MODEL FOR SIMULATION OF SUPPLY CHAIN RESILIENCE

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Abstract

For effective management of supply chain resilience is necessary to use advanced quantitative methods. The authors recommend create the simulation based decision support models. The aim of this article is to design a basic model to simulate supply chain resilience, to determine its structure, the required input data, the possible experiments performed on the model and the anticipated outputs.

Keywords: simulation, modelling, resilience, supply chain

1. INTRODUCTION

Today´s supply chains must face a wide spectrum of factors causing their disruption. According to the World Economic Forum (WEF) [1], the major ones include: natural disasters, extreme weather changes, conflicts and political troubles, terrorism and sudden radical changes of demand. The concept of supply chain resilience is response to this situation. The word resilience has its origins in the Latin word „resiliere", which means to „bounce back". Christopher and Peck emphasize two basic cornerstones of the system resilience - flexibility and adaptability: resilience is the ability of a system to return to its original state or move to a new, more desirable state after being disturbed [2]. Similar definition of resilience is presented by Sheffi and Rice - resilience is the ability to bounce back from a disruption [3]. According to Fiksel's economic definition, resilience is the capacity of an enterprise to survive, adapt, and grow in the face of turbulent change [4].

According to kinds of disruptions identified by WEF and mentioned resilience definitions, authors of the article define the supply chain resilience as the ability of a supply chain to return to its original state in case of its serious disruptions. Design of suitable decision support models is necessary to manage the supply chain resilience effectively. The aim of this article is to design a basic model to simulate supply chain resilience, to determine its structure, the required input data, the possible experiments performed on the model and the anticipated outputs.

2. LITERATURE REVIEW AND METHODOLOGICAL BASIS

2.1 Computer Simulation

The computer simulation is defined as a numerical technique used to simulate a real system by means of an experimental model, with dynamical processes ongoing within the system factored in, in order to identify the behaviour and effect thereof on the system operation [5], [6]. There are numerous simulation types and their classification. Authors of the article use dynamic stochastic discrete event simulation to model supply chain resilience.

The use of simulation techniques in solving supply chain problems requires an efficient simulation tool, which would also be easy to use. The DOSIMIS-3® package meets both these conditions [7]. DOSIMIS-3® is a module-oriented simulation tool, adapted to, inter alia, designing and creating models of supply chains. The

DOSIMIS-3® package is an interactive graphic simulator, the operation of the simulator is modelled in event controlled discrete processes.

2.2 Literature Review of Supply Chain Resilience Simulation

The selection of computer simulation as a useful tool for the modelling supply chain resilience is motivated by its successful application in the sphere of simulation of supply chain management [8], [9], [10], [11], [12]. There is only a limited number of research works dealing directly with the computer simulation of resilient supply chains. The major ones include researches [13], [14], [15], [16], and [17].

Research work [13] proposes a simulation based decision support framework to assess supply chain resilience. The authors suggest examining three basic determinants of supply chain resilience: supply chain density, supply chain complexity and supply chain node criticality. It also suggests the possibility of measurement of the given determinants and their influence on the course of the supply chain disruption. However, the authors do not create a specific simulation model, but they only propose the basic methodology of its creation and the simulation scenarios.

A similar approach can be found in research work [14], which sets a framework for modelling of supply chain disruptions: parameters, experimental factors, and performance measures of the simulation models. The attention is focused mainly on the approaches towards the analysis of simulation-based experimental data.

Again, a concrete simulation model is not proposed in this case.

Research work [15] already offers a concrete model of a supply chain from the automotive industry. However, the model is highly simplified and it represents only a selected part of the supply chain (supply side) and covers only one manufacturer and five suppliers. The model works with a relatively high level of detail. Each link in the chain involves a model of four basic processes (plan, source, make, deliver) and their sub-processes. There are transport processes taking place among the plants. The model created in this way is used to simulate several scenarios involving various disruptions. Two basic parameters are selected for the evaluation: lead time ratio and total cost. The input data are obtained on the basis of semi-structured interviews with logistics and operations managers, and the total simulation time is in the order of several weeks.

Study [16] is associated with the research work mentioned above. The authors propose Supply Chain Disturbance Management Fuzzy Decision Support System. The original model is completed by including the fuzzy set theory to model the uncertainty associated with the disturbances and their effect on the supply chain.

Another research work, which proposes a concrete model of supply chain for the purpose of simulation of supply chain resilience, is research [17]. The authors analyze inventory placement and back-up methodologies in multi-echelon network and demonstrate their effect on reducing supply chain risk. However, resilience is understood from the point of view of a wide spectrum of risks, not from the point of view of disruption of the entire supply chain.

On the basis of a critical evaluation of the literature review, we can say that the utilization of computer simulation in modelling of supply chain resilience is still in the initial research state:

- The existing models work especially with disruptions that do not cause a long-term reduction in performance of the entire supply chain. The attention is paid to the disruptions that should be solved using the methods and tools of Supply Chain Risk Management.
- Simulation frameworks and models are not created for the purpose of strategic decision-making in supply chains. They work with a short-term horizon. Major disruptions, however, occur with much lower periodicity, and to reduce their impact, it is necessary to make strategic decisions affecting the supply chain for decades.

- The models simulate only selected parts of the supply chain and include only a very limited number of subjects. To investigate the impact of major disruptions on the supply chain performance, it is necessary to model the entire structure.
- The existing simulation-based decision support systems rarely make use of other exact approaches and tools that could improve the acquired simulation outputs (the tools of advanced statistical analysis or artificial intelligence).

3. DESIGN OF SIMULATION MODEL

The model designed by the authors reacts to the shortcomings of existing simulation models analysed in Chapter 2.2.

3.1 Model Framework

This model takes into account the whole length of the supply chain, i.e., from the point of origin to the point of consumption [18]. The model was created on the basis of a supply chain from automotive industry:

- The automotive industry is central to Europe's prosperity. It is a huge employer of skilled workforce and a key driver of knowledge and innovation. It represents Europe's largest private investor in R&D. It also makes a major contribution to EU's GDP, and exports far more than it imports. [19]
- The automotive industry is a representative of global supply chains (worldwide). These supply chains are affected by all major disruptions defined by the World Economic Forum.
- The automotive industry is the leader in supply chain management.

The model considers the crucial disruptions identified by the World Economic Forum. These disruptions do not affect only selected links in the chain (concrete manufacturers, suppliers, distributors and customers), but the entire areas. According to the nature of disruption, it will affect areas defined geographically, politically or economically. That is why the model works with a high degree of aggregation. Each element of the model represents the supply chain elements in a given area (e.g., a group of suppliers of Northeast Europe).

Due to the nature of those disruptions, the model is designed in such a way to study supply chain resilience in the long-term horizon (decades) and it supports decision-making of a strategic nature.

The model uses the loss of unrealized production caused by a disruption as a supply chain performance measure. This loss is represented by sales (multiple of the number of unsold units and their value).

3.2 Model Elements and Input Parameters

The model deals with the following elements:

- Source - group of suppliers in the given area.
- Transport - group of providers of logistics services and operators of traffic routes (e.g. railways and roads) in the given area.
- Manufacturing - production plants in the given area.
- Storage - group of warehouses in the given area (e.g. cross docks on the supply side or warehouses in ports on the demand side).
- Consumption - target markets.

Each element has its determined capacity (measured by the number of units per a given period). The disruptions lead to a loss of performance of the element, resulting in a decrease in performance of the entire supply chain. The disruption is simulated for each of the elements using four basic parameters [14]:

1. Disruption periodicity - time interval between disruptions.
2. Disruption time period - time interval between disruption beginning and capacity recovery.
3. Disruption capacity loss - the number of units lost at the outset of the disruption.
4. Disruption profile - the shape of the disruption capacity loss from beginning to end. Typical disruption profile is shown on **Fig. 1**.

The model uses pull supply chain strategy. Procurement, manufacturing and distribution are demand-driven. The individual elements in the supply chain can be arranged in a series or in a parallel form. A disruption of an element in the series part of the supply chain will reduce the performance of this part. In case of a disruption of an element in the parallel part of the supply chain, the loss of capacity can be compensated by an alternative element.

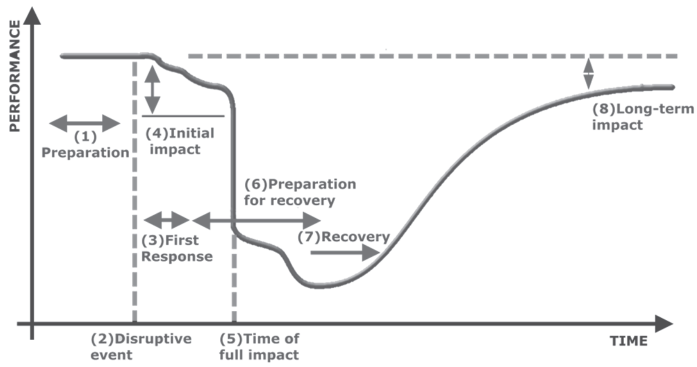

Fig. 1 The disruption profile [3]

3.3 Model Creation in DOSIMIS 3

An example of a model of a supply chain created in DOSIMIS 3 simulation tool is shown in **Fig. 2**. The model is balanced as far as its capacity is concerned, the simulation step is one week and the simulated period is 20 years. The capacity of the elements and the performance of the whole chain are measured in tones per week.

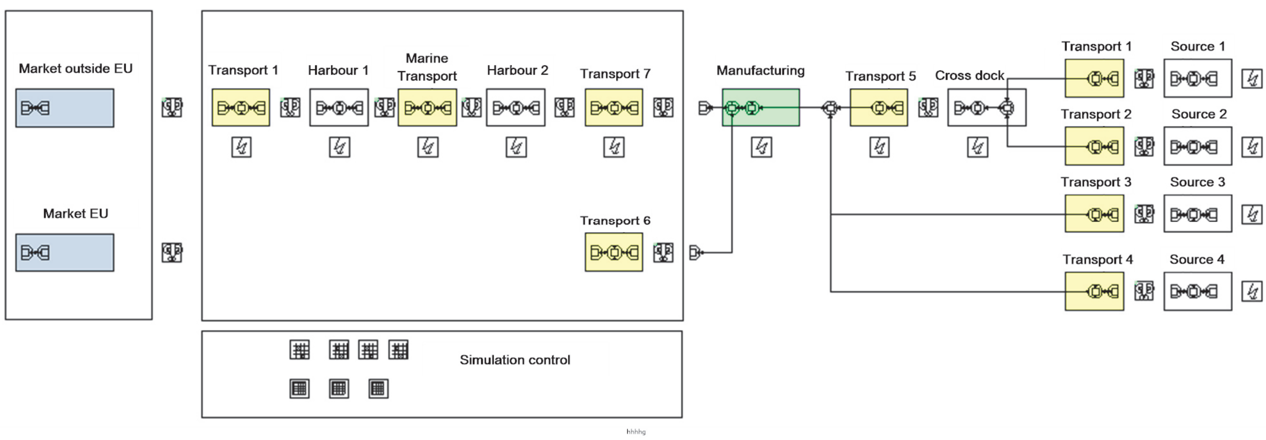

Fig. 2 An example of a supply chain model in DOSIMIS 3

An illustration of disruption parameters setting of Manufacturing element is shown in **Fig. 3**.

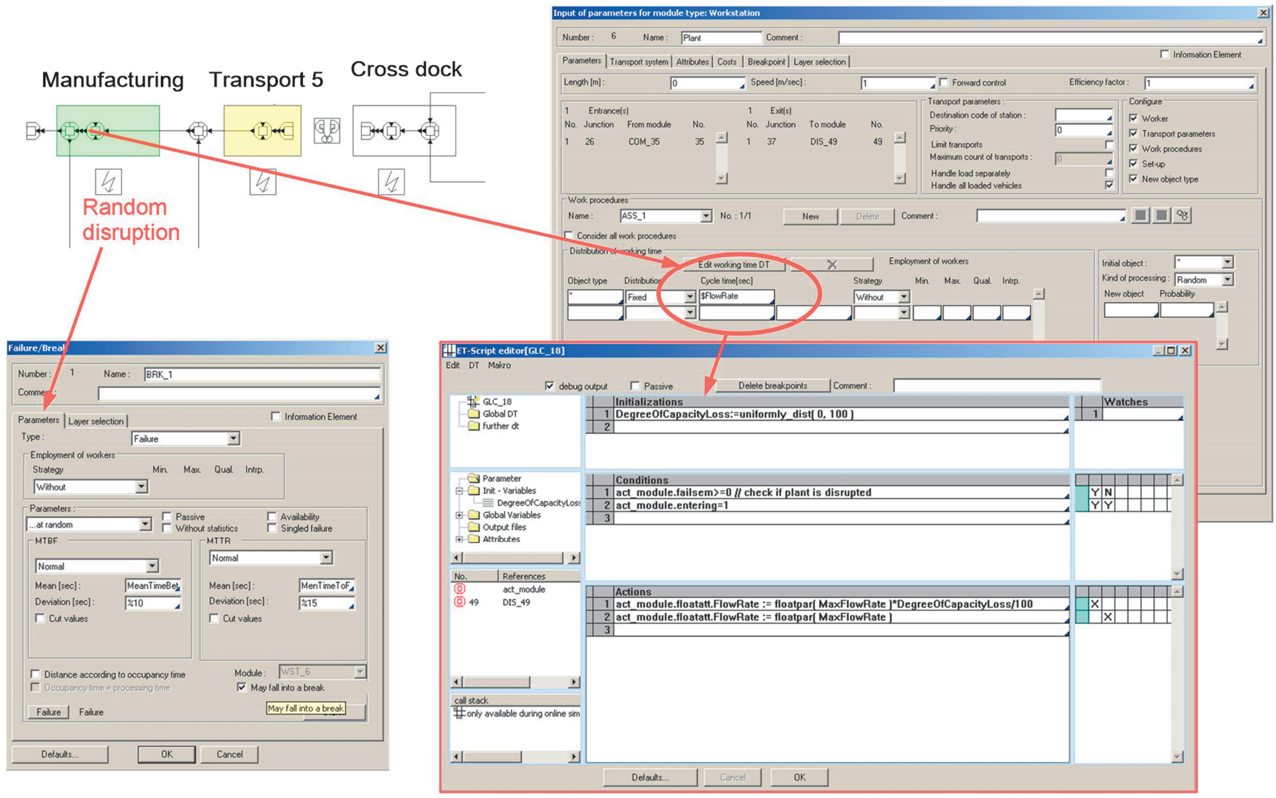

Fig. 3 An illustration of the disruption parameters assignment in DOSIMIS 3

The simulation of disruption periodicity, disruption time period and disruption capacity loss took advantage of normal distribution in case of all the elements. The disruption profile has a simple „step“ form.

3.4 Expected Simulation Experiments and Results

The designed model allows using the execution of the simulation experiments to examine:

- The effect of the changes in the model structure (elements and links) on the supply chain performance.
- The effect of the change of the model input parameters on the performance of the supply chain.
- The effect of the change of the logistics strategy on the supply chain performance.

The acquired results can be used in two ways:

1. Determine the generally valid principles of building resilience of supply chains. The conclusions related to supply chain density, supply chain complexity and supply chain node criticality can serve as an example [13].
2. Check the possibility of using the specific capabilities and ways to increase the resilience of the modelled supply chain. The implementation of the individual capabilities and ways in the model are reflected in the change of the structure or the parameters setting of the model. For example, the establishment of a close cooperation among the various network elements will reduce the disruption time period or the disruption capacity loss, which will result in the increased performance of the supply chain. It will be possible to use the acquired reduction in the loss of unrealized production to compare it with the investments necessary to build the given capability or way, or to make the final decision on its implementation.

Both outcomes will facilitate strategic decision support in designing new resilient supply chains or in increasing the resilience of existing supply chains in a longer time horizon.

CONCLUSION

The designed model is just the initial phase of the research in the area of increase of supply chain resilience by means of computer simulation-based approach. The objective is to create Strategic Decision Support System for Resilient Supply Chain Management, consisting of:

- Simulation subsystem - creating a model based on a real supply chain from the area of automotive industry, reflecting the widest possible range of problems of existing supply chains.
- Input data subsystem - the key role in terms of the relevance of the simulation model results is played by the quality of the input data. To determine the disturbance parameters and their changes after the implementation of the resilience capabilities and ways, it will be necessary to build a special subsystem. The essence of this subsystem should be the advanced methods of statistical analysis (taking into account the available historical data) and the artificial intelligence tools (taking into account the experience of experts).
- Design of experiments subsystem - given the enormous number of combinations of the structure, the input parameters of the model and the applied logistics strategies, it will be necessary to significantly reduce the number of experiments on the model. This task will take advantage of the methods of advanced statistical analysis.
- Output data analysis subsystem - the significance of the results obtained by the simulation experiments should always be thoroughly checked. The presented subsystem will again be based on the methods of advanced statistical analysis.

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