VULNERABILITY OF INDUSTRIAL SUPPLY CHAIN

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Abstract
The vulnerability analysing in industrial supply chain system is presented as a means to reduce the risk, to become better prepared to manage the system’s vulnerabilities and to improve the system’s resilience. The analysis establishes the relationship between relevant threats and risks, and the potential scenarios and consequences that determine the vulnerability of the industrial supply chain. This paper covers the comparative analysis based on literature review and deals with the structure of vulnerability original key factors that are going to have the huge impact on the vulnerability of industrial supply chain in the future. These factors should be used as a basis for developing the vulnerability scenarios.

Keywords: Supply Chain Resilience, Risks, Vulnerability of Supply Chain, Threats

1. INTRODUCTION
One of the few certainties in today's world that we have is the knowledge that there is nothing absolutely perfect. And perhaps because one of the basic principles of modern management and the principle of continuous improvement. It is an important part of achieving and maintaining competitiveness and should be a permanent objective of every organization. Its essence is the argument that, without exception, all organizations will always have plenty of opportunities for further improvement. This principle obviously applies to all links in the supply chain.

Supply chain vulnerability is a relatively new and unexplored area of management research, though one that is in the ascendency. Research of the vulnerability construct in supply chains is limited. A few efforts have been done in the field. For example, G. Svensson [1] develops a conceptual framework and a model for the analysis of vulnerability in supply chains. The model consists of three principal components, namely: source of disturbance, category of disturbance, and type of logistics flow. The conceptual framework is limited to the inbound logistic flow of vehicle manufacturers and consists of two dimensions, namely: category of disturbance and source of disturbance. Furthermore, G. Svensson [2] introduces a different conceptual framework for the vulnerability construct that consists of two components: disturbance and the negative consequence of disturbance. From the point of view of a focal company, it is proposed that the vulnerability in the inbound logistics flows from sub-contractors, and the vulnerability in the outbound logistics flows to customers, may be measured and evaluated by four principal dimensions, namely service level, deviation, consequence and trend. In addition, G. Svensson [3] develops another conceptual framework for the vulnerability construct based upon time-dependence and relational-dependence. Time dependence refers to sequential dependence between business activities in supply chains, while relational dependence refers the interaction process between business activities in supply chaos [4].

2. DEFINITIONS
It is very important to understand the basic terms, that's why general understanding of supply chains is explained first and followed by definition of the term of vulnerability in supply chain. Apart from the general
2.1 Definition of Supply Chain

The concept of a “supply chain” has recently been defined by many authors, which led to several different viewpoints. One the crucial ones defines a supply chain as a group of activities which fall within a few different companies. The closest definition to the above presented understanding of resilient supply chain was presented by the European Committee for Standardization [5] “supply chain is a sequence of processes to add value to the product during its flow and processing of raw materials, through all the intermediate forms, to form in line with end customer requirements” [6].

Other respected definitions include, for example, a definition by R. Ganeshan and T. Harrison [7], who defines supply chain as “a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of finished products to customers”. A much respected and well known definition is the one by M. Christopher [8] „the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer”. Similar definition is presented by P. K. Bagchi [9] saying that „a supply chain consists of a network of companies and carriers supplying raw materials and components and, later, they transform them into semi-finished products and final products designed to be consumed by the ultimate consumers”. The simplest and shortest definition is by D. Lambert, J. Stock and L. Ellram [10] „a supply chain is the alignment of firms that bring products or services to market”. There are many more definitions of a supply chain; however, despite a great number of various interpretations, they are all quite uniform in terms of their content.

The characteristics of each supply chain include: modified on the basis of [11]

- supply chain is a complete process in order to provide products and services to ultimate consumers,
- supply chain includes all logistic operations, from sourcing to distribution,
- the scope of activities includes production and distribution,
- supply chain management extends beyond the boundaries of individual organizations to plan and control processes in other organizations,
- supply chain allows the realization of individual goals of the organization,
- supply chain elements include suppliers, production equipment, warehouses, carriers, consumers and customers,
- the flows among these elements can be divided into information, material and financial.

2.2 Definition of Vulnerability

Vulnerability is a condition that affects a firm’s goal accomplishment dependent upon the occurrence of negative consequences of disturbance. The degree of vulnerability for a given disturbance may be interpreted as being proportional to the chance of disturbance and the expected negative consequence of the disturbance, given that it has occurred. The construct of vulnerability refers to the focal firm’s inbound and outbound logistics flows. In general, it may be understood that firms succeed in diminishing the vulnerability in their inbound and outbound logistics flows when preventive activities are introduced [2].

Vulnerability in supply chains is of immediate importance due to the fact that logistics flows in many industries strive to be lean, responsive and agile. G. Svensson [1] states that vulnerability is an underestimated and unexplored construct in logistics research and concludes that a further refinement is required.
3. METHODS, TOOLS AND CONCEPTS TO MANAGE THE VULNERABILITY

In literature, there are many methods, tools and concepts described on how to reduce and manage vulnerability in order to prevent disturbances from appearing in manufacturing or logistic flows. For example, Kaizen [12] is like an umbrella concept for many activities that strive to achieve continuous improvements and preventive actions. Subsequently, it is an approach that does not contain descriptions on how to prevent or handle disturbances. Jidoka means making the equipment or operation stop whenever an abnormal or defective condition arises. The objectives are to prevent making too many defective products and that the control of abnormality becomes easier. Andon is a visible control system. It is an electric light board, which is hung high in a factory so that everyone can see it. For example, when an employee calls for help and delays a job, he turns on the yellow light on the board. If the employee stops the line to adjust a machine, then the red light is activated [2].

It is significant to determine the real and relevant factors of vulnerability on the basis of vulnerability analysis before all factors are managed and reduced. For that purpose the below mentioned methods and tools can be used [2,13] as core tools:

- Ishikawa diagram – „fishbone“ tool can help to find potential vulnerability factors integrated in different factor Gross
- 5 WHY Method - asking, five times "WHY" researcher identifies the rootcause. 5WHY technique of asking questions is appropriate to use the quick solution to a particular problem, where the results of analyzes based on data collection from the past are not, whether any reason not available. It is advantageous to use the technique of asking questions "WHY" because it is easily able to remove layers of symptoms that can lead directly to the root cause of vulnerability.
- Problems Solving Concept – method based on principle of application of structured way to resolve the problem
- Pareto diagram – method that can separate the most probable factors of vulnerability from the irrelevant

There are also the other techniques that can be used to recover the vulnerability factors [14]:

- Supplier Quality Audits and Supplier Quality Review
- Supplier’s Risk Management
- Analysis of past performance
- Lessons Learned feedback
- Temporary Inventory and Inventory
- Process capabilities
- Critical Path Analysis
- Supplier Development Programme
- Supply Chain Mapping – relationship and influence
- Supplier capability Assessment
- Lean Manufacturing Techniques etc.
4. VULNERABILITY FACTORS – VULNERABILITY ANALYSIS

Internal and external sources (factors) of disruption of the examined supply chain can be identified on the basis of previous analyses. The task of vulnerability analysis is to identify the key factors that have and will have the biggest impact on the vulnerability of supply chain in the future. B.E. Asbjornslett suggests that individual factors should be identified using Ishikawa diagram [15]. Figure 1 shows the main groups of internal and external factors.

![Ishikawa diagram of internal and external factors contributing to vulnerability](image)

**Fig. 1** Ishikawa diagram of internal and external factors contributing to vulnerability; Source: (modified according to [15])

The most important factors influencing vulnerability of supply chains include [16,17]:

- Globalization
- Outsourcing
- Lean processes
- Centralization
- IT-dependence
- Complex product and service
- Deficit of information
- Specialized factories
- Volatility of demand
- Technological innovations

The main criterion used for the identification of key factors increasing the vulnerability is supply chain performance. It is necessary to examine the scale of performance decreased caused by disruption and the recovery time of the supply chain (see Figure 2). In the longterm, it is suitable to monitor the stability of performance.
The basic approaches to diagnosis of supply chain performance, depending on the occurrence of various disruptions, include an expert estimate, analytical calculations using model situations, and computer simulations. The final selection of the key factors can be performed using Pareto analysis (20/80 principle) [19].

T. J. Pettit, J. Fiksel and K.L. Croxton defines the final seven vulnerability factors (see Figure 3). However, in order to translate the vulnerability factors into measurable attributes, each factor was refined during the research resulting in 40 specific vulnerability sub-factors. Table includes the entire vulnerability taxonomy with sub-factors matched with a select sample from literature [20].

![Fig. 2 The disruption profile; Source: [18]](image)

### VULNERABILITY FACTORS

<table>
<thead>
<tr>
<th>Vulnerability Factor</th>
<th>Definition</th>
<th>Sub-Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbulence</td>
<td>Environment characterized by frequent changes in external factors beyond your control</td>
<td>Natural disasters, Geopolitical disruptions, Unpredictability of demand, Fluctuations in currencies and prices, Technology failures, Pandemic</td>
</tr>
<tr>
<td>Deliberate threats</td>
<td>Intentional attacks aimed at disrupting operations or causing human or financial harm</td>
<td>Theft, Terrorism/sabotage, Labor disputes, Espionage, Special interest groups, Product liability</td>
</tr>
<tr>
<td>External pressures</td>
<td>Influences, not specifically targeting the firm, that create business constraints or barriers</td>
<td>Competitive innovation, Social/Cultural change, Political/Regulatory change, Price pressures, Corporate responsibility, Environmental change</td>
</tr>
<tr>
<td>Resource limits</td>
<td>Constraints on output based on availability of the factors of production</td>
<td>Supplier, Production and Distribution capacity, Raw material and Utilities availability, Human resources</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Importance of carefully controlled conditions for product and process integrity</td>
<td>Complexity, Product purity, Restricted materials, Fragility, Reliability of equipment, Safety hazards, Visibility to stakeholders, Symbolic profile of brand, Concentration of capacity</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Degree of interdependence and reliance on outside entities</td>
<td>Scale of network, Reliance upon information, Degree of outsourcing, Import and Export channels, Reliance upon specialty sources</td>
</tr>
<tr>
<td>Supplier/Customer disruptions</td>
<td>Susceptibility of suppliers and customers to external forces or disruptions</td>
<td>Supplier reliability, Customer disruptions</td>
</tr>
</tbody>
</table>

![Fig. 3 Vulnerability factors; Source: [20]](image)
5. CONCLUSION

Many supply chains are particularly vulnerable because management is not fully aware of the threats that the system is exposed to and the vulnerable situation these threats impose on the supply chain. This paper based on literature review presents structure of vulnerability original key factors that are going to have the huge impact on the vulnerability of industrial supply chain. The methods, tools and concepts described on how to determine, manage and reduce vulnerability in order to prevent disturbances from appearing in manufacturing or logistic flows.

However, there is a common feature or denominator between the described concepts and methods. None of them provide any real conceptual theoretical framework that could be operationalised in an overall or generalised environment of vulnerability in a supply chain context. Instead, the described methods and concepts concentrate mostly on how to do it practically in order to prevent or handle disturbances. A disturbance is defined as a deviation that causes negative consequences for the firm involved in the supply chain.

Author of this paper believes that the vulnerability and resilience management may become a practical part of supply chain management, establishing a process of understanding, analysing and handling risks and vulnerabilities in supply chains.

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