Supply Chain Vulnerability and Resilience – Case Study of Footwear Retail Distribution Network

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The aim of this article is to present and investigate the main concepts of supply chain vulnerability and resilience. Thus, the fundamental differences between vulnerability and resilience definitions are discussed. The main issues on vulnerability and resilience assessment are investigated, and the case study of footwear retail supply chain disruption problems is analysed.

Keywords: supply chain, vulnerability, resilience, assessment methods.

1. INTRODUCTION

Supply chain may be defined as *an integrated process wherein a number of various business entities (like suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials, (2) convert these raw materials into specified final products, (3) deliver these final products to retailers and final customers* [4]. Such a logistic network is then characterized by a forward flow of materials and a backward flow of information. As a result, in today's uncertain environment, the reliability, resilience, and vulnerability of supply chain performance can be affected by many different factors. Moreover, based on the authors' previous research works (see e.g. [10, 25]) it may be stated that these concepts sometimes are used interchangeably or as polar opposites. There is also visible the diversity of their interpretations and reformulations across the area of supply chain performance. Thus, this research area still demands an examination of real logistic systems performance and development of the new complex framework for system vulnerability and resilience measurement.

Moreover, there are developed many models in the literature which are concerned with material procurement, production, transportation, and storage or distribution activities and with information flows performance. However, most of them treats each stage of a supply chain as a separate performance system [12]. Thus, many of the supply chain interactions are ignored. This in turn may lead to an improper identification of elements, which may influence the proper performance of a given chain also in the context of its resilience level (Figure 1).

Following this, in the presented paper authors focus on the investigation of vulnerability and resilience assessment issues. As a result, in the article the main vulnerability and resilience definitions are discussed. Later, there is presented a comprehensive literature review connected with assessment methods used in the analysed research area. Based on this, the problem of supply chain vulnerability and resilience assessment is investigated on the simple example of the supply chain of the market leader in the Polish footwear retail. The authors focus on the disruption problems connected with distribution network organization in the case company. The vulnerability analysis encompasses the main disruption sources definition and possibilities of their estimation.

The research work is a preliminary step of the authors research focused on new resilience assessment method development connected with new vulnerability index definition.

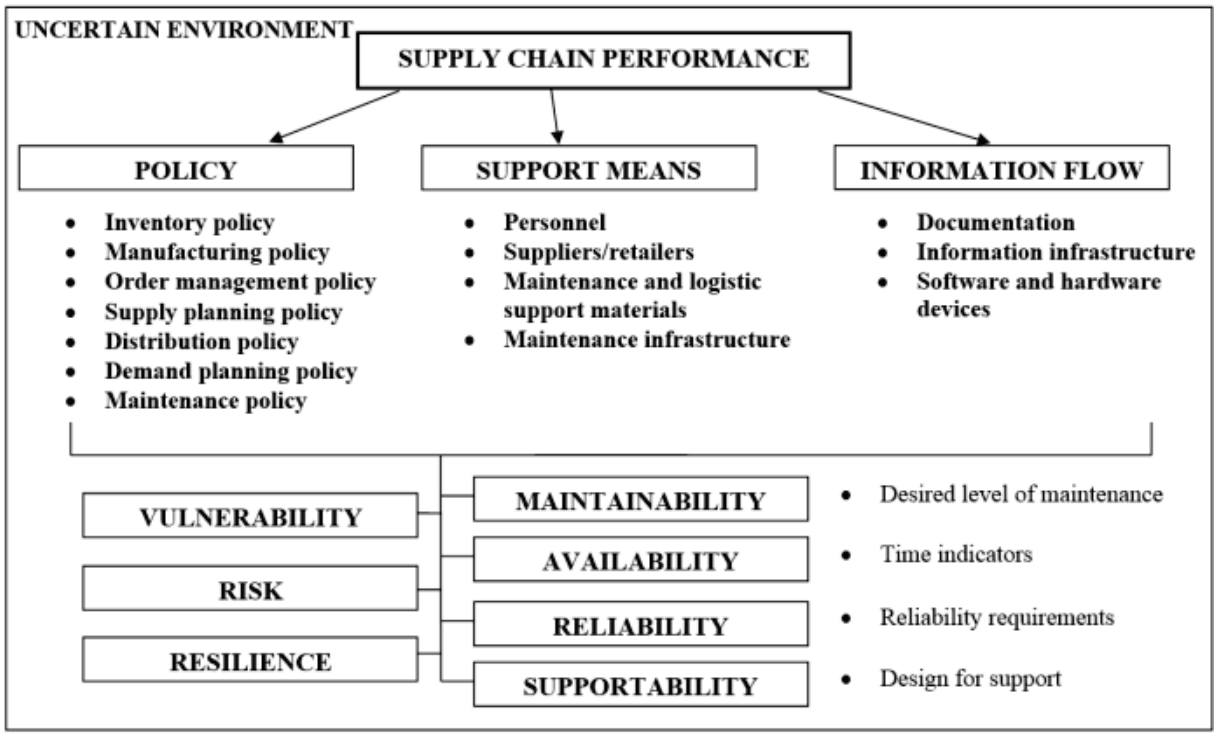

Fig. 1. The key characteristics in achieving supply chain performance.
Based on: [6, 23, 26, 43].

2. SUPPLY CHAIN VULNERABILITY AND RESILIENCE ASSESSMENT ISSUES

Supply chain networks are vulnerable to disruptions and each failure at any point in the supply chain may cause the entire network to fail. A key factor in the effective supply chain management is the ability to minimize the effects of such undesired hazard events occurrence. Following this, investigating and understanding what kind of disruptions may occur in a supply chain, how they will affect a supply chain system, and how far reaching these effects will be, would be of considerable benefit [45].

Treating the supply chain disruptions in terms of unexpected events occurrence, one can describe them as having uncertainty in supply chain operations [45]. Uncertainty in the supply chain can be seen from different aspects, such as [40]:

- time (in the sense of duration of activity/process, starting/ending moment of activity realization, a frequency of activity/demand occurrence),
- quantity (of supply, demand or physical transfer of goods),
- location/place (where activity starts/ends),
- quality (of service/products),
- cost (fluctuation, occurrence).

For example, Landeghen and Vanmaele in their work [19] profiled sources of uncertainty in the supply chain. They highlighted 13 sources of uncertainty across three supply chain's planning horizons (operational/tactical/strategic) and categorized them as Low, Medium, and High.

Taking the presented perspective of supply chain disruptions definition, *to prevent vulnerability, it is essential to manage risks in chains through creating more resilient supply chains that are able to respond to disruptions and adapt themselves to necessary changes* [11]. Thus, the issues of vulnerability and resilience of supply chains should be based on risk management perspective [39]. More information can be found e.g. in [33], where authors provide a comprehensive review and classification of literature on supply chain risk management.

The term supply chain vulnerability is studied and defined by researchers in various ways. Some of the researchers studied supply chain vulnerability conceptually (see e.g. [27, 35, 36]), or mathematically (see e.g. [1, 2, 18]). Most of the known supply chain vulnerability definitions are consistent that this concept in a multidisciplinary approach determined by certain characteristics, supply chain design variables and the environmentally influenced [41]. The overview of some recent definitions on supply chain

vulnerability is given by the authors in [10, 22, 25]. In their context, supply chain vulnerability can be defined as *an exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain* [9].

Similarly, the number of research studies introduced the concept of supply chain resilience. Following the literature, supply chain resilience may be defined as *the ability of the supply chain to handle a disruption without significant impact on the ability to serve the supply chain mission* [5]. As reported e.g. in [14], the resilience definitions took into account the following supply chain aspects: its flexibility, agility, velocity, visibility, and redundancy. A brief survey of resilience definitions from different disciplinary perspectives was given in [16]. The comprehensive literature review on supply chain resilience is presented e.g. in [7, 11, 20, 28, 31, 24].

To sum up, there can be presented the three definitions of conceptions connected with effective performance of supply chains which are vulnerable to disruptions.

Reliability assessment is focused on the possibility of an unwanted event occurrence. Many researchers claim that the term supply chain reliability has been defined for the first time by Thomas in 2002 (see e.g. [21]). Author in his work [38], has investigated the system reliability as *a set of processes for providing the procurement, distribution, storage, and transportation of people, supplies, materials, and equipment*. The supply chain reliability is defined as *the probability of the chain meeting mission requirements to provide the required supplies to the critical transfer points within the system*.

Measures of the reliability should express uncertainty about the appearance of such an event, like a failure, fault, error, or other event. Thus, in this sense reliability (dependability) of a logistic system can be understood [8] as *the ability to deliver correct service under normal (ordinary) work conditions in a given time interval*. For more information see e.g. [37].

Safety means the *absence of critical/dangerous events while security is focused on protecting the system environment against the effects of these damages*. Safety is generally measured by risk – two-dimensional combination of the probability of an undesirable event and possibility of loss (consequences). Risk assessment consists of the process of risk identification related to a threat, includes its possibility (likelihood or probability), impact, and consequences. More information can be found e.g. in [29], where the main definitions are investigated.

Resilience takes into consideration not only the discussed issues (reliability and safety) but also the possibilities of restoring the original properties of the system. Thus, resilience means [8] *readiness for secure and acceptable service under abnormal (uncommon) work conditions (e.g. disruptions, attacks, accidences, disaster)*. Moreover, the measure of resilience can be understood as a time to restore the capabilities of the system (worse than new, as good as new, better than new [22]). Following this, the resilience is about handling the consequences of a disruption, not about preventing a disruption from occurring. However, the effort to create a resilient system is made before a disruption occurs. For more information, we recommend reading [25].

In the current literature, there can be found research works dedicated to vulnerability and resilience measurement issues. The vulnerability assessment issues are investigated in details by the authors in [10]. The examples of supply chain resilience measurement systems/methods are given e.g. in [3], where authors present two resilience-based component importance measures for networks, in [13], where authors investigate the assessment issues of passenger transportation system's resilience, in [15], where a method for measuring resilience based on fuzzy logic is proposed, and in [17], where authors develop generic metrics for quantifying system resilience. In work [16], authors introduce a resilience metric that incorporates the three resilience capabilities (absorptive capacity, adaptive capacity, recovery capacity) and the time to recovery. Following this, in the Figure 2, the resilience measurement framework is presented.

Moreover, the complexity of the problem is connected with the necessity of taking into account some factors that might increase the level of risk, like [34, 44]:

- focusing on efficiency targets instead of effectiveness issues,
- supply chain globalisation,
- focussing on factories and centralised distribution,
- outsourcing,
- reduction of the supplier base,
- demand variability,
- lack of visibility and control procedures.

These factors are discussed in more depth e.g. in [33, 34].

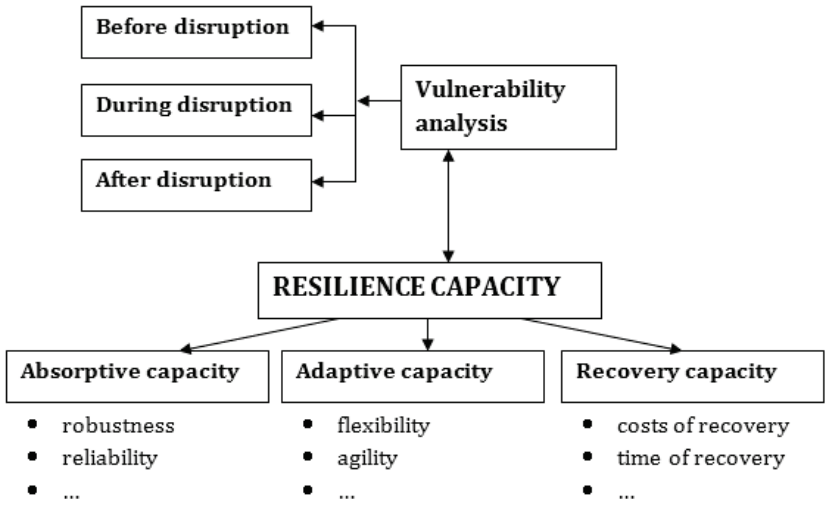

Fig. 2. Resilience framework.
Based on [16, 30, 42].

3. FOOTWEAR RETAIL SUPPLY CHAIN – CASE STUDY

The analysed company is a leader in the Polish retail footwear market. Products sale is carried out in over 700 stores located in modern galleries and shopping centres in 14 countries, where the company sold 25 million pairs of shoes yearly. The company has its own leather shoes manufacturing factory. In one season there are offered collections containing almost three thousand models of shoes. The Group owns more than 67 brand names. The company's share in the retail footwear market in Poland is around 17-18%. The company's products are dedicated to customers of the middle segment of the market.

3.1. SUPPLY CHAIN STRUCTURE

The current structure of the supply chain of final products for the consumer market is shown in the Figure 3.

The distribution supply chain includes domestic suppliers, company's own manufacturing facilities and foreign suppliers (mainly from China). Footwear imported from the territory of China comes from dozens of manufacturers. However, the main delivery part is realized by a single unit acting as the export-import agency. The structure of the purchases in the first quarter of 2015 is shown in the Table 1.

Table 1. Purchasing structure in value 1Q2015.

Foreign suppliers	Own manufacturing	Domestic suppliers
70.3%	21.6%	8.1%

Currently, the largest sales market is Poland, but there is noticed an increasing and significant impact on sales results of foreign distribution. The products are offered to customers in company's own stores e.g. in Poland, Hungary, Slovakia, the Czech Republic, Austria, Slovenia, Croatia, Turkey, and Germany. The franchise stores are operated in the Baltic countries, Russia, Romania, Ukraine and Kazakhstan. The sales structure is dominated by women's shoes sale in terms of both value and volume (Table 2).

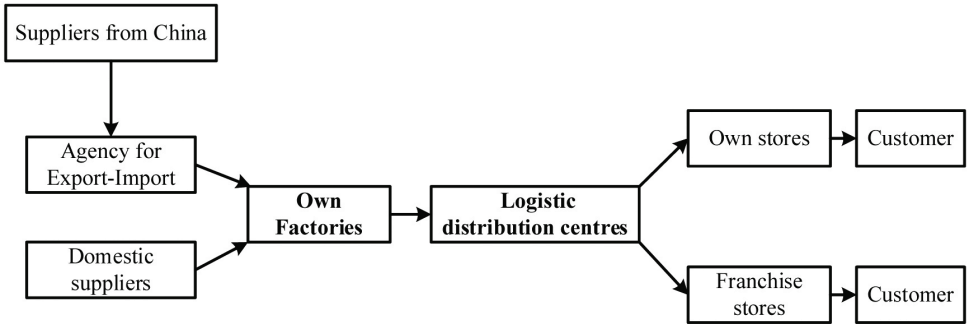

Fig. 3. Current structure of supply chain.

Table 2. Sales structure 1Q2015.

Sales structure	Women's shoes	Men's shoes	Children's shoes
in value	61%	25%	14%
in volume	56.2%	19,6%	24.2%

The company's logistics centre now becomes an innovative complex of large objects. The most important building is a fully automated high-bay warehouse of mini-load type, with a total area of 23,064 m2, which is able to accommodate a minimum of 500,000 cartons of various sizes, thus more than 5 million pairs of shoes. The new distribution centre, together with existing sorting facility, creates conditions to handle more than 100,000 cartons, what are about 1.1 million pairs of shoes, during the two working shifts. The process of mechanization guarantees the operation for future development and is fundamental for the further development of logistics processes. Additionally, it enables optimization of storage space, the surface of which is currently about 82.3 thousand m2.

3.2. THE PROCESS OF GOODS DELIVERY FROM THE LOGISTICS CENTRE TO THE POINTS OF SALES

The authors' research is focused on the process of goods delivery from the logistics centre to the company-owned stores located on Polish territory. The logistics centre is located in Lower Silesia region. Its aim is to supply 406 stores (the number of stores in 03/31/2015) located in shopping malls throughout the country.

The process of footwear supply to points of sale is based on the VMI strategy (Fig. 4). The processes of inventory monitoring in stores, demand forecasting, and orders delivery are managed by the central distribution. All the shops are incorporated in the computer system which sends daily reports of daily sales and current inventory levels to a central distribution. On the basis of this information and inventory availability parameters for each brand and each shoe size, the system generates the demand for delivery to various points of sales. Orders for individual stores, after the approval of the responsible person, are sent to the logistics centre. In this centre, with the use of automated completion process there are prepared ordered goods, and then they are directed to the dispatch zone. The physical delivery process from the distribution centre to the store is operated by external logistics operators. Currently, the company cooperates primarily with two logistics companies. Later, goods shipped to the point of sale are unpacked by employees and laid on the shelves. The location of goods is consistent with the accepted standard for individual brands and collections in the current season.

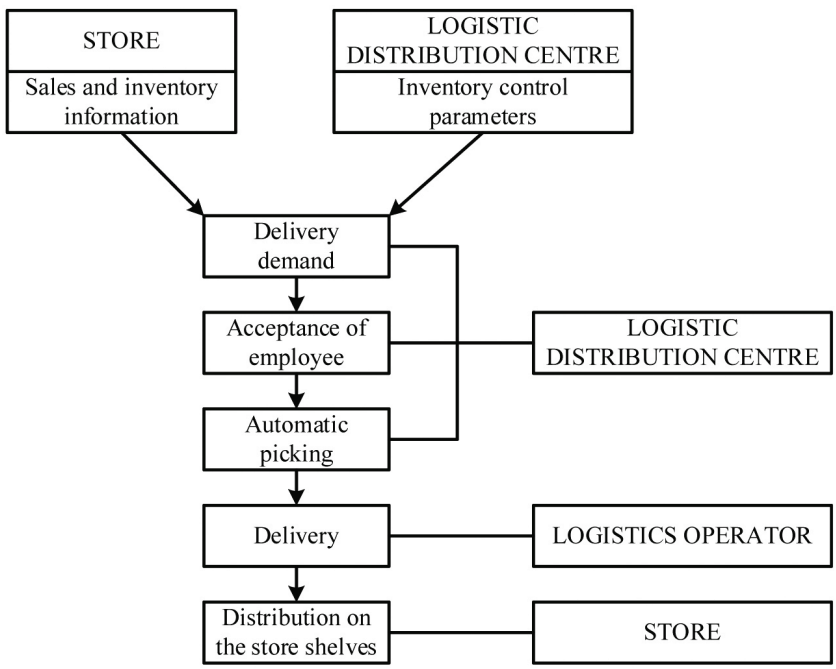

Fig. 4. The process of footwear supply to points of sale.

3.3. IDENTIFICATION OF GROUPS OF DISRUPTION EVENTS THAT MAY OCCURRED IN THE ANALYSED PROCESS

The concept of logistic processes continuous performance assumes four-element operational model [8]: (1) identification of potential sources of hazard event occurrence; (2) prediction of possible scenarios for the occurrence of these hazards; (3) monitoring, detection and recognition of occurred hazards; (4) prevention, i.e. prevention and protection against identified hazards. The current stage of authors' research is focused on the first step of the discussed performance model. The analysis regards to the process of planning and delivery of shoes from central distribution centre to stores located in Poland (the process described in the Section 3.2).

In the studies on supply chains management, there are identified 14 sources of hazards/uncertainties in their performance [32]. During the performance of chosen supply chain vulnerability analysis, there are omitted two aspects - behavioural issues and parallel interaction. According to the authors, these elements are not the source of disruptions in the analysed supply network. For each source of disruptions defined in the model of supply-chain uncertainty, there is assigned a hazard event/disruption being identified in the given footwear retail supply chain. Threats/hazards are defined on the basis of process and infrastructure analyses being conducted for the investigated supply chain and sectoral analysis implementation.

Table 3. Identification of disruptions in the analysed supply chain of footwear retail.

Sources of disruptions	Risks in the defined supply chain
Product characteristic	Shoes - product that is dependent on the weather conditions and fashion trends with short product life cycle
Manufacturing process	The production is based largely on the skills of employees
Uncertainty in control processes (control chaos)	The strong dependence of ordered values requested by shops on external factors being beyond the company's control. Stores do not have control over the amount and type of ordered footwear
Decision-making process complexity	Footwear distributed to stores located in different regions, with its own specific sales characteristic, which should be included in the developed future sales and marketing plans
IT/IS systems complexity	The entire distribution system is strongly supported by IT systems. Failure of one of them stop the process of distribution and delivery to stores
End-consumer dem and variability	Demand is seasonal, difficult to forecast due to the strong dependence on external factors
Demand amplification	Saturation of Polish market in footwear shops
Suppliers	About 70% of the products supplied to the shops come from foreign suppliers. In most cases, these products are delivered by the sea from China
Order forecast horizon	Dependence on fashion and weather conditions makes long-term demand forecasts more vulnerable for estimation errors. It is possible to reliable forecast orders for the short time horizon.
Supply chain configuration, infrastructure, facilities	One central warehouse, which stores all products. Managing the flow of goods through the supply chain is implemented by a central processing unit
Environment	There operate several strong players in the footwear market. The main competitor is a company with foreign capital that has organized its supply chain in a similar way
Disasters and natural disasters	Location of headquarter in the intensive mining operation area - risks of tremors, failures of underground equipment. Flood risk – in the neighbourhood is located Odra river and Żelazny Most reservoir

These risks can be classified into three groups (Fig. 5):

1) **Internal organisation uncertainty**. This group can include product characteristics, manufacturing process, control chaos, decision complexity and IT/IS complexity. The responsibility for the management of this risk group rests primarily on the manufacturer. Most of these disruptions remain under its control, which allows for the development of scenarios for preventive and limiting the likelihood of a particular threat occurrence.
2) **Internal supply-chain uncertainty**. Here should be introduced the following risks: end-

customer demand, demand amplification, supplier, order forecast horizon and chain configuration, infrastructure and facilities. Under the control of the supply chain participants, there are only a few sources of risk associated with creating demand, improving the quality of forecasts and creating chain configuration and infrastructure. For these components, it is possible to prepare a strategy to prevent the occurrence of hazard. In the case of other disruption sources occurrence, the manufacturer is liable to develop scenarios that can only limit their negative effects.

3) **External uncertainties**, which include environment and disasters. These elements remain entirely outside the control of the supply chain participants. The only way to manage this type of risk is to prepare scenarios for reducing the effects of hazard event occurrence.

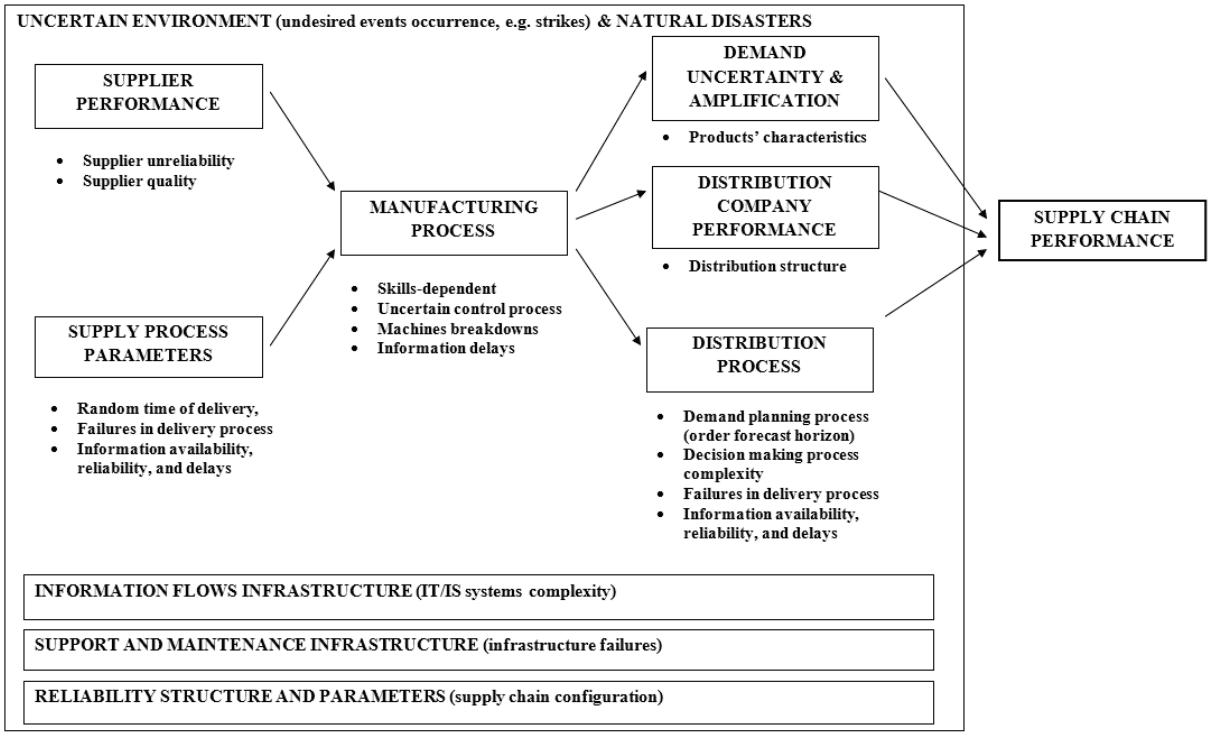

Fig. 5. Main disruptions that influence chosen supply chain performance.

Analysing the disruptions in manufacturer's logistics processes performance, it was found that the sources of risk are derived from all the three groups simultaneously. The example of conducted Ishikawa analysis for the defined disturbance - "low quality of created sales forecasts" are shown in Fig. 6.

In the Table 4, the causes highlighted in the Ishikawa diagram were classified as sources of risks defined in the Table 3.

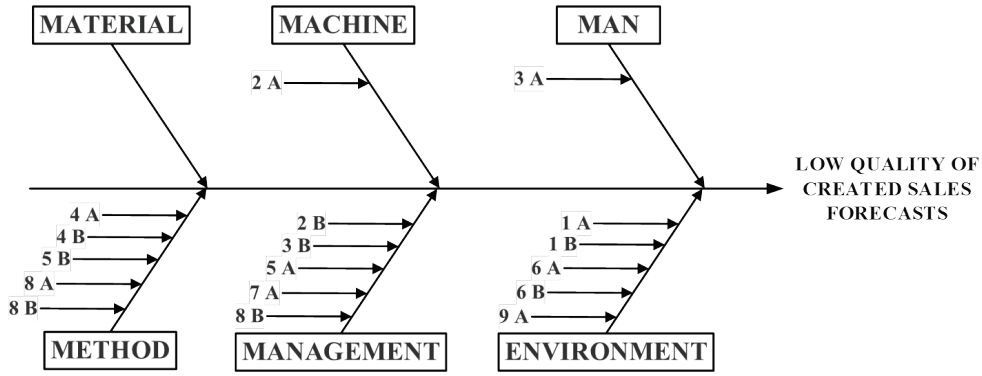

Fig. 6. Ishikawa diagram for low quality of created sales forecasts.

Table 4. The main causes of law quality of created sales forecasts consequence defined in the Ishikawa diagram.

The causes' symbol	The causes of disruptions	Source of disruption
1A	The sale subject to weather conditions	Product characteristic
1B	Product dependent on fashion and current trends	
2A	Manufacturing constraints resulting from the machines and people efficiency	Manufacturing process
2B	Make to stock, (production surplus force company to organize the promotion that is not included in the forecasts)	
3A	Staff mistakes in recording of entry and release of goods in the shops	Uncertainty in control processes (control chaos)
3B	No measurement of the organized promotion influence	
4A	Forecasts created for many regions, each with different sales trends	Decision-making process complexity
4B	Forecasts created on the basis of historical data about the customers behaviour at previous time periods	
5A	Lack of important information about the external factors affecting the sale	IT/IS systems complexity
5B	The lack of various algorithms for determining the sale levels for different regions	
6A	Demand strongly dependent on external factors being difficult to predict	End-consumer demand variability
6B	Promotions strongly affecting consumer behaviour	
7A	Lack of changes in sales definition being a result of new stores opening	Demand amplification
8A	Only a short-term forecasting horizon can be optimized	Order forecast horizon
8B	Lack of determined methods and required information to make long-term sales forecasts	
9A	The strong impact of competition activities on the realized sale volume	Environment

The presented example clearly suggests that carrying out of risk analysis for logistics processes performance cannot be limited to only one group of the defined source of disruptions. Logistics systems, due to its complexity and interdisciplinary nature, have to be the subject of multi-criteria analysis, which is able to comprehensively investigate the existing problem.

The operations to prevent the occurrence of the defined risks can include the implementation of systems and procedures for securing the performance of IT tools (IT complexity) and the introduction of additional employee's training and checkpoints on the production line (manufacturing process). Scenarios directed on reducing the effects of hazards occurrence can include strategies for the development of a distribution network in other markets (demand amplification) or can base on the development of special procedures in case of tremors or local flooding (disasters). The authors' further research studies are to be focus on the development of scenarios and strategies for preventing or reducing the effects of defined risks occurrence.

4. SUMMARY

The high degree of coordination and the sales characteristic make described deliveries of footwear to retail chains are exposed to all kinds of disruptions. The company, in order to maintain a high competitive position, must strive to reduce the impact of any occurred hazard events. Hence the high importance is given to properly carried out vulnerability analysis. The identification of hazards and determination of their nature will allow managers to better manage risk, both within the enterprise and across the supply chain. Because the manufacturer is a leader in the described supply chain and most of the associated chain units are his own or remains in a franchise, its ability to control and influence on individual units are much greater than in the classic supply chain performance. This fact should be used by him in order to reduce uncertainty of at least the first two classified groups (internal organization uncertainty and internal supply-chain uncertainty). Therefore, there should be taken steps regarding the appropriate procedures and the implementation of solutions based on planning scenario issues. In this way, managers will receive clear guidance on their actions performance in the event of the threat occurrence and, as a result, they shorten the time of their reaction.

The presented results provide an introduction to the initiated research on the use of vulnerability analysis as a tool for process controlling implementation in order to improve decision-making processes in the entire supply chain. The further research will be focused on the development of the tools to support risk management in supply chains and introduction of selection of analyses that support the controlling leader activities performance.

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