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The nature of the intercontinental supply chain and the building of its resilience in a company performing quality analyzes of engine oils

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Abstract

This study aims to identify a model for building a resilient supply chain in a company testing engine oil samples. Unstructured face-to-face and structured remote interviews were used as the research methods. The proposed contextual research procedure allows for the elucidation of the content of the components of the final resilient supply chain model and may facilitate theory building on the basis of future multiple case studies. As a result of the research, it was found that at the level of the described chain, its strength and continuity of flow are based on the durability of relationships with suppliers, speed, trust, and information sharing, the role of which has been explained in relation to the nature of the supply chain. Due to the nature of the chain, building its resistance on the basis of agility, which is most often indicated in model approaches, has no justification in this case. It was also established that in this process, 4.0 technologies such as the internet of things (IoT), machine learning, artificial intelligence, and cloud technologies are more important for management at the level of the entire corporation than at the level of the tested chain. The analysis covered the supply chain embedded in the industry, which (according to the author's knowledge) was not discussed in the context of logistics processes in world literature. Therefore, the results of the work undertaken are of great cognitive value.

Introduction

Taking into account the dominant research topics over the last three decades in the field of the supply chain, it can be concluded that they mainly relate to inventories (1990–1999), cost aspects (2000–2014), sustainability (2015–2019) and, currently, digitization (Maryniak et al., 2020). The topic of chain resilience appears in the context of eliminating disruptions in flows and determining the appropriate level of inventory, risk management, the issue of costs of lost benefits and penalties related to non-delivery, and the use of 4.0 technology to strengthen the chain or in the context of showing the relationship of resistance to the chain sustainable and green issues. Due to recent events related to the pandemic, the war in Ukraine, and the unstable geopolitical situation, as well as due to strategic changes in supply chains, this topic is gaining importance and, thus, becoming an increasingly interesting and needed research field. Based on the review of the SCR definition (Orlando et al., 2022), it can be concluded that resilience refers to the phase of preparation before disruptions, the response to them, and the ability to find oneself

in the new economic reality. This study assumes that the resistant chain is a chain that, as a result of disturbances of internal or external factors, can quickly reach the starting position or change it (through location and product configuration, relationships with contractors, and internal reorganization) so that it does not disturb the essential ways of business continuity. It is, therefore, a certain ability to resist shocks occurring in the supply chain. Hence, it is important to show how companies cope with this challenge. Models and research frameworks for resistant chains are discussed in the literature on the subject (Table 1).

Some authors have discussed the factors that determine their vulnerability, while others point to eliminating disturbances. Regardless of the nomenclature, the present authors try to identify lists of resistance-supporting elements or lists of constructs/

Table. 1. Factors that make up the model of building resilience supply chain – literature not present in the previous review lists

Number of factors	Type of research	Authors
6	empirical	Tasnim, Z., Shareef, M.A., Dwivedi, Y.K. et al. (2022)
3	empirical	Iftikhar, A., Purvis, L., Giannoccaro, I. et.al. (2022)
15	empirical	Baig, M.M.U., Ali, Y. & Rehman, O.U. (2022)
7	empirical	Ozdemir, D., Sharma, M., Dhir, A. et al. (2022)
10	empirical	Kaur, H. & Singh, S.P. (2022)
4	empirical	Queiroz, M.M., Wamba, S.F., Jabbour, C.J.C. et al. (2022)
4	empirical	Wang, J. & Zhao, C. (2022)
2	empirical	Orlando, B., Tortora, D., Pezzi, A. et al. (2022)
13	literature review	Maharjan, R. & Kato, H. (2022)
2	empirical	Irfan, I., Sumbal, M.S.U.K., Khurshid, F. et al. (2022)
2	empirical	Bag, S., Rahman, M.S. Srivastava, G. et al. (2022)
3	theoretical	Ramachandran,S. & Balasubramanian, G.(2022)
12	empirical	Zamiela, C., Hossain, N.U.I. & Jaradat, R. (2022)
4	empirical	Yazdanparast, R., Jolai, F. & Pishvaee, M.S. et al. (2022)
11	empirical	Das, D., Datta, A., Kumar, P., Kazancoglu, Y. et al. (2022)
6	literature review	Bechtsis, D., Tsolakis, N., Iakovou, E. et al. (2022)

elements decomposed into detailed parts. These elements are examined by indicating their importance in the hierarchy or by showing the strength of their relationship. Among others, Tasnim et al. (Tasnim et al., 2021) proposed a model for supporting the resilience of the tourism supply chain, which consists of six modules. Baig et al. (Baig, Ali & Rehman, 2022) examined the importance of fifteen elements in the oil supply chain. Ozdemir et al. (Ozdemir et al., 2022) focused on the velocity epicenter of retail supply chain resilience and studied seven constructs. Queiroz et al. (Queiroz et al., 2022) studied the resistance of chains embedded in several different industries using four constructs. In turn, Iftikhar et al. (Iftikhar et al., 2022) also tested resistance on the basis of various industries using three constructs. Wang and Zhao (Wang & Zhao, 2022) considered four constructs, additionally linking this issue with carbon footprint reduction. Kaur and Singh (Kaur & Singh, 2022) distinguished ten elements in relation to the humanitarian supply chain. Orlando et al. (Orlando et al., 2022) examined two constructs dividing entities into those dealing with the flow of medical goods related to the pandemic and the trade in other goods. Research proposals from earlier years were included, *inter alia*, in the review articles by Karl et al. (Karl et al., 2018), Maharjan and Kato (Maharjan & Kato, 2022), and Maryniak et al. (Maryniak, Bulhakova & Lewoniewski, 2021).

Material and methods

Due to the fact that the supply chains of individual enterprises are specific, and their examination is multi-faceted, the use of qualitative methods in relation to them is justified. Based on bibliometric research on supply chain research methods, it is stated that 65% of the works concern this type of procedure (Abbasi & Mohamadi, 2022). In the presented study, a case study was used, which is employed in a quarter of works in the field of the supply chain, and it is the second most common method used after mathematical modeling. The research subject is specific because it belongs to a global corporation, serves clients from many continents, is the only company stationed in Europe and, at the same time, is a small entity where the flow supervision is not assigned to a logistics unit consisting of many people. This solution works efficiently because the general flow procedures are developed at the corporate level, and the operational sphere is organized and controlled at the level of the audited unit. The study adopted a five-stage research procedure for

case studies proposed by Stuart et al. (Stuart et al., 2002) and took into account comments directed to each of the stages (Koulikoff-Souviron & Harrison, 2005). The *a-priori* study identified constructs from the literature that helped to better embed the theoretical framework of the study.

Since the knowledge of the creation of resistant chains is only in the development phase, the research considered a wide range of factors that may affect the constitution of resistance to arbitrarily assess their suitability in a given case. Therefore, a research question was formulated "Which of the elements supporting the building of resilient chains are adequate for the examined enterprise?" Simultaneously, it is noted that certain elements such as agility and transparency appear much more often in research models. Therefore, it is important to answer the question: "Does the popularity of a given construct in research models determine its driving force in the creation of resistant chains?" In the second step, a supply chain was selected for the research, which is not described in the literature, to enable an increase in the cognitive value of the presented material. A case was selected that may be a potential source of questioning popular statements appearing in the theoretical layer. This is one of the basic approaches in selecting case studies. Little is known about the methods used to create robust chains; therefore, the data collection method made it possible to understand:

- the context of strategic and operational conditions in which resilience is built,
- why the identified constructs might be important.

The need to show the context of the activities makes it impossible to perform multiple case studies in one study. Therefore, in the future, it is justifiable to repeat the research in order to create a series of multiple case studies and better substantiate the conclusions drawn. In the third step, data was collected on the basis of data provided openly by the company and data collected through contact with the company. Three times individual in-depth interviews (IDIs) were used as the basic research method. The first two interviews were designed to gather information about the company's supply chain and disruptions in flows. In the second interview, some threads were clarified. In the third interview, they were asked to rank the factors that influence building the resilience of the supply chain according to the given scale. The first two interviews consisted of direct contact with the company and were in an unstructured form, while the collection of data using a structured survey questionnaire took place through remote communication using the Microsoft Teams platform. Qualitative bibliometric studies were conducted to identify the elements constituting the resistant chain models (Booth et al., 2021). Systematized elements from the perspective of the existing research models (Maryniak, Bulhakova & Lewoniewski, 2021) were used to evaluate them at the level of the discussed case study. A total of 20 test items were assessed.

The contact person for the transmission of information was the company manager, who is responsible for contacts with other actors in the supply chain and with companies located around the world. Simultaneously, the manager had the opportunity to collect information from other employees in order to provide reliable answers. In total, the data collection on the side of the researchers lasted several hours over three meetings. To exclude biased judgments and to ensure the quality of the information collected, it was not stated before the study which of the test items were mentioned more often in the research models, and they were asked to explain the causal relationships regarding the answer given in the context of the information obtained about the nature of the organization. In the fourth stage, we cleaned up the data from the side threads that appeared during the interview and focused on a limited set of data that illustrated the context and rationale for selecting the elements that make up the resistant chain. The purpose of this stage was to understand contextual data and explain and interpret the phenomenon under study. In the last stage, an attempt was made to critically assess whether the relations between the cause and the selection of the model were properly established, and a theoretical replication was performed, i.e., based on a broader theory. It was shown that obtaining different results than previously conducted is rational.

Characteristics of the research subject

Based on the interviews, it was found that the subject of the research is the supply chain of a company, which carries out qualitative analyzes of engine oils, cooling fluids, and fuels that are necessary for the proper operation of, for example, gas engines powering electric turbines, wind turbines, hydraulic transmissions, etc. The main goal of the company is to improve the reliability of machines. The company has been operating since 2014, with foreign capital and a flat organizational structure. The company has been an integral part of a global corporation that has operated since 1999. The entities are related to the network in terms of capital and finances. All laboratories are linked to the headquarters. Budgets, financial

statements, expenses for laboratory equipment, and other fixed assets must also be accepted by the head office. The corporation has seven global laboratories worldwide: in South America, Central America, North America, and Europe. The audited entity is the only entity located in Europe – in Poland. Due to the synchronization of information and logistics flow, 165,000 customers worldwide are served. The processes are unified based on the American Society for Testing and Materials (ASTM) standards. Materials for testing are transferred between units located on different continents, while on the plane of the flow of auxiliary, non-commercial materials – each unit performs independent logistics services. The units are equipped with the same equipment (apparatus). This allows a significant reduction in the cost of consumables. In addition, laboratory analyses performed on the same equipment enable the results to be compared between all laboratories. This is of particular importance in today's age of globalization. Customers who are largely global concerns, such as Chevron, Shell, and Mobil, are present on all continents and, therefore, the results prepared for them must always be comparable.

In particular, the audited company, the branch of which is located in Poland, is engaged in the activities of: physicochemical analysis of industrial oils (i.e., hydraulic, gears, and engines, etc.); physicochemical analysis, i.e., the determination of the amount of wear metals in the oil, precise determination of the water content, soot content, examination of the amount, and size of solid particles (also known as impurities), and consultancy aimed at extending the failure-free operation of machines and the related cost reduction. The company contributes to extending the life cycle of assets and minimizing the costs of repair and replacement due to the possibility of predicting the date of necessary equipment maintenance. The company's network is located in Greater Poland and in foreign partner location points. The supply chain is especially developed at the exit. At the corporate level, the target customers are located in over 90 countries, while the European branch serves customers from Europe, North Africa, and Asia. The vast majority – around 85% of the samples – originate from customers based in the European Union. The remaining 15% of samples were supplied from customers in Africa (11%) and Asia (4%). As much as 95% of the created samples are sold on the foreign market, which requires the implementation of efficient distribution logistics in international supply chains. All samples are shipped by air freight for all countries (except for local, Polish customers). In this case, the delivery is made by courier companies. Air transport is the most expensive but at the same time the fastest, which guarantees customers almost immediate access to the results and parameters of a given oil.

Samples and parts of the apparatus are moved within European or intercontinental chains, while reagents and small equipment originate from regional entities. The reagents are mainly purchased from distributors of renowned world producers, such as Merck, VWR, and Sigma-Aldrich. It is necessary because the laboratory has ISO17025 accreditation, i.e., a system for unifying technical and quality management requirements for the research laboratories. Other accessories, such as pipettes, glass, and sorbets, are purchased in commercial units. Deliveries of samples are carried out, in 45% of the cases, from entities taking the role of intermediaries in the supply channel (in terms of the number of samples) and directly from customers for 55% of the time. In Europe, there are three small logistics centers located in Germany, Belgium, and the United Kingdom, to which samples from smaller customers are shipped. Each point acts as a separate company. The largest customers send samples directly to the laboratory in Poland.

Based on the conducted interviews, it can be concluded that: the configuration of the analyzed supply chain is based on external infrastructure (i.e., transport, warehouse, and office); the complexity of the input supply chain, measured by the number of direct suppliers, is much smaller compared to the output chain structure; the input and output chain is short taking into account the number of links, because in the majority of logistics operations the company contacts the producers of purchased materials and end customers; most of the logistics operations on the entry and exit sides are intercontinental in nature; and in some European countries, the consolidation of the cargo (samples) takes place, which is performed by an external entity and then the material is transported to the unit located in Poland. Since 2014, the volume of products moved has increased, while supply chains have lengthened only slightly.

There was also a slight geographic diversification. Based on the information obtained, it can be concluded that increasingly more customers are sending samples from outside the European Union. This is because the main emphasis is on the development of Asian clients and clients from the Persian Gulf region. There is also a noticeable increase in the chain complexity resulting from the rise in the number of final recipients who are also the ordering parties. The company reaches increasingly more

customers. In the case of large corporations, the involvement of intermediary companies is not justified, as each large company has its own specific requirements that must be considered when performing laboratory tests.

Detailed flow paths in the characterized supply chain include (Figure 1):

initial flows

1. USA – Poland: plastic bags and bottles (from corporate headquarters).

basic domestic flows

2. Poland (Poznań): cartons, work clothing, and labels.
3. Poland (Warsaw) – Poland (Poznań): pipette, gloves, and spare parts used for the diagnostic equipment [5%].
3. Poland (Warsaw) – Poland (Poznań).
4. Poland (Kędzierzyn Koźle and Tarnowo Podgórne) – Poland (Poznań): solvents.
5. Poland (Tarnowo Podgórne) – Poland (Poznań): office articles.
6. Poland (Zielona Góra) – Poland (Poznań): sorbents.
7. Poland (Gliwice) – Poland (Poznań): reagents [20%].

basic international flows

8. Germany – Poland (Poznań): sample tubes.
9. Asia – Poland (Poznań): laboratory glassware and reagents (e.g., China and Taiwan) [80%].
10. USA – Poland (Poznań): diagnostic equipment and spare parts used for the diagnostic equipment [95%].

reverse flows

11. Poland (Toruń) – Poland (Poznań): post-test reagents, used sorbents, and used bottles.
12. Poland (Sieradź) – Poland (Poznań): used oils.

warehouses – the place of receipt of samples from only one country.

13. Germany, Belgium, and the UK.

customers in various locations

– Poland to customers: plastic bags, bottles, and cartons;
– customers to Poland: Europe [85%], for example, Spain, Italy, Portugal, Estonia, Lithuania, and Latvia; other locations, for example, Asia and Africa [15%].

Results and discussion – the ways to build resilience in supply chains

To diagnose which elements of the supply chain are used to build chain resilience, twenty elements selected on the basis of an extensive review of the research models presented so far (Maryniak, Bulhakova & Lewoniewski, 2021) were assessed. A seven-point Likert scale was used to rank the answers, in which 1 is very significant and 7 is definitely irrelevant (Figure 2).

Due to high costs and extended usability, the purchase of test equipment is made every few years; therefore, it is not a subject of current logistics. Among the fixed assets, the company's equipment includes mainly research machines that require periodic replenishment of parts. Due to the high costs of this type of investment, the acquired basic devices are not purchased on the primary market. At the entrance – in addition to the samples received from customers and intermediaries – the supply chain is supplied with materials and the aforementioned non-commercial materials such as reagents, small equipment (pipettes and laboratory glassware), gloves, oil-absorbing mats, and workwear. The purchase

Figure 1. The supply chain of an oil testing company

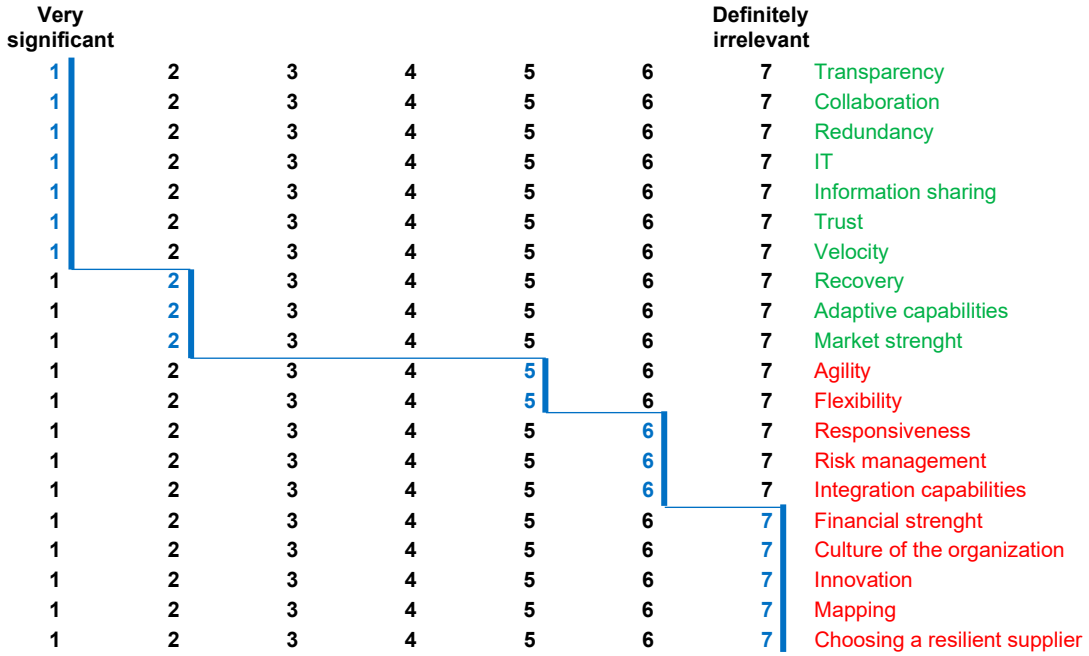

Figure 2. Factors that make up the model of building resilience in the examined enterprise

of auxiliary materials depends on the number of orders; however, a critical, necessary inventory level is maintained. The length of the channel supply for the materials in question ranges from 200 to 400 km, and it is mostly of a regional nature. The number of vendors does not change as they are accredited vendors. Due to the quality of the services provided, the analyzed entity concludes contracts with suppliers who guarantee the delivery of certified products. The materials are supplied by final producers or are purchased from the distributors.

In day-to-day work, disruptions are caused by the failure rate of machines that are not related to their efficiency but result from a high turnover of employees. Operating the equipment requires several months of training; therefore, it is a significant problem that requires a solution in the future. During the pandemic, there were additional logistical problems with the supply of reagents, machine components, and the availability of auxiliary equipment. This forced an increase in the level of inventories and, thus, built a kind of redundancy to ensure the continuity of laboratory tests and the adopted time regime. Due to the complexity of the equipment, and the fact that (in most cases) the elements are imported from abroad, the waiting time for spare parts has been extended. Ultimately, it increased the storage costs. However, no correlation was found between the pandemic and the number of orders.

Continuity of flow is ensured thanks to the trust and long-term relationships which, due to formal reasons and to the specificity of contacts and delivered materials, cannot be replaced with other dynamic relationships. The durability of the chain is a result of long-term contracts with suppliers, on the basis of which the trust and quality of the analyzes are developed; high transaction costs of a possible change of supplier; no need to multiply supply and distribution channels and adapt to current fashions and trends, such as in the case of the clothing chain or innovative products. In the event of disruptions related to, for example, equipment failure or deliveries of test components, the company tries to restore resources or flows according to the same operating patterns in the shortest possible time. This is, on the one hand, due to the nature of the links in the supply chain and, on the other hand, to the declared level of service. Speed is, therefore, the asset on which the company bases its strength. Hence, the company guarantees a very short time, i.e., 48 hours, to analyze the sent samples.

The company also cares about uninterrupted and constant access to information. This is accomplished by using high-class IT systems. After sending the oil for testing, detailed data on its parameters, type of device, operation of the device it is used for, etc. are entered. At the time of delivery of such a sample to the laboratory, the QR code is scanned. The Horizon system allows all customers to log samples online, and the same system will enable clients to access reports. All the data on the number of registered samples, the number of orders, the number of customer orders, and the number of performed and completed tests are visible in real-time. This data is available for every laboratory that is part of the

corporation. The company provides IT support solutions in the field of integration of sample data with the laboratory. It manages laboratory equipment through the CMMS system and performs periodic inspections and calibration. Through the EAM system, it archives data on the maintenance of devices in operation and forecasts how the parameters of materials may change, and with what frequency they need to be tested.

The entire service system is, therefore, extremely transparent. It also manifests itself in the system of building relationships with customers who remotely share data on the operation of machines and can count on online assistance in the event of a failure. Only as a last resort is a service technician required. Usually, it concerns very expensive machines, the breakdown of which, for example, due to faulty oil parameters, would cause huge losses or even bankruptcy of the company. Therefore, building efficient samples and information flows must be embedded in deep and mutual trust. The adopted resilience model based on cooperation, redundancy, transparency, information sharing, trust, and speed is only partially consistent with the models proposed in the literature on the subject. For example, from the model of Belhadi et al. (Belhadi et al., 2021), resilience is influenced by collaboration. According to Mohammed and co-authors (Mohammed et al., 2021), it is affected by trust and information sharing and, from the study by Johnson, Elliott, and Drake (Johnson, Elliott & Drake, 2013), the speed of the operation is also important. However, in model terms, it is most often emphasized that agility and flexibility are the key factors in the construction of resistant chains (Christopher & Peck, 2004; Brusset & Teller, 2017; Cui, Idota & Ota, 2019; Mohammed, 2020). It is especially visible in the reviews, which list the individual constructs that make up the research models (Maryniak, Bulhakova & Lewoniewski, 2021). Considering the characteristics of the described supply chain, it can be stated, however, that the obtained results are rational and contextually justified.

Conclusions

The study shows the specifics of the supply chain, which was discussed for the first time in the scientific literature. Its nature justifies the adopted model of resistance. It differs from the classic approach, in which agility is most often indicated as the basis for eliminating disturbances. In the analyzed chain, the ability to adapt to changing market needs is of secondary importance, as agility and flexibility were assessed as rather insignificant, and sensitivity is also insignificant. Moreover, risk management, ability to integrate, financial strength, organizational culture, innovation, process mapping, and the selection of resilient suppliers turned out to be irrelevant or definitely irrelevant factors. The model specific to the examined enterprise is a system in which transparency and information sharing play an important role. Therefore, it is clearly a communicative model in which efficient IT systems are used to transfer information, perform tasks quickly, and can recreate resources that are largely immaterial. It is also a model in which potential disruptions in the flow of material resources are eliminated through redundancy. It is a unit that builds its strength on the basis of brand strength, trust, cooperation, loyalty, partners' reliability, and lasting relationships on the side of deliveries, key customers, and the development of permanent procedures. Based on the research, it has been proven that the popularity of the occurrence of a given construct in research models does not determine its causative power in the creation of resistant chains. That is why it is important for science and economic practice to show various ways of achieving the durability of chains, including those that differ from popular patterns.

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