

The Role of Logistic Enterprises in Strengthening the Resilience of Supply Chains

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The paper discusses the role of logistic enterprises, including especially the transport ones, in strengthening the resilience of supply chains. The research was carried out in the sector of metallurgic products distribution. The paper aims at building a model of strengthening the resilience of supply chains for the flow of products manufactured to order. The author proposed a research methodology involving the measurement of disruptions, the measurement of deviations, a statistical analysis and simulation modelling. In simulation modelling the author used the management system dynamics technique.

Keywords: resilience, distribution, logistic enterprises, supply chain.

1. INTRODUCTION

The dynamic environment of enterprises cooperating in a supply chain induces to increase the organizational relations at selected stages of the supply chain. Network relations are created both between industrial companies (production networks), trading agencies (distribution and supply networks) as well as logistic enterprises (logistic networks). Complex systems coming into existence as a result of extending network relations are exposed to different types of disruptions coming into existence at the stage of material flows.

The paper discusses the role of logistic enterprises, including especially the transport ones, in strengthening the resilience of supply chains on disruptions in material flows. The author indicated the literature output in the field of the strategy of strengthening the resilience, including especially the research regarding the strategy: surpluses of supplies, subcontracting, surpluses of suppliers and flexible resources. The research carried out in the sector of distribution of metallurgic products has shown that the mentioned strategies allow compensation of disruptions in logical processes for mass products, multi-variant products or products differentiated according to orders. Stronger individualisation of products, demanding

involvement of new subjects, using materials, parts and non-standard components, makes the proposed strategies become ineffective. Strengthening the resilience through the surplus of supplies only generates costs, preventing reaction to orders requiring materials, parts and non-standard components. Flexible resources neither allow big individualisation nor give possibilities of innovative solutions. Subcontracting and a wide base of suppliers prevent innovative solutions; however it increases disruptions at the stage of material flows. Consequently, a high degree of individualisation of orders, namely product differentiation as ordered, require searching for other possibilities of strengthening the resilience. Building a model of strengthening the resilience of supply chains for the flow of products manufactured as ordered is the main objective of the paper.

Disruptions and deviations in material flows were investigated in supply chains of metallurgic products. In the proposed structural solutions the author took into account transport enterprises, assessing their influence on the resilience of supply chains.

The author proposed a research methodology involving measurement of disruptions, measurement of deviations, a statistical analysis and simulation modelling. In simulation modelling

the technique of management system dynamics was used.

2. STRATEGIES OF STRENGTHENING THE RESILIENCE OF SUPPLY CHAINS

Networks shaped at individual stages of creating the value added are an answer to uncertainty and differentiation of orders. It is so because the more strongly differentiated product, the more difficult it is to adapt indispensable resources to its realization. Each levels of a supply chain have different needs regarding the intensity and the width of network relations. The most important determinants of the structure of a supply chain, including the level of creation of network relations mentioned in the literature are: fluctuations of demand, the degree of product differentiation, the degree of product complexity, the number and the recipients' segments differentiation.

The scale of product differentiation proposed in the paper refers to the publication by Harrison, van Hoek (2010) and Kramarz (2013):

- Products produced as ordered (late differentiation in a production company or in a distributional enterprise) - the degree of differentiation 4
- Products designed to order - the degree of differentiation 5

Moreover, at each degree of product differentiation, the level of product differentiation can be worked out, taking into account its complexity and the number of the executed operations.

Products manufactured as ordered can be differentiated in an industrial company and also in the definite node of the distribution network. The essence of the postponed production strategy is production of the so-called base product. The base products manufactured in a production company after placing an order is differentiated in different degrees and sent to the final customer. Certain variants of product differentiation were presented on Fig. 1 and 2.

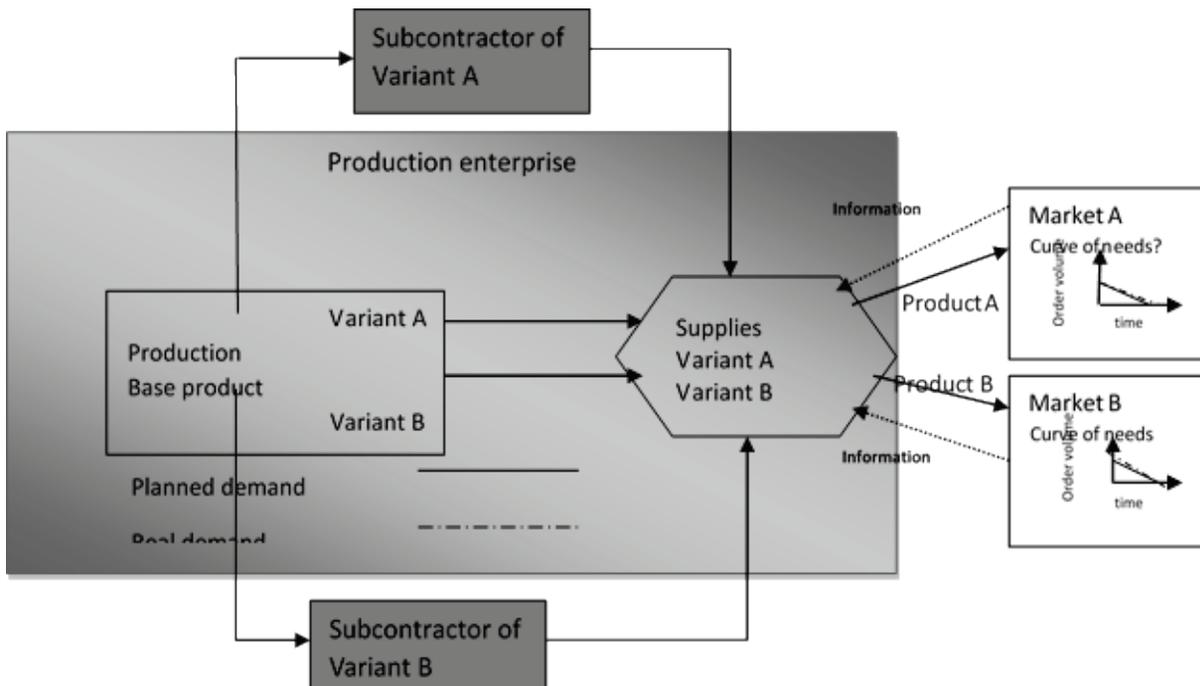


Fig. 1. A model of production to order, differentiation in a production company. Source: The author's study using a study by Kramarz M., 2014.

- Standard products - the degree of differentiation 1
- Multi-variant products (early differentiation) - the degree of differentiation 2
- Modular products (assembly to order) - the degree of differentiation 3

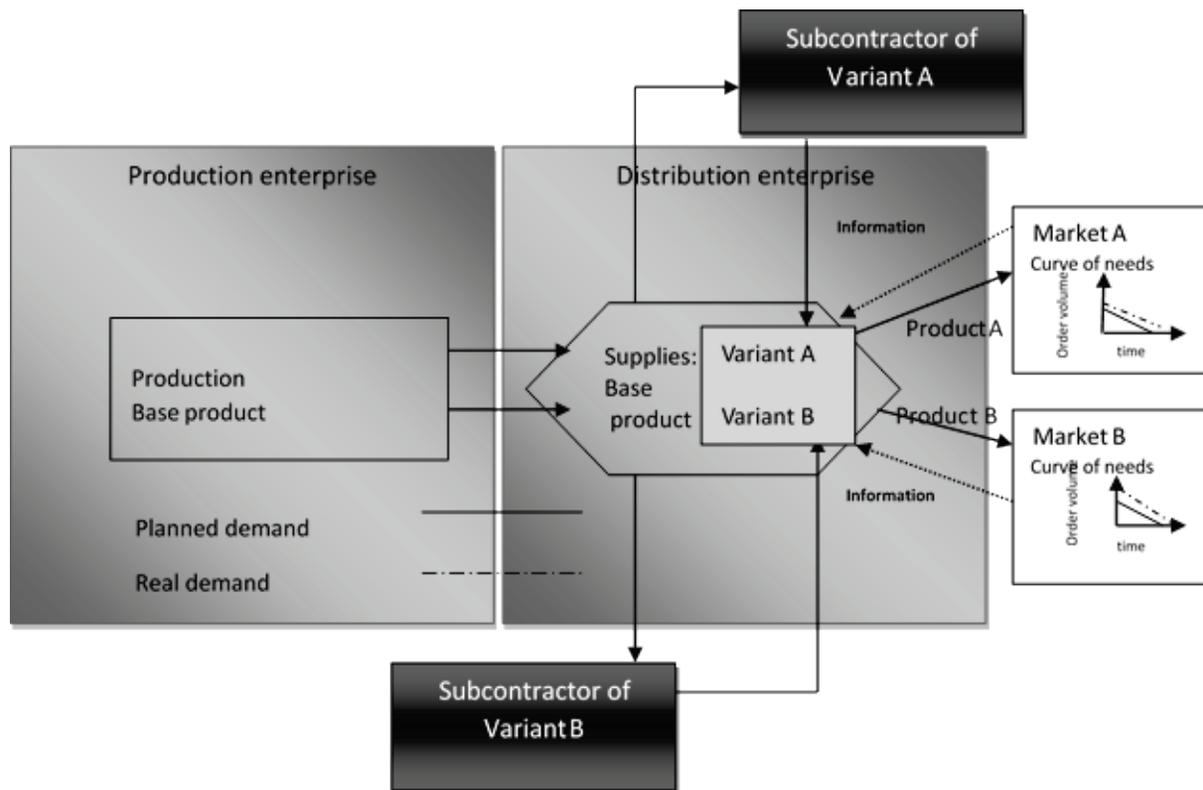


Fig. 2. A model of production to order, differentiation in a distributional enterprise.
 Source: The author's study using a study by Kramarz M. 2014.

The complexity of relations in modern supply chains results, among other things, from the necessity of subcontracting tasks of the postponed production. The formation of network relations comprehended in this way is especially well-founded in extremely innovative sectors and also in business lines where products are differentiated according to the recipients' needs. Consequently, elements responsible for extending network relations are especially those chain links of supply chains which use the postponed production strategy or are also accountable for distributing products on diverse markets. These organizations are qualified as central links of networks or flagship enterprises.

Lin, Yang and Arga (2009) notice that the position of a node in the relational sense means authority essential for exerting efficient influence on other participants of the network. Taking into account the social networks theory in characterizing the network it can be noticed that the social status of the node reflects its authority in the form of one-sidedly directed emotional ties - respect, liking, recognition (Czakoń 2012). Hagedoorn, Roijackers, Van Kranenburg (2006) remark that the centrality and the popularity of nodes in the network create a potential of exerting

influence on other members of the network. The central link in the network, fulfilling the above conditions, is defined in the paper as the flagship enterprise. Flagship enterprises have a decisive influence on the resilience of the network supply chain. Created network relations can both strengthen the resilience of the entire supply chain, as well as weaken it.

The resilience of the supply chain is understood as an organization / system property (attribute) expressing the rules, the procedures, the methods, the management techniques and the strategy, protecting the organization against negative effects of deviations occurring under the influence of disruptions. In the literature one can encounter an attempt to formulate recommendation for designing a resistant supply chain (Christopher, Lee 2001, Lee, Wolfe 2003, Rice, Caniato 2003, Kleidorfer, Saad 2005, Tang 2006). Sheffi (2005) notices that every type of disruption requires other activities, namely depending on the risk key factors the manner of building the resilience will be different. Kenyon and Neureuther (2012) present findings of the research concerning an adaptive model of risk assessment in a supply chain. They assess the risk through identification of disruptions in material flows because, as they stress, many

organizations, among key risk factors, mention deviations in materials flows, which result in worsening customer service indicators. At the same time, apart from identified factors causing disruptions in material flows it is essential to identify endogenic and exogenic factors which cause strengthening of effects of disruptions (Kramarz 2013). Transmission of disruptions along the stream of the value added, as shown by Świerczek (2013) in her research, is an essential determinant of the power of disruptions in the entire supply chain.

Tang (2006) perceives the resilience as an essential competitive superiority of the supply chain and suggests strategic development via smoothing the effects of disruptions (deviations). The author also stresses the meaning of the strategy of the postponed production, a flexible base of suppliers, multi-modularity and flexible transport. Christopher and Peck (2004) define the resilience of the supply chain as the ability of the supply chain to return to the original state (flexibility) or transition to a new and more suitable state under the influence of the occurring changes (adaptability).

Therefore, a flagship enterprise, whose task is to strengthen the resilience of the supply chain, can use three approaches referring to the regulatory methods in the management systems:

- Elimination of disruptions: counteraction to disruptions through influence on the state of

entry to the system, e.g. a narrowly conceived group of suppliers with signed contracts (contracts can define e.g. contractual fines for breaking their conditions), methods of improving processes, etc.

- Compensation of disruptions: influence on disruptions in the system through the different kinds of mechanisms increasing the flexibility, including supplies, subcontracting, etc.
- Smoothing of deviations: using an adjuster in the feedback system, influence on deviations (including delays during the order completion, lack of material e.g. at an extraordinary transport organization). The basis of the regulation are deviations of the state of exit from the required standard.

The research presented in the paper focused on strengthening the resilience through the system gaining its original state (compensation of disruptions) without transferring disruptions onto the following chain links of the supply chain.

Figure 3 shows relationships between the strategies of strengthening the resilience, mentioned in the literature, showing that certain activities are required to allow possible fulfilment of the aims of the superior strategy.

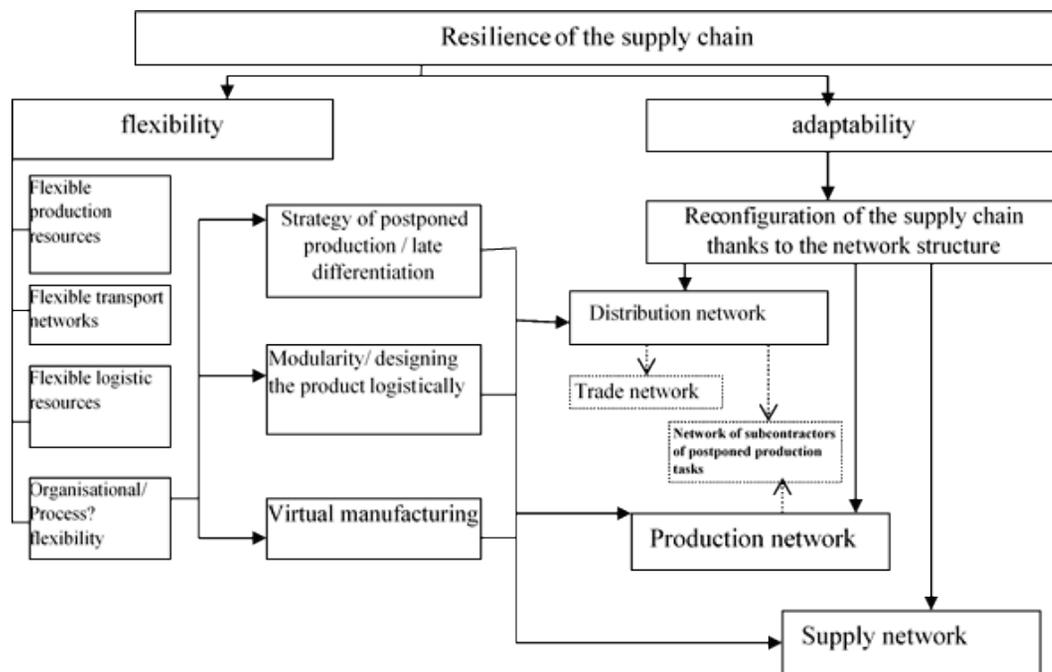


Fig. 3. Strengthening the resilience of the supply chain. Source: The authors' study.

The modularity and design of the product logistically are a manner of fulfilment of the postponed production strategy and one of possible strategies of product differentiation. The indicated strategies, being a consequence of the flexible organization and an endeavour to increase the flexibility in reaction to variable customers' preferences, require structures allowing adaptation to changes. Network structures enlarge the complexity of the whole production and the logistic system but also allow adaptation thanks to redundancy of resources (including both complementary ones and substitution ones) and their reconfiguration depending on the state of the environment. The postponed production can be completed through complex network relations between the base enterprise and subcontractors and the organization manner can take into account virtual production. The postponed production, as indicated before, can be completed both in the industrial company and in the distributional enterprise. Network relations and the redundancy of resources are shown as key items in creating adaptability. Adaptability uses the possibility of reconfiguration of networks built in each phases of the supply chain in order to achieve a new level of the equilibrium of the system.

The presented discussion induces to put forward two research questions based on which the author formulated the research hypotheses.

Research question 1: Does the degree of product differentiation influence the selection of the strategy of strengthening the resilience given that the strategy of strengthening the resilience depends on the effects of the disruptions in material flows?

H1. The growth of the degree of product differentiation increases the effects of the disruptions in material flows

Research question 2: Do flexible transport networks influence favourably on the resilience of the supply chain?

H2. Flexible transport networks decrease the effects of the disruptions in material flows of products differentiated according to the customer's order.

3. THE ASSESSMENT OF THE DISRUPTIONS IN MATERIAL FLOWS OF A SUPPLY CHAIN OF METALLURGIC PRODUCTS

In his previous works the author analysed three alternative strategies of building the resilience of the supply chain, depending in the level endogenic and exogenic interferences (Table 1).

Taking into account the findings to date, including especially determined limits of strengthening the resilience of the supply chain in three strategic variants, the research was broadened by the variant of flexible transport networks. Flexible transport networks are defined as integrated networks of logistic enterprises enabling complex fulfilment of logistic tasks. An example of flexible transport networks are logistic centres and logistic clusters.

While testing the first research hypothesis the author used data about disruptions in material flows in the network supply chain of metallurgic products. The data was gathered by means of cards for measurement of disruptions. The cards were supplemented by workers of the nodes of the network supply chain of metallurgic products every day for 12 months.

The findings show that the degree of the product differentiation has a significant influence on the effects of disruptions in material flows; however, the direction of the influence is different for each deviation. The effect of the disruptions which is most strongly stressed in the case of strongly differentiated products is an increase in the number of extraordinary shipments (O4). In the case of strongly differentiated products for the needs of recipients, enterprise prevent to the transmission of disruptions in supply chains (fig 2.), which is a proof of a decreasing number of identified deviations in material flows such as: the number of unfulfilled orders (O3), the number of incomplete orders (O2), the number of unpunctual orders (O1) and only slight deviations from the appointed stock levels (O5).

This relationship can be explained with the adopted process models because together with the growth of the degree of product differentiation the process models change from the model of production-to-store towards the models of assembly-to-order, production-to-order or, last but not least, for strongly complex and individualised products - designing a product to order.

Table 1. Characterization of strategic variants of strengthening the resilience of the supply chain.

	Model of supplies	Model of flexible resources	Cooperation model
Common assumptions	Materials decoupling point fulfilling tasks of the postponed production differentiating the base product to orders placed by the recipients		
	Transport cycle between the material decoupling point and the recipients		
	Occurrence of supplies of finished products (differentiated)		
	Occurrence of supplies of the base product (supplies on the entry to the system)		
	Unit costs of supplies		
	Unit costs of the transport		
Assessment criterion:	The logistic customer service and logistic costs (e.g. the assumption that the logistic customer service cannot be smaller than 0.90 and given this assumption searching for a solution with the lowest logistic costs)		
Assumptions characteristic for the model			
Characterization of demand	Multi-variant mass-differentiated product with a relatively stable demand for individual variants	Product differentiation depending on orders placed for individual variants of the product, large deviations from the forecast demand	Product differentiation depending on orders flowing on individual variants of the product or resulting from the specification included in the design of the variant of the product, very strong deviations from the forecast demand
The prevailing model of the process	BTF Build-to-forecasts	BTO Build-to-order	CTO/BTO Configure-to-order/ Built-to-order
Attributes of resources	Dedicated resources in MPR (material decoupling points)	Flexible resource in MPR, dedicated substitution resource at the subcontractor's	`
Cooperation	Limited, refers only to substitution resources, irregular relations (loose relations between the MPR and the subcontractor)	Limited, refers to the substitution resource, cooperative contracts (strong relations between the MPR and the subcontractor)	Strong, refers to substitution and complementary resources Diverse relations between the MPR and subcontractors

Source: The study based on: W. Kramarz, Modelling of material flows in the network supply chain. The resilience of the supply chain of metallurgic products. Difin 2013.

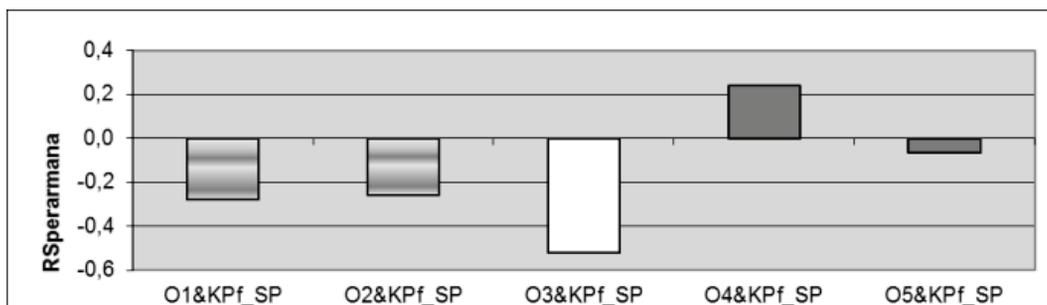


Fig. 4. The influence of the degree of product differentiation on deviations in material flows.
Source: The author's study.

It is worth drawing attention to the negative relationship between the growth of the degree of product differentiation and the punctuality and completeness of the fulfilled orders. The increase of the degree of product differentiation entails a decrease in the frequency of orders not fulfilled on time and those fulfilled incompletely. Such a state is in accordance with the differentiation of customers' requirements and therefore the

standards of the logistic customer service. Products with a slight degree of differentiation and standard products should be available from the reserves and the key element is the lead time. Metallurgic products are strongly differentiated, required at the following stage of production of final products, they are characterized with a long time of their production and logistic cycle, hence also the waiting time for the product, available by the

following chain link of the supply chain, is considerably longer than in the case of simple products, however expectations regarding punctual and complete fulfilment of the order are considerably higher.

The obtained results do not allow answering explicitly to the raised research question. It is so because the growth of the degree of product differentiation increases the number of extraordinary shipments without affecting negatively unfulfilled orders, orders fulfilled unpunctually or incompletely as well as deviations from the appointed stock levels.

Therefore, the first hypothesis failed to be tested favourably but the findings allowed designing a new variant of strengthening the resilience. This variant refers to the extraordinary transport fulfilled through flexible transport networks.

4. MODELLING THE STRATEGY OF STRENGTHENING THE RESILIENCE OF NETWORK SUPPLY CHAIN OF METALLURGIC PRODUCTS

The most important feature of flexible transport networks is fulfilment any transport order in the period of time appointed by the employer without having to pick (complete) the order. Flexible transport networks, including logistic centres and logistic clusters are characterized by a diverse and broad base of logistic resources composed of a logistic infrastructure of all organizations forming this type of network. Consequently, the unit cost of transport is appointed based on the cost of transport by a vehicle of a certain load capacity, treated in the model as the constant, divided by the number of loading units in the transport order.

When investigating the sensibility of the variant of strengthening the resilience through transport solutions the authors conducted simulation experiments based on a model created in Vensim DSS (Management System Dynamics). According to the findings of earlier research the author focused on extraordinary transport whose meaning in smoothening disruptions (strengthening of the resilience and not transferring disruptions onto the following chain links of the supply chain) increases directly proportionally to the degree of product differentiation. In the experiments, the sensibility of the system to changes of demand was examined. The author analysed two variants: a system with traditional transport (contract with a transport company) and a system with flexible

transport (cooperation with a transport network). For two products: product A is a product of a small degree of differentiation, Product B is a product of a large degree of differentiation.

In the model, the following assumptions were adopted:

- the growth of the degree of product differentiation requires greater involvement of a resource and means an increase in operations on the resource,
- operations connected with product differentiation can take place in the base enterprise or at the subcontractor's, the cooperation in the area of substitution resources),
- the growth of the degree of product differentiation increases the time of the production cycle,
- ordering an operation of product differentiation increases the time of the cycle of order fulfilment,
- the traditional transport (Trw) means fulfilment of transport tasks according to the contract and the schedule, it requires picking in compliance with the load capacity of the vehicle,
- flexible transport (TrNDZW) does not require picking, the lead time is shorter, the unit costs of transport are higher and dependent on the batch commissioned for the extraordinary transport,
- logistic costs (Kl) are costs of storage and transport,
- the level of the logistic customer's service (lok) was limited to the completeness of the fulfilled orders, appointed as the number of orders fulfilled completely in the time according to the stipulations of the contract compared to of the entire number of orders. The standards of the logistic customer service were determined on the level of 0.99.

The model developed in the Vensim DSS system was presented in Fig. 5.

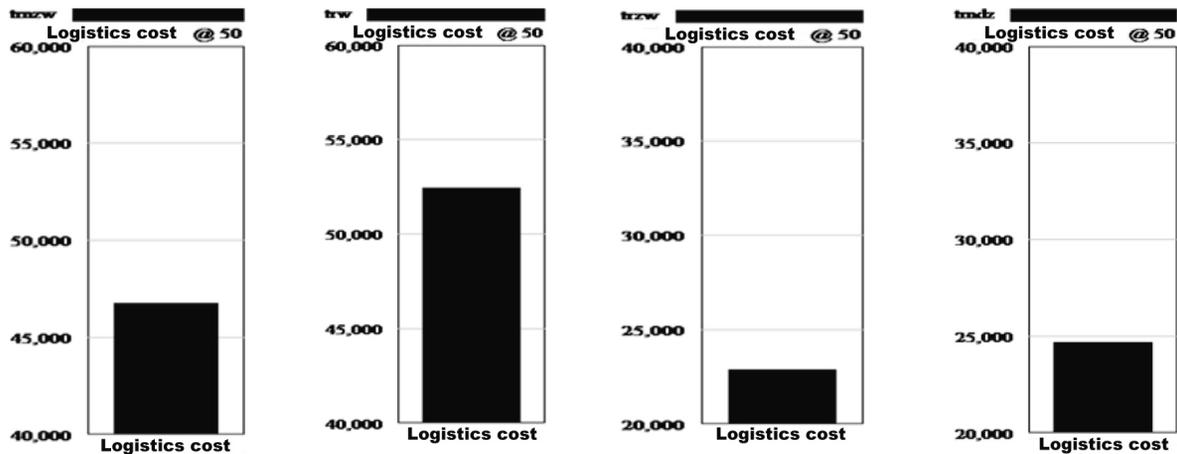


Fig. 6. Results of experiments simulation: level of logistic costs for the variant: a) product B, elastic transport, b) product B, traditional transport, c) product A, traditional transport, d) product A, elastic transport. Source: The authors' study.

5. CONCLUSIONS

The conducted literature research indicates an empirical and theoretical gap in the area of shaping the strategy of strengthening the resilience of network supply chains with a large degree of differentiation. Therefore, the strategies of strengthening the resilience presented in Chapter 2 were supplemented by the strategy of flexible transport networks (Table 2)

The conducted empirical research in the network supply chain of metallurgic products did not allow testing the first hypothesis positively. The results of the statistical analyses have shown, through, regularities connected with the increase in the extraordinary transports together with an increase in the degree of product differentiation. These relationships were used in the design the simulation model. The conducted simulation experiments show that the positive effects of the fulfilment of the extraordinary transport with the utilization of flexible transport networks increase as compared to the variant of normal transport (a contract signed with a selected transport company) together with the degree of product differentiation. The results of experiments do not allow rejecting the second hypothesis in the metallurgic products industry.

Table 2. New variant of improving the resilience.

	The model of flexible transport networks
Assumptions	Material decoupling point fulfilling tasks of the postponed production differentiating the base product to orders placed by the recipients
	Transport cycle between the material decoupling point and the recipients
	Occurrence of supplies of finished products (differentiated)
	Occurrence of supplies of the base product (supplies on the entry to the system)
	Unit costs of supplies
	Unit costs of the transport
Assessment criterion:	The logistic customer service and logistic costs (e.g. the assumption that the logistic customer service cannot be smaller than 0.99 and given this assumption searching for a solution with the lowest logistic costs)
Characterization of demand	Product differentiation depending on orders flowing on individual variants of the product, very strong deviations from the forecast demand
The prevailing model of the process	BTO (Batch to order) Designing to order, Production to order
Attributes of resources	Flexible resource in the base enterprise, dedicated substitution resource at the subcontractor's
Cooperation	Limited, refers to the substitution resource, cooperative contracts (strong relations between the base enterprise and the subcontractor)

Source: The authors' study.

The individualisation of products is one of the key competitive strategies in the metallurgic industry. Metallurgic products are differentiated to the needs of many different industry lines, including especially the construction industry, the machine industry, household equipment and electronic devices, as well as the motor industry. Metallurgic products are one of many examples of using the strategy of late product differentiation. Concentrating the research on one industry line was essential due to the adopted methodology and the construction of the simulation model. However, it is worth developing research over strategies of strengthening the resilience of strongly differentiated network supply chains extending it on other business lines, which will allow generalization of the obtained results.

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