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A COMPUTER SIMULATION-BASED ANALYSIS OF SUPPLY CHAINS RESILIENCE IN INDUSTRIAL ENVIRONMENT

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The article presents a computer simulation-based model for analysis of supply chain resilience, which allows determining and verifying the generally valid principles, capabilities and ways for building long-term resilience of global supply chains against serious disruptions. The model is created on the basis of a supply chain from automotive industry and contains the main logistics flows used by present automotive producers. Any real automotive supply chain can be modelled as a combination of these logistics flows. The model was created in DOSIMIS-3® and verified using experimental data. The performed simulation demonstrates a significant decrease of the supply chain performance in case of serious disruption occurrence.

Key words: supply chain, resilience, computer simulation, industrial environment

INTRODUCTION

Leanness was the leading approach to supply chain management in past years [1], but today's supply chains must face volatile environment with a wide spectrum of factors causing their disruption. New tools for increasing the supply chain resilience must be developed for that reason. One of the promising tools, which can be used for that purpose, is computer simulation. The aim of this article is to design a computer simulation-based model for analysis of supply chain resilience, which allows determining and verifying the generally valid principles, capabilities and ways for building long-term resilience of global supply chains against serious disruptions.

LITERATURE REVIEW

Supply chain resilience is defined as follows - it is: (1) the ability of a system (supply chain) to return to its original state or to move to a new, more desirable state after being disturbed [2], (2) the ability to bounce back from large-scale disruptions [3], (3) being better positioned than competitors to deal with – and even gain advantage from - disruptions [4], (4) the ability to maintain output close to the potential one in the aftermath of shocks [5]. The main idea of these definitions is to create such a supply chain that is not vulnerable to serious disruptions. According to the World Economic Forum (WEF) [6], the most important ones include: natural disasters, extreme weather changes, conflicts and political troubles, terrorism and sudden radical changes of demand.

There is only a limited number of research works dealing with the computer simulation-based analysis of supply chain resilience. The major ones include researches [7 – 11]. On the basis of these studies, it can be deduced that [12]: (1) there is only a limited number of research works focused on a specific simulation model for supply chain resilience analysis, (2) the existing models work especially with disruptions that do not cause a long-term reduction in the performance of the entire supply chain, (3) simulation frameworks and models are not created for the purpose of strategic decision-making in supply chains, (4) the models simulate only selected parts of the supply chain and include only a very limited number of subjects.

DESIGNED MODEL

The authors of this article have developed the initial version of computer simulation-based model to eliminate the above presented shortcomings of the existing simulation models.

The model takes into consideration the crucial disruptions identified by the WEF. These disruptions do not affect only the 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 links in a given area (e.g., the element of Source contains a group of suppliers of Northeast Europe). It's an original and unique feature of the proposed model which hasn't been used in any other simulation-based model so far. It allows modelling the whole length of the supply chain, not only a small part of a real supply chain. Due to the nature of WEF disrup-

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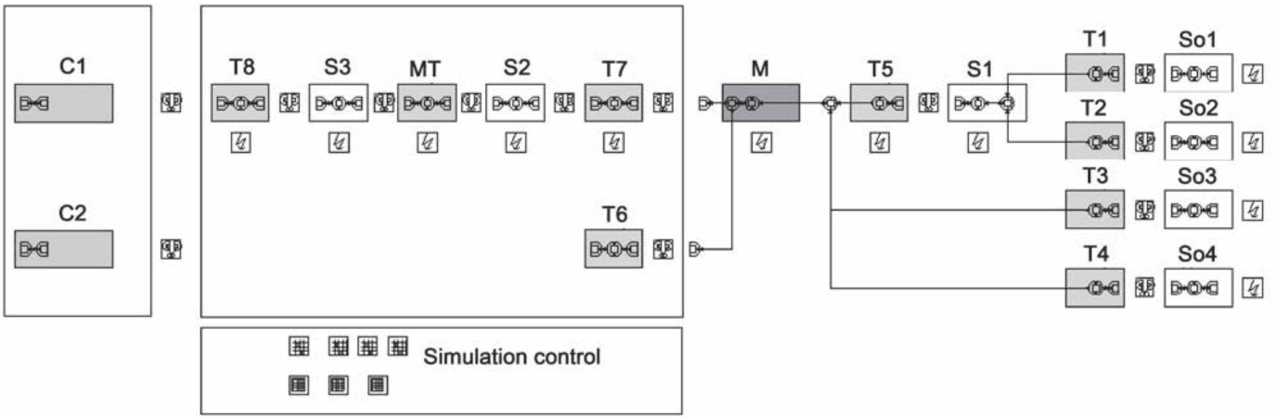

Figure 1 The initial model in DOSIMIS 3®

tions, the model is designed in such a way to analyse supply chain resilience in a long-term horizon (decades) and to support decision-making of a strategic nature.

The model is created on the basis of a supply chain from automotive industry, because: (1) the automotive industry is crucial to Europe‘s prosperity [13], (2) the automotive industry is a representative of global supply chains (worldwide), which contain all kind of elements, from a supplier of steel materials and other components, trough manufacturing plants, to a distribution network, (3) these supply chains are affected by all major disruptions defined by the WEF, (4) the automotive industry is the leader in supply chain management.

The model was created in DOSIMIS-3® (dynamic, stochastic, and discrete event simulation tool) – see Figure 1. The model contains the main logistics flows used by present automotive producers: (1) sourcing by means of hub and spoke or cross docking system – the branch of Manufacturing (M) – Transport 5 (T5) – Storage 1 (S1) – Transport 1 (T1) and 2 (T2) – Source 1 (So1) and 2 (So2), (2) direct sourcing – the branch of Manufacturing (M) – Transport 3 (T3) and 4 (T4) – Source 3 (So3) and 4 (So4), (3) distribution to transmarine destinations – the branch of Consumption 1 (C1) – Transport 8 (T8) – Storage 3 (S3) – Maritime transport (MT) – Storage 2 (S2) – Transport 6 (T6) – Manufacturing (M), (4) direct distribution – the branch of Consumption 2 (C2) – Transport 7 (T7) – Manufacturing (M).

Any real automotive supply chain can be modelled as a combination of these logistics flows.

The model uses JIT supply chain strategy. The individual links in the supply chain can be arranged in a series or in a parallel form. A disruption of a link in the series part of the supply chain will reduce the performance of this whole section.

The model is balanced as far as its capacity is concerned (capacity is equal to demand). The whole capacity of the supply chain is 500 000 tonnes per year. 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 tonnes per week.

A serious disruption can appear in each element of the model (including Consumption) with the same disruption parameters (parameters were selected on the basis of [13]): (1) disruption periodicity (time interval between disruptions) is set according to the exponential distribution where mean value is 4 years, (2) disruption time period (time interval between the disruption beginning and capacity recovery) varies from 1 to 3 months, according to uniform distribution, (3) disruption capacity loss (the number of units lost at the outset of the disruption) is assumed in the amount of 100 % (total capacity loss), (4) disruption profile (the shape of the disruption capacity loss from the beginning to the end) is represented in Figure 2.

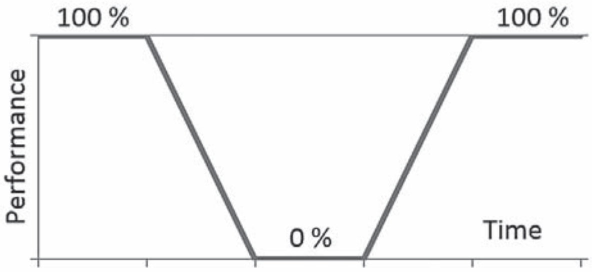

Figure 2 Used disruption profile

The model uses the loss of unrealized production caused by a disruption as a supply chain performance measure. This loss is represented by unsold units.

EXPERIMENTS AND RESULTS

The performed simulations demonstrate a significant decrease of the supply chain performance. The ideal performance, i.e. without disruptions, is 10 million tonnes per 20 years. When disruptions were included and simulation was run 30 times (to get statistically significant results), the supply chain performance (see the OC column in Table 1) is on the average 7 612 thousand tonnes per 20 years (app. 76 % of the ideal performance). Such a significant decrease is caused especially by the used JIT supply chain strategy. A disruption in any element causes stoppage or substantial limitation of the other supply chain elements. The performance of the manufacturing element from selected simulation run is presented in Figure 3 in order to demonstrate this fact.

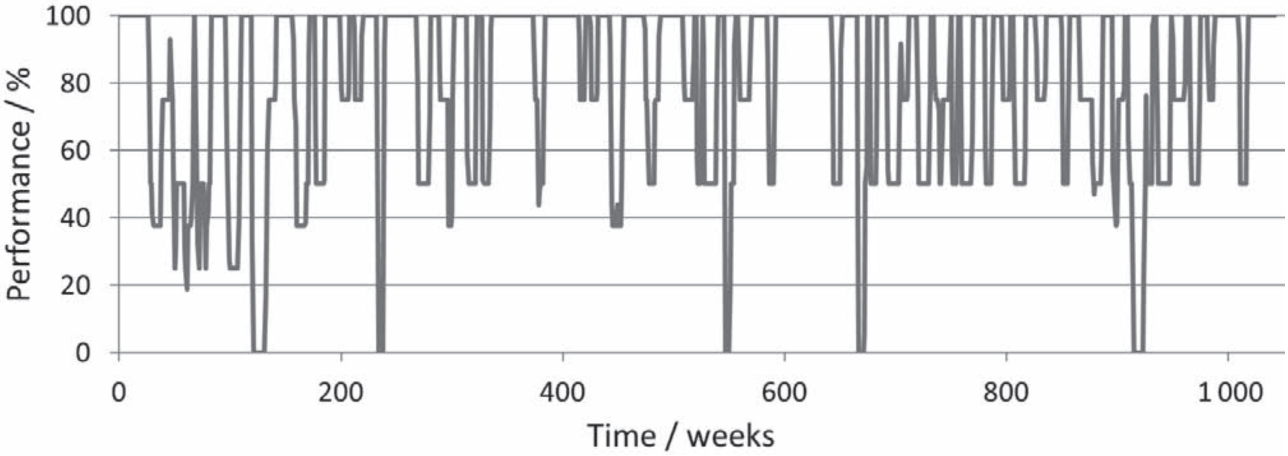

Figure 3 Performance of the Manufacturing element

Table 1 **Performance of selected elements**

Selected elements		OC	C1	C2	M	S1	So1	So2	So3	So4
Performance / thousand tonnes / 20 years	Without disruption	10 000	5 000	5 000	10 000	5 000	2 500	2 500	2 500	2 500
	With disruption	7 612	3 805	3 807	7 612	3 663	1 844	1 819	1 976	1 972
Difference / thousand tonnes		2 388	1 195	1 193	2 388	1 337	656	681	524	528
Percentage of max. performance		76,12	76,10	76,14	76,12	73,26	73,76	72,76	79,04	78,88

Full performance decrease is caused by a disruption appearing directly in this element. The other falls are related to disruptions of other elements.

The performance of the selected network elements is shown in Table 1.

CONCLUSION

The designed model allows using the execution of the simulation experiments to examine the effect of the changes in the model structure (elements and linkages), the model input parameters, and the change of the logistics strategy on the supply chain performance. The acquired results can be used in two ways: (1) to 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 [6], (2) to 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 an increased performance of the supply chain. It will be possible to use the acquired decrease in the loss of unrealized production to compare it with the investments necessary to build the given capability or way and to make the final decision on its implementation.

Both of these 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.

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Note: The responsible translator for English language is Petr Jaroš (English Language Tutor at the College of Tourism and Foreign Trade, Goodwill - VOŠ, Frýdek-Místek, the Czech Republic)