuzzy sets theory.

Abstract

In a global business environment characterized by high complexity and uncertainty, companies are forced to manage their supply chains effectively in order to increase efficiency and reactivity. This study has investigated, through the use of case study data, how risk is defined within a supply chain management context. The purpose of this paper is to provide a grounded definition of supply risk. An approach system developed to support risk assessment framework is presented in the paper. The authors hope that the approach will facilitate effective risk handling.

Podejście do zarządzania ryzykiem łańcucha dostaw

Streszczenie

Postępująca globalizacja w znaczący sposób wpływa na zagrożenia występujące w łańcuchach dostaw. Dotychczas podlegały one kontroli wewnętrznej, zaś obecnie funkcjonują w gospodarce globalnej niosącej za sobą wiele zagrożeń. Wątek zagrożeń w funkcjonowaniu łańcucha dostaw nabiera coraz szerszego znaczenia, tym samym zasługuje na bliższe poznanie i prezentację w niniejszej publikacji. Praca podejmuje temat analizy zagrożeń istniejących w łańcuchu dostaw oraz zrąbkalizowanie tych niebezpieczeństw. Prezentuje przegląd literatury tematu. W dalszej części pracy przedstawione zostało podejście bazujące na teorii zbiorów rozmytych, które może być pomocnym narzędziem w procesie zarządzania ryzykiem łańcucha dostaw, na etapie szacowania ryzyka danego łańcucha dostaw.

REFERENCES

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