



GATHERING KNOWLEDGE ABOUT DISRUPTIONS IN MATERIAL FLOW IN NETWORK SUPPLY CHAIN

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ABSTRACT. Background: The article aims at presenting a study into disruptions in a network supply chain of metallurgic products. The research was carried out in the years 2011-2013. Network supply chains include key chain links for building the resistance. These chain links affect material flows of the whole supply chain through silencing disruptions. Those predisposed to form a strategy strengthening the resistance of the whole network supply chain are organizations fulfilling the assumptions of flagship enterprise.

Material and methods: The research is carried out in two stages: the stage of identification of disruptions (risk factors) and the stage of identification of strengthening disruptions zones. The authors carried out simulation experiments based on three models built in the management system dynamics technique (VensimDSS). The proposed methodology required constructing original tools for measuring disruptions and zones strengthening the disruptions in the form of cards for measuring disruptions.

Results: The value added is grouping of disruptions in risk factors distinguished in terms of the frequency of the occurrence of disruptions and their results. The authors proposed and defined the notion of zones of strengthening disruptions. The zones are formed from sets of factors strengthening disruptions with similar influence on disruptions.

Conclusions: The IT system composed of a module for identification of disruptions in material flows and a simulation model is a proposal dedicated to organizations controlling material flows in a network supply chain in the conditions of disruptions.

Key words: gathering knowledge, flagship enterprise, network supply chain, disruptions.

INTRODUCTION

The first stage of knowledge management is knowledge acquisition in the organization and in its environment [Probst, Raub, Romhardt 2002, Salmador, Florin 2012]. Information turns into knowledge when it is interpreted and related to a context by its holder. Knowledge management in supply chains refers to a wide spectrum of issues, including the manner of decision making in particular organizations, gaining and processing knowledge about customers, etc. Relatively little attention is devoted in the research to factors causing deviations from the planned material flows.

Gathering knowledge about disruptions is an essential task of the flagship enterprise whose part is to silence disruptions so that they will not transfer to the subsequent supply chains. The flagship enterprise controls material processes in supply chains, coordinates tasks performed by participants of the network and, having knowledge on disruptions in the entire supply chain, stands a chance to strengthen its resistance.

The paper presents the idea of gathering knowledge in order to strengthen the resistance of a network supply chain.

The first part of the paper indicates approaches to measurement the disruptions in a supply chain which have been presented for the past years in the literature. The first part was closed with the expression of the research hypotheses. The second part indicated the author's idea and the resulting methodology of gathering knowledge within the range of disruptions in material flows, referring to contemporary solutions in this field. The worked out methodology was applied in a network supply chain of metallurgic products.

NETWORK STRUCTURE OF SUPPLY CHAIN - FLAGSHIP ENTERPRISE

The complexity of the relations in contemporary supply chains results from dynamic changes in the environment as well as variable recipients' needs. Because of the fact that contemporary supply chains are characterized with a complex structure on each stage of creating the value added, in this paper they will be defined as "network supply chains". Between the entities functioning in the supply chain, the network of connections and relationships is established. The strength of the positive relations represents the level of integration (consistency). Integration (consistency) is one of the constitutive elements of the supply chain which depend on the quality of relationships between the entities constituting the supply chain as well as the size of the established system [Awasthi, Grzybowska 2014].

Creating network relations is especially justified in extremely innovative sectors and in those industries where products are diversified according to the recipients' needs [Brzóška 2013; Chan, Wang, Luong, Chan 2009]. Harryson, Dudkowski, Stern [2008] point out that not only the number of network relations but also the variability of their forms constitute the basis which provides the foundation for organizations to develop new ideas and skills using their key competences and resources.

When defining the role of each link in the network it is worth looking at the graph theory.

Determining the centrality of the node according to the degrees of tops (numbers of relations built on the entry and the exit by a given organization) often also means the assessment of the popularity or influentiality of nodes. The centrality according to the degrees of tops is useful for determining which nodes are the key ones from the point of view of spreading information or affecting the nodes situated in the immediate vicinity. Another indicator of the role of a node in a network is mediation. Mediation shows which nodes are the most important from the perspective of communication between nodes. Large mediation nodes are potential points of loss of cohesion of the network. 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 a network creates a potential for exerting influence on other members of the network. The central link in the network, fulfilling the above-mentioned conditions, is defined in the paper as the flagship enterprise.

During the life of a flagship enterprise networks have features which predispose them to create new relationships. Consequently, these nodes more often than others decide about adding new nodes to the network. The phenomenon of preferential addition of results when creating a network in which a small number of nodes has a very high degree of networkness. The remaining nodes of such a network have a considerably lower degree of networkness. Preferential adding usually results in the phenomenon of small worlds (cliques).

When referring these features of the flagship enterprise to the supply chain it can be noticed that these organizations are not only partners of their suppliers and recipients but simultaneously they widen relations on a given stage of the supply chain creating network

relations. A coordination of material flows is a basic task of the flagship enterprise. The coordination is based on three storage payments: effort of participants in the given system, the synergy of their action and the general aim [Grzybowska 2012]. Coordination in the supply chain is one of the barriers of their integration alongside the lack of trust, the lack of understanding the regulations, inappropriate IT systems and differences in the indicated objectives [Grzybowska, Kovács 2014]. Flagship enterprises in the network, understood in this manner, have an essential influence on the amplification of the resistance of a supply chain.

Sheffi [2005] notices that every type of disruptions requires other activities so, depending on key risk factors, the way of building the resistance will be different. Consequently, the first step in the research into the resistance of a supply chain is to identify disruptions and factors amplifying them. Deviations in the anticipated and real level of customer service is the most important measure showing the results of disruptions in material flows.

Sheffi [2005], while investigating ways in which enterprises can respond to strong disruptions and conduct activities reducing threats connected with disruptions, claimed that:

- Reduction of bottlenecks connected with disruptions occurs through monitoring, early-warning systems (an increase in the sensitivity of a supply chain), a quick reaction to the change of needs, collaboration and redundancy
- Operating flexibility is increased through standardization of parts, facilitating their replaceability (product modularity, product designing from the logistic perspective), the postponed production strategy or mass customization of products (multi-variantness) in response to changes of needs which are difficult to forecast, management of relations with customers and suppliers.

Taking into account these requirements the authors proposed an original methodology of gathering knowledge for the needs of strengthening the resistance of a network supply chain. Two research questions, which

became the basis of the put forward hypotheses, were as follows:

Research question 1. What is the influence of disruptions in a network supply chain of metallurgic products on deviations in material flows.

H1. Disruptions affect an increase in the frequency of deviations in material flows

Research question 2. What is the influence of factors strengthening the disruption on disruptions in a network supply chain of metallurgic products

H2. Factors defining the zones of strengthening disruptions intensify disruptions in material flows.

THE CONCEPT OF GATHERING KNOWLEDGE ABOUT DISRUPTIONS IN MATERIAL FLOW IN A NETWORK SUPPLY CHAIN

Problems indicated by managers, occurring as a result of including subcontractors into the structure of flows induced to channel the research in such a way as to allow working out tools permitting identification and assessment of disruptions as well as an analysis of decision-making variants connected with compensation of disruptions, through considering two options depending on the frequency of the appearing disruptions [Machado et al 2007; Chopra et al 2007]:

- flexibility allowing compensation of disruptions via designed mechanisms (e.g. the flexibility of resources, the supplies surplus, the redundancy of subcontractors, suppliers, logistic co-operators),
- adaptability involving a change of procedures or network structures

In the research the authors used secondary data gathered for analysing a network supply chain of metallurgic products concerning formation of supplies as well as initial data in the area of the identification of disruptions and assessment of their influence on material flows.

Gathering the initial data was conducted by means of the diary method. The measurement

tool was a questionnaire called the "the disruption measurement card". The questionnaire contained both closed as open questions. The research conducted by means of disruption measurement card aim at:

- determining which disruptions are not caught by the IT systems supporting material flows in the investigated organizations,
- limitation of potential disrupting factors, selected on the basis of the literature research, to the ones essential for the investigated supply chain.

Disruption measurement cards were made available in three research objects which are different stages of the supply chain of metallurgic products. The cards were filled every day for 12 months by workers of different organizational units. The obtained data were converted in the Statistica software.

The process of the analysis of disruptions is a multi-staged one [Blackhurst, Craighead, Elkins, Handfield 2005]. At the first stage the authors suggested using the cause and effect analysis for identifying the relationship between disruptions and deviations. Thanks to this, this stage of research was conducted according to the following steps [Kramarz 2013]:

- identifying deviations in material flows,
- indicating the relationship: a deviation in material flows - a result of the disruption (organizational results, e.g.: difficulty in functioning of the process, lack of workers, equipments, lack of materials, lack of information, financial results, including costs connected with extraordinary transport, costs of lost sales),
- identifying the place where the disrupting factor occurs (the base enterprise, the supplier, the subcontractor, transport processes),
- identifying factors strengthening the disruption
- assessment of the total of losses connected with the appearance of the deviation.

The classification of disruptions is based on the system approach which allows dividing disruptions according to the following phases: entry, inside the system, which involves

processes of transformation and exit. The cause and effect analysis allows sorting out the investigated variables in the following sets: deviations in material flows, factors causing disruptions, chain links of the supply chain generating disruptions, factors strengthening disruptions. Thanks to such an approach it is possible to assess the power of their influence on deviations in the realized processes. The set of factors causing disruptions was categorised into endogenous factors connected with the characterization of the order, with the characterization of the base enterprise and with the characterization of the partner, and exogenous actors connected with the environment of the process of order completion.

At this stage research the authors:

- conducted pilot studies which confirmed the thesis that current IT tools were not sufficient for strengthening the resistance of network supply chains
- identified the most frequent deviations in material flows and their results for organizations in a network supply chain of metallurgic products
- defined risks factors distinguished in respect of similar frequencies of the occurrence of disruptions
- defined zones of strengthening of disruptions.

Factors strengthening disruptions as well as risk factors were distinguished by means of the factor analysis.

In the disruption measurement card factors causing disruptions were left in the form of an open question, allowing workers who filled the questionnaire every day to name freely the event which caused deviations in material flows. It was a conscious approach to the manner of measurement which aimed at catching all possible events, and not only those which were known to the author of the questionnaire while creating it. The mentioned disruptions were characterized descriptively in respect of the reasons of occurrence and the results, the subject responsible for the occurrence of a disruption, and they were assessed according to the power of the influence on the organization according to the

organizational and financial criterion. The manner of rating the power of the influence of disruptive factors was provided in the table. Factors strengthening disruptions in material flows were also assessed every day. Respondents marked if a given event took place on that day and, if they rated (in the event of a positive response) what power of influence it had on disruptions in material flows.

DISRUPTIONS AND ZONES OF STRENGTHENING DISRUPTIONS IN A NETWORK SUPPLY CHAIN OF METALLURGIC PRODUCTS

The carried out literature and pilot research allowed selecting 32 factors causing disruptions in material flows in a network supply chain of metallurgic products. The initial analysis of the relevance of the relationship between selected variables, showed correlations between certain variables, therefore the authors decided to carry out the factor analysis in order to connect strongly correlated variables, and consequently reduce the number of variables. Risk factors distinguished in this way were analysed in respect of the factual justification of connecting definite variables in a given risk factor. As a result of the carried out analysis the authors selected 6 risk factors significantly diversified in respect of the frequency of occurrence of disruptions.

- Factor 1 refers to the organization of production and logistic processes, disruptions are generated by wastage ('muda' according to Lean),
- Factor 2 refers to supplies, disruptions are generated by suppliers,
- Factor 3 involves disruptions arisen at the stage of the realization of logistic processes between the base enterprise and the customer,
- Factor 4 involves disruptions generated by the subcontractor,
- Factor 5 involves disruptions generated by the supplier in the area of the reliability of supplies,
- Factor 6 involves disruptions generated by the base enterprise in the area of order

realization including monitoring and processing of orders.

The distinguished risk factors not only represent significantly the variability of disruptions in respect of the frequency of their occurrence but also have their essential reason. The division of the factors is compatible with the phasic (system) perspective in logistics so it involves suppliers, the base enterprise, logistic enterprises, customers. The authors distinguished two types of risk factors within the base enterprise itself. The first risk factor expresses disruptions resulting from bad organization of work. Variables forming this factor refer to wastage factors in an organization (muda), well-known from the literature. The sixth risk factor referring to the risk generated by the base enterprise refers to events happening as a result of the maladjustment of the supply base of the organization and inspection procedures of the quality inspection to the real requirements of material flows. Similarly, disruptions generated by the supplier in respect of the frequency constituted two risk factors. The second risk factor comprises events connected with completeness, quality or lack of supply, and the fifth risk factor contains events associated with the time of delivery realization.

At the stage of identification of disruptions in material flows in a network supply chain the authors also distinguished key deviations (as results of disruptions):

- Unpunctual order realization O1,
- Incomplete order realization O2,
- Unrealized order O3,
- Deviations from the determined stock levels O4,
- Extraordinary transport O5.

The correlation analysis showed that the increase in the frequency of disruptions generated by suppliers is accompanied by an increase in the frequency of unpunctual orders and extraordinary transports. However, the growth of factors from the wastage group (muda) is accompanied by an increase in the frequency of deviations from the determined stock levels. The growth of disruptions generated by the subcontractor causes an

increase in the frequency of deviations from the determined stock levels.

The canonical analysis, where deviations in material flows were the dependent variable and risk factors were the independent variable, confirmed the influence of the frequency of disruptions on deviations (the canonical correlation coefficient $R^2=0,74$ at the relevance level $p=0,0042$). Consequently, hypothesis 1 was confirmed.

Disruption in material flows can become stronger through the influence of other factors which in the literature are defined as factors of amplification of disruptions. The assessment of factors of amplification of disruptions was carried out on a research sample of 54 enterprises of a network supply chain of metallurgic products. Particular zones were selected on the basis of the factor analysis. Taking into account the findings of the literature research (finished with the selection of factors of amplification of disruptions) and also the findings of the empirical research carried out in earlier stages (including especially separating risk factors in respect of frequency) zones of amplification of disruptions were indicated.

The factor analysis was carried out in two steps. At the first step the authors singled out 12 groups of factors which were represented by 20 factors of amplification of disruptions and 97% explained the variability of the examined phenomenon. Not all groups were characterized with a significant representation of factors of amplification of disruptions. At the second step the authors distinguished 5 zones of amplification of disruptions. The description of zones of amplification of disruptions was presented in Table 1. The distinguished 5 zones is represented altogether by 17 factors of amplification of disruptions:

Zone 1 - Zone of amplification of disruptions in the microenvironment of the base enterprise in the suppliers' environment
Zone 2 - Zone of amplification of disruptions in material flows on the line of communication between the nodes of the network supply chain
Zone 3 - Zone of amplification of disruptions in the area of the market
Zone 4 - Zone of amplification of disruptions resulting from limitations of capacity

Zone 5 - Zone of amplification of disruption in the area of the macro-environment of the network supply chain.

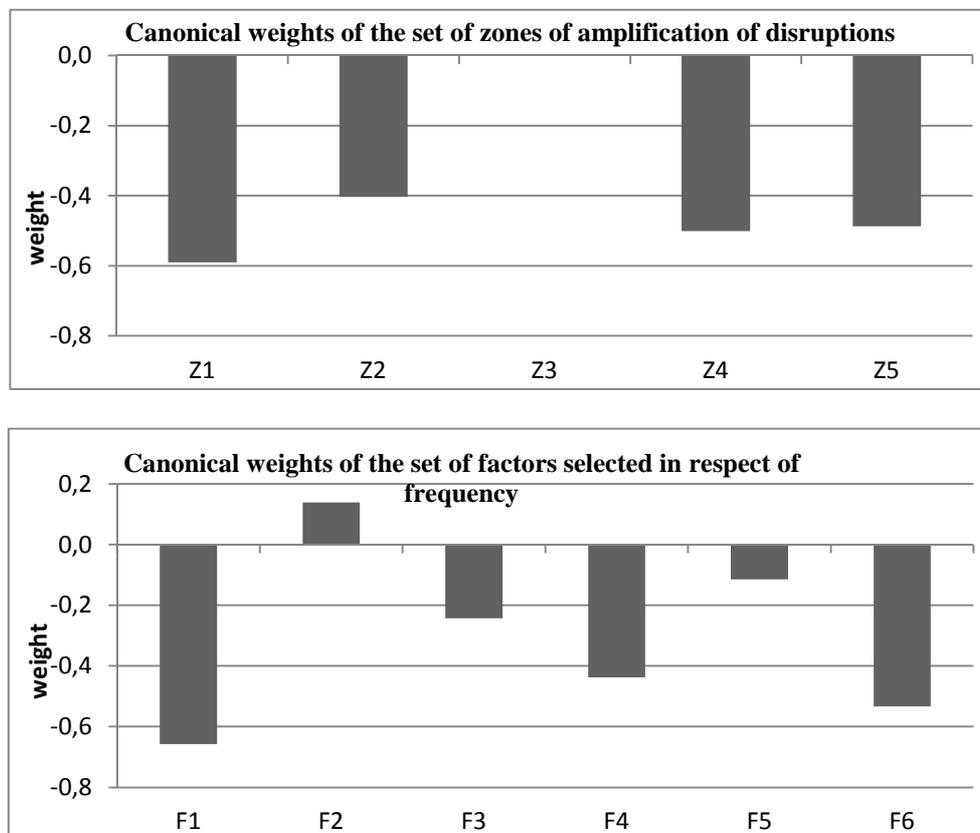
The factors mentioned in zones of amplification of disruptions in 93% explain the variability of factors of amplification of disruptions. The content-related analysis of factors of amplification of disruptions representing particular zones of amplification of disruptions allows acceptance of the division received by means of the factor analysis. The authors indicated a possibility of dividing the factors of amplification of disruptions into homogeneous, in respect of the effect on the frequency of disruptions presented in risk factors, groups defined with zones of amplification of disruptions.

The analysis of the influence of factors strengthening disruptions on the frequency of disruptions expressed in risk factors was effected by means of the canonical analysis, where the components of the independent variable were zones strengthening disruptions, and the dependent variable was represented by risks factors separated in respect of frequency. The obtained configuration of components of the dependent and the independent variable (fig. 1), which significantly explains the influence of zones of amplification of the disruption on risks factors distinguished in respect of frequency, took the canonical correlation coefficient $R=0.699$ at the relevance level $p=0.0054$.

Zones 1,2,4 and 5 strongly and favourably amplify the risk factors distinguished in respect of frequency, whereas they exert the strongest influence on the growth of the frequency of disruptions connected with wastage in the base enterprise and connected with unpunctuality of deliveries generated by the supplier. In the obtained configuration only the second risk factor (disruptions generated by suppliers, including defective or incomplete delivery) has a negative and very low canonical coefficient. Consequently, it can be noticed, first of all, an essential influence of zones strengthening disruptions on the punctuality of processes realized by the supplier and on the organizations of processes in the base enterprise. The findings of this part of the research allow adopting Hypothesis 2. At the

same time, the obtained findings in the area of testing both of the research hypotheses became

the basis for constructing a simulation model which is a module of an IT tool.



Source: The authors' study

Fig. 1. Results of the canonical analysis
Rys. 1. Rezultat analizy kanonicznej

CONCLUSIONS

The network structure of the supply chain enlarges the flexibility through the redundance of production and logistic resources. Flexibility, however, increases the resistance of the entire supply chain on disruptions

In such structures it is extremely essential to gather knowledge on disruptions. The proposed methodology of measuring disruptions including identification of disruptions, indication of the risk factors and zones of amplification of disruptions aims at adjustment of the designed IT tool which allows knowledge gathering under the specificity of a given industry.

The modules designed in the tool, i.e. the modules for tracking disruptions and for

tracking real material flows, compatible with the ERP system, allow undertaking activities to correct the size and the frequency of deliveries and the volume of buffer reserves according to the developed real-time strategies of amplification of the resistance.

The system also allows recording deviations in the past periods and making a list of historic data. These provide the basis for estimating the trends connected with disruptions and referring them to the cooperators' attributes.

The system takes into account the stochastic aspect of cooperation. Through historic analyses it is in a position to assess the variability of demand and deliveries on the part of cooperators as well as the sizes and the reasons of deviations and use this knowledge for material flow management.

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GROMADZENIE WIEDZY O ZAKŁÓCENIACH W PRZEPIYWACH MATERIAŁOWYCH W SIECIOWYM ŁAŃCUCHE DOSTAW

STRESZCZENIE. Wstęp: Artykuł ma na celu prezentację badań nad strategiami wzmacniania odporności w sieciowym łańcuchu dostaw wyrobów hutniczych. Badania przeprowadzono w latach 2011-2013. W sieciowych łańcuchach dostaw istnieją ognia kluczowe dla budowania odporności. Ognia te oddziałują na przepływy materiałowe całego łańcucha poprzez wytłumianie zakłóceń. Predysponowane do kształtowania strategii wzmacniającej odporność całego sieciowego łańcucha dostaw są przedsiębiorstwa flagowe. Prowadzone badania miały na celu wskazanie metodyki gromadzenia wiedzy pozwalającej przedsiębiorstwom flagowym wzmacniać odporność sieciowego łańcucha dostaw.

Metody: Wzmacnianie odporności w sieciowych łańcuchach dostaw wymaga opisu struktury sieciowego łańcucha dostaw, charakterystyki przedsiębiorstw sterujących przepływami a także zdefiniowania czynników ryzyka i stref wzmacniania zakłóceń. Uwzględniając te wymagania zaproponowano oryginalną metodykę gromadzenia wiedzy dla potrzeb wzmacniania odporności sieciowego łańcucha dostaw. Definiowanie czynników ryzyka oraz stref wzmacniania zakłóceń a także charakterystyka sieci według wyodrębnionych atrybutów są rekomendowanymi przez autorów etapami budowy modelu wspomaganie decyzji strategicznych materiałowego punktu rozdziału w zakresie wzmacniania odporności łańcucha dostaw. Badania obejmują zarówno wskazanie wpływu struktury łańcucha dostaw na zakłócenia oraz strategii i roli materiałowego punktu rozdziału w wygładzaniu zakłóceń, jak i wytypowanie zbioru czynników zakłócających, przeprowadzenie analizy przyczynowo skutkowej obejmującej zakłócenia i skutki zakłóceń z perspektywy poszczególnych ogniw łańcucha dostaw oraz wskazanie potencjalnych czynników wzmacniających zakłócenia.

Wyniki: Wartością dodaną, wzbogacającą teorię zarządzania jest zgrupowanie zakłóceń w czynnikach ryzyka wyodrębnionych pod względem częstotliwości występowania zakłóceń oraz ich skutków. Ponadto zaproponowano i zdefiniowano pojęcie stref wzmacniania zakłóceń. Strefy ukształtowane są ze zbiorów czynników wzmacniających zakłócenia mających podobny wpływ na zakłócenia.

Wnioski: Proponowane podejście gromadzenia wiedzy pozwalające na modelowanie przepływów materiałowych i budowę strategii wzmacniania odporności sieciowego łańcucha dostaw zostało zweryfikowane w wybranej organizacji spieniającej założenia przedsiębiorstwa flagowego sieciowego łańcucha dostaw wyrobów hutniczych.

Słowa kluczowe: przedsiębiorstwo flagowe, gromadzenie wiedzy, zakłócenia, sieciowy łańcuch dostaw

SAMMELN VON WISSEN ÜBER STÖRUNGEN IM MATERIALFLUSS INNERHALB EINER NETZWERK-LIEFERKETTE

ZUSAMMENFASSUNG. Einleitung: Der Artikel bezweckt eine Präsentation von Forschungen über die Strategien der Stärkung von Beständigkeit innerhalb der Netzwerk-Lieferkette für Hüttenerzeugnisse. Die Forschungen wurden in den Jahren 2011-2013 durchgeführt. Innerhalb der Netzwerk-Lieferketten bestehen Glieder, die schlüsselhaft und ausschlaggebend für den Aufbau derer Beständigkeit sind. Die einzelnen Glieder können die Materialflüsse der ganzen Lieferkette durch die Eindämmung von Störungen beeinflussen. Für die Ausgestaltung der Strategien, die die Beständigkeit der ganzen Netzwerk-Lieferkette zu stärken vermögen, sind am meisten die Flaggunternehmen prädestiniert. Die durchgeführten Forschungen hatten zum Ziel, eine Methodik für das Sammeln von Wissen zu ermitteln, die den Flaggunternehmen erlaubt, die Beständigkeit der Netzwerk-Lieferkette zu stärken.

Methoden: Die Stärkung der Beständigkeit in den Netzwerk-Lieferketten bedarf einer Beschreibung von Struktur der Netzwerk-Lieferkette, ferner einer Charakteristik der die Materialflüsse steuernden Unternehmen und einer Definierung von Risikofaktoren und Zonen für die Stärkung von Störungen. Unter Berücksichtigung dieser Anforderungen hat man eine originelle Methodik für das Sammeln von Wissen zwecks der Stärkung der Beständigkeit der Netzwerk-Lieferkette vorgeschlagen.

Die Definierung von Risikofaktoren und Zonen für die Stärkung von Störungen sowie die Charakteristik eines Netzwerkes nach den ausgewählten Attributen machen die durch die Autoren rekommenierten Etappen des Aufbaus eines Modells für die Unterstützung strategischer Entscheidungen im Bereich der Stärkung der Beständigkeit der Lieferkette aus. Die Forschungen umfassen die Festlegung der durch die Struktur der Lieferkette bedingten Beeinflussung der Störungen sowie die Ermittlung der Strategie und Rolle der Material-Verteilungsstelle bei der Ausglättung der Störungen. Sie lassen darüber hinaus die störenden Einflussfaktoren erkennen und erlauben die Ursache-Wirkungs-Analyse durchzuführen, die die Störungen und ihre Auswirkungen aus der Perspektive der einzelnen Kettenglieder erfasst und auf die potenziellen, die Störungen stärkenden Einflussfaktoren hinweist.

Ergebnisse: Die Wertschöpfung, die die Management-Theorie bereichert, besteht in der Gruppierung der Störungen innerhalb der Risikofaktoren, die hinsichtlich der Intensität des Auftretens der Störungen und ihrer Auswirkungen ermittelt werden. Anschließend hat man den Begriff für die die Störungen stärkenden Zonen vorgeschlagen und definiert. Die Zonen werden aus den Mengen der die Störungen stärkenden und sie ähnlicherweise beeinflussenden Faktoren ermittelt.

Fazit: Das vorgeschlagene Herangehen an das Sammeln von Wissen, welches das Modellieren der Materialflüsse und den Aufbau einer Strategie für die Stärkung der Beständigkeit der Netzwerk-Lieferkette erlaubt, wurde in einer ausgewählten, die Anforderungen des Flaggunternehmens erfüllenden Organisation der Netzwerk-Lieferkette für Hüttenerzeugnisse verifiziert.

Codewörter: Flaggunternehmen, Sammeln von Wissen, Störungen, Netzwerk-Lieferkette

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