

## Article

# Global Changes and Disruptions in Supply Chains—Preliminary Research to Sustainable Resilience of Supply Chains

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**Abstract:** The contemporary world becomes more and more volatile and unpredictable every year (dynamic development of technology—Industry 4.0 and Industry 5.0, dynamic global changes related to the COVID-19 pandemic, great changes in consumer behavior, climate crisis, geopolitical disruptions). Individuals, companies, and supply chains face challenges emerging from economic, sociological, and political phenomena. These phenomena disrupt regular performance and limit the efficient functioning of companies and economies. Due to numerous relations and connections in the economy, disruptions in one area affect the others and spread, growing in range and severity. Hence, disruptions should be dealt with to provide continuity of supply chains and to ensure their efficient and effective performance. The study aims to identify crucial characteristics of disruptions to facilitate disruption minimization strategies. The characteristics of disruptions in supply chains are identified based on a literature review, synthesized and validated by the experts. A study is implemented to validate identified characteristics and to confront theoretical findings with the practical experience and observations of the experts. The results of the study are discussed and commented on. The conclusions from the study refer to the nature and characteristics of disruptions in the contemporary economy, equipping managers with useful knowledge when dealing with disruptions, and academics with observations that can stimulate further discussion on stability, flexibility, and resilience of companies and supply chains.

**Keywords:** sustainable resilience of supply chains; disruption; resilience; sustainability



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## 1. Introduction

Supply chains have become increasingly complex in recent years, both in terms of geographical range (being international/global networks) and the scope of activities covered (as they can cover the entire lifecycle of a product). Being a part of a supply chain has become a key factor in the growth and competitiveness of many enterprises. However, the size, scope, and structure of supply chains, and often their global nature, make them increasingly vulnerable to many disruptions. Moreover, global changes, such as (1) dynamic development of technology and organization of production, commonly referred to as Industry 4.0, (2) dynamic global changes related to the COVID-19 pandemic and its consequences, and (3) great changes in consumer behavior, which are, inter alia, the result of the global COVID-19 pandemic influenced the operational activity of supply chains [1], have contributed to making supply chains unpredictable, and volatile.

There is a clear trend toward a sustainable supply chain—not only recognized in research (indexed since 2000; the number of works published is dynamically increasing after 2010) but also in the practical approach promoted by organizations and authorities [2]. However, there is another trend observable—namely, a decrease of focus on sustainability caused by the consequences of the long pandemic period and the latest Russian invasion

of Ukraine. These phenomena have resulted in severe economic consequences and a destructive impact on the economy (dynamic increase of raw materials, food, and energy prices—causing dramatically growing inflation pressure all over the world). Unsustainability practices are a challenge that can strike in an economy if not managed resourcefully [3]. The current situation means that both the entire supply chain and its participants may not be resilient enough to survive disruptions and shocks, both internal and external.

According to the authors, modern supply chains have significantly changed the way they function, compared to supply chains functioning before the pandemic and global changes. The key issue in terms of survival seems to be the identification of disruptions and an understanding of their nature and strength. To effectively and efficiently minimize the probability and consequences of disruptions that supply chains and economic organizations are struggling with, their characteristics should be well recognized.

Since we are observing global changes, it is necessary to determine the current state of disruptions with which the supply chain is struggling. However, the analysis of the state of the art lacks the attribute characteristics of disruptions which could be used to develop the list of features shaping and defining the morphology of disruptions in supply chains. This is called the research gap.

The goal of the article is to identify the characteristics of disruptions in the functioning of supply chains and verify the recognized list with an expert method. The results may be useful from the epistemological perspective as they show how the disruptions have been changing over the years, and from the utilitarian perspective as recognizing the disruption may help companies and supply chains in responding to challenges they face. The paper aims to contribute by proving the relations between global changes and characteristics of disruptions and by identifying attributes of the disruptions observed and expected. The research is inspired by the changes, events, and phenomena that in the last three years have affected organizations, supply chains, and economies.

The article is organized as follows: part 2 presents and discusses the concepts of disruptions indicating the theoretical approach to this issue. Part 3 discusses the context of global changes. Part 4 discusses the methodological approach implemented and characterizes the experts employed. Part 5 presents the results of the study along with their interpretation. Part 6 presents the research results. The paper ends with a summary and an indication of further research directions (part 7).

## 2. Context

The industry is an economic activity that has a strong influence on spatial planning and the environment. It is characterized by multilateral supply and production links with other branches of the economy and growing links with the development of science. There are many-sided links between economic and social development. The current history of Industry shows significant changes in the rules of the game—from the first mechanization and electrification, through digitization, to system integration and business networking within Industry 4.0. According to many scientists, the development of the industry is also a threat related to the natural environment. The development of the industry also means threats related to the social space. Therefore, it is necessary to strive for sustainable development in which both natural and social rights are respected. Industry and sustainable resource management are not mutually exclusive. In many cases, a company's sustainability efforts can bring new business opportunities and attract new customers.

Uncertainty and volatility in the market force changes and modifications to supply chains that can be easily and quickly adapted to the rapidly changing levels and structure of supply and demand.

We distinguish three components of global changes [1]:

- Dynamic development of production technology and organization, commonly known as the “fourth industrial revolution” or Industry 4.0 [4–7]; Industry 4.0 affects people, who need to develop their skills to meet high-tech requirements [8], organizations, that need to change their technologies [9], and economies, which need to adapt their

business models to changing processes [10]. The impact is on cost, productivity, and performance [11,12], hence it affects the supply chains on a global scale; Industry 4.0 technologies can enable firms to mitigate the risk of disruption so that they can continue their operations [13].

- Highly dynamic global changes related to the COVID-19 pandemic and the resulting consequences for the sustainability and continuity of supply chains. Supply chains had to adapt quickly to demand-related shocks that resulted from unpredictability and panic buying or supply-related disruptions in their planning. The COVID-19 pandemic has affected supply chains by demonstrating their lack of resilience and the effects felt by the negative impact of disruptions on a global scale. The COVID-19 pandemic is one of the most severe supply chain disruptions in history and has challenged practitioners and scholars to improve the resilience of supply chains [14–16].
- Great changes in consumer behavior, consumption, and environmental changes are also related to the new European green deal. The new green deal promises interrelated initiatives (e.g., in climate, environmental, energy, transport, industrial, agricultural, and sustainable finance policies). It also points to promoting and working towards a more dynamic, resilient, and competitive European industry. Uncontrolled consumption leads to environmental degradation through the overexploitation of renewable and non-renewable natural resources [17–19].

### 3. Disruptions in Supply Chains: Characteristics, Attributes, Consequences

Variation is an inseparable part of every system. It is considered a natural occurrence in realizing any processes. Varying effects of processes have two causes: accidental (random and chronic), determined by a considerable number of minor factors being difficult, impossible, or uneconomic to determine, but influencing the precision of processes, and identifiable, non-probabilistic, (sporadic), which may be recognized and eliminated [20]. The variability and instability of the environment and supply chain introduce disruptions.

Supply chains are complex and heterogeneous structures which makes them vulnerable and difficult to manage. Vulnerability means that supply chains are prone to disruptions of various kinds and origins. The structure of a supply network consists of a collection of nodes (facilities) and the connecting arcs (transportation). From this perspective, small events that disrupt a node or arc in the network can have major consequences for the network. A failure in a node or arc can potentially stop the flow of material across the network [21]. Hence, a disruption is identified as an event that interrupts the material flows in the supply chains, resulting in an abrupt cessation of the movement of goods [22]. Even a small disruption can have a devastating impact as it cascades through the chain.

Disruptions and uncertainty are becoming the main factors limiting the achievement of a high level of supply chain efficiency and disturbing the current functioning of cooperating companies in the supply chains [2]. The disruptions are random and have a strong impact on the system of supply chains. They may be measurable—measured during supply chain operation and management—and their current status may be used to control supply chains, or they may be non-measurable. Disruptions management can focus on counteracting the impact of disruptions on supply chain functioning.

As Snyder et al. note [23], disruptions are costly and, depending on the range of impacts, can harm local, domestic, or even global economies; hence, the vulnerability of supply chains has been drawing the attention of business and science for many years, as highlighted by [23], especially when events, such as terrorist attacks, political or economic crises, and traffic accidents, had an impact on their efficient and effective functioning. The problem of disruptions seems to be growing due to the dynamic nature of the world. The growing number of disruptions has resulted in the growing number of publications on supply chain disruptions aimed at an explanation of the phenomena.

Considering the explanation of the phenomena, the following aspects are introduced:

- source of disruption,
- characteristics of the disruptions

Considering disruption mitigation strategies, various approaches are presented.

Taking into account stakeholders responsible for the disruption we can distinguish the following types of disruptions:

- external: independent of any of the parties involved in the supply chain
- internal: caused by one of the parties involved in the supply chain

Disruptions beyond the control of either party are any random situations causing a delay in delivery beyond the control of either party. Such situations are, for example, natural disasters such as earthquakes, floods, hurricanes, etc. (natural disasters [24,25] also include pandemics—avian flu, swine flu, SARS, SARS-CoV2 [26,27], etc.) as well as bad weather conditions, e.g., heavy snowfall, rain, hail that prevent on-time delivery. Nowadays, the threat of terrorist attacks and war spreading is also increasing. This group also includes various types of strikes that disrupt the work of suppliers or interrupt the continuity of traffic by road blockades by protesters. As a result of protests, traffic jams are also often formed, which significantly extended the delivery time of goods. Internal disruptions may be caused by suppliers, contractors, or freight forwarders.

The most often mentioned characteristics of disruptions are the following [28]:

- Disruption periodicity (frequency)—period/time interval between events disrupting supply chains; may be long or short resulting in daily, weekly, monthly, etc. occurrence of disruption.
- Disruption period (duration)—time of disruption presence; may be long, medium, or short.
- Disruption quantity loss (severity)—loss in production caused by a disruption in supply chains; refers to the severity of loss to an organization or supply chain.
- Disruption breadth—the scope of disruptions.

The characteristics of disruptions determine the size of disruptions, the severity of impact, and countermeasures that should be taken to minimize disruptions. The size and severity of damage to the supply chain depend on the duration of the disruption, as well as on the geographic range and the scope—since the COVID-19 pandemic has been affecting various industries across economies worldwide for more than two years now, its impact and damage caused in supply chains are undoubtedly serious [27].

Nevertheless, the COVID-19 pandemic was not the only disruption faced by the world; what is more, the number of disruptions grew rapidly. As presented in Resilinc's EventWatch (risk-monitoring system) there have been about 4200 disruptions in the first nine months of 2020, and the most impact generating events were: the collapse of two dams in Michigan in May, summer flooding in Japan and China, the Beirut explosion in August, and the record-acreage West Coast wildfires in September. Except for environmental risks, there were also other threats, including disruptive events at airports, factories, and ports; labor strife; cyberattacks; and mergers and acquisitions. Considering the variety and number of disruptions it is crucial to undertake disruptions mitigation initiatives. Christopher and Lee [28] recommend end-to-end visibility of supply chains, Sheffi and Rice [29] flexibility in supply chain activities and culture, and Zsidisin et al. [24] a four-stage framework including awareness, prevention, remediation, and knowledge management.

None of the previous works referred to had taken into consideration global range disruption that would have broken supply chains for a significant period. The important aspect of risk mitigation strategies is their cost confronted with the financial performance of supply chains. Without proper planning, recovery of the supply chain after disruption is associated with a lot of damages and costs, which in most cases are far more than investing in disruption management strategies [29]. Moreover, disruptive disruption requires companies to build their resilience despite additional costs [30]. Resilience seems to be one of the most important characteristics of contemporary individuals, companies, and supply chains. The occurrence of the COVID-19 pandemic is a disruption that has adversely affected many supply chains around the world and proved the necessity of combination and interaction of resilience and sustainability [31], evidenced by several scientific works on the topic, growing rapidly in the last few years (Figure 1).

## Documents by year

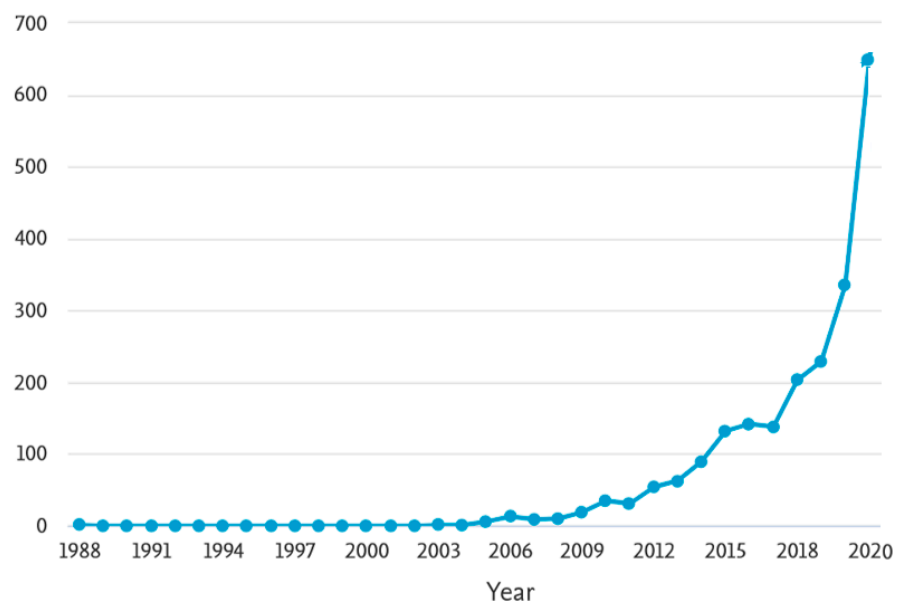


**Figure 1.** Publications on supply chain resilience in title, keywords, abstract in Scopus database, own work.

Supply chain resilience is the ability to deal with the consequences of risk events to return to the original state or reach a more desirable state after the occurrence of the disruption [32]. According to Ponomarov and Holcomb [33] resilience is “The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function”. To augment resilience in SCs, usually one or more resilience strategies are used [34]. Some of the most important resilience strategies are multiple sourcing, using backup facilities, fortification of facilities, capacity expansion, and holding emergency inventory [35]. Optimization algorithms can also be used in other areas, such as in network optimization. Disruptions in production and distribution networks can be dealt with thanks to implementing a simulation environment (benefits in cost reduction and reduces the burden on human resources) as indicated by Ivanov and Dolgui in their work [35]. Numerous solutions can be exploited to mitigate the disruption, depending on the source and nature of the potential location of disruption. The role and importance of collaboration are stressed, even though there is no clear link between collaboration and resilience [36]. Nevertheless, it needs to be highlighted that managers are aware of potential disruptions that may cause them, and strive for selecting the best combination of countermeasures to minimize and mitigate and minimize disruptions” impact on the supply chain’s performance.

#### 4. Materials and Methods

For the needs of the empirical study, an expert opinion poll was conducted. The sample was selected based on knowledge, experience, and competences within the supply chain area. The method concerned an expert declaration on the identification of the features of current disruptions in the functioning of supply chains. The expert method is regarded as a significant contribution to determining the future or present of the research subject. The method is universal. The planned empirical research is part of the research topic in the field of management and quality sciences. Concerning the subject of the research, the analysis touches upon the existing, contemporary reality.

The study used a research procedure based on diagnostic assumptions. This means that it consisted in determining the specific, current state of disruptions that the surveyed companies had to deal with in the recent period. Considering that in the last 3 years, as mentioned earlier, a substantial increase in global changes resulting from three components

(changes resulting from Industry 4.0, changes resulting from the COVID-19 pandemic, and changes in consumer behavioral changes) have been observed, it is necessary to answer the research question: is the current state of disruptions facing the supply chain?

The research was conducted with a Focused Interview method with a selected group of experts, characterized by the following attributes (Table 1).

**Table 1.** Demographics Focused Interview participants.

|         | Job Experience<br>(in Years) | Level of Knowledge in the Field of . . . |           |              | Top-Expert |
|---------|------------------------------|------------------------------------------|-----------|--------------|------------|
|         |                              | Management                               | Logistics | Supply Chain |            |
| Expert1 | 27                           | 5                                        | 4         | 4            |            |
| Expert2 | 25                           | 4                                        | 3         | 3            |            |
| Expert3 | 24                           | 4                                        | 4         | 4            |            |
| Expert4 | 15                           | 3                                        | 3         | 3            |            |
| Expert5 | 17                           | 3                                        | 4         | 4            |            |
| Expert6 | 15                           | 5                                        | 4         | 4            |            |
| Expert7 | 17                           | 4                                        | 5         | 5            | Yes        |
| Expert8 | 12                           | 4                                        | 5         | 5            | Yes        |

Experts who are experienced practitioners were selected for the study. They have constant contact with the live market. Their competencies are constantly improved and supplemented with new trends and changes in the business. Each of them has many years of experience in areas related to management, logistics, and supply chains. They also have theoretical preparation acquired during their field studies at domestic and foreign universities and an MBA. The scale of assessing the level of expert knowledge used to test knowledge ranges from 1 to 5, where 1 means no knowledge, 3 knowledge at the level of an experienced manager, and 5 knowledge significantly exceeding the required level.

Among the experts, there is a group of top experts with special knowledge and skills that exceed the limits of standard knowledge and experience of formally educated people. They constitute 25% of the surveyed community.

The procedure is based on a few basic questions (Figure 2).

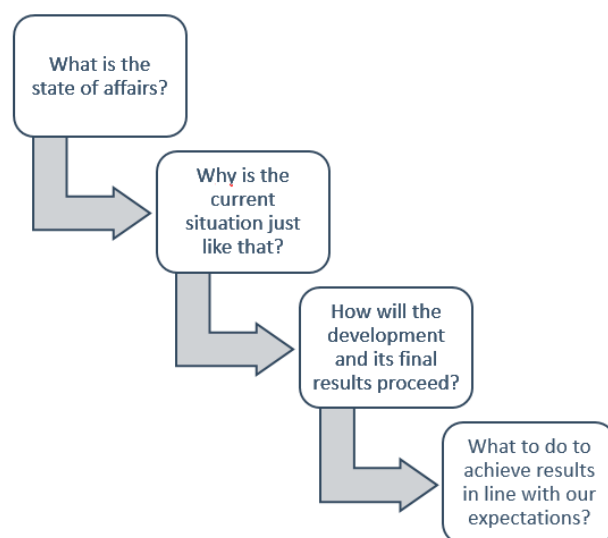


**Figure 2.** Research procedure based on diagnostic assumptions.

The work focuses on answering the first question and the second question. The answers to the next two questions will be subject to future research.

The result of the research conducted and described in the article is the description of the current situation, and the phenomenon. Its form takes into account the grouping of events occurring in the study and indicates the relationships between them. These diagnoses will be the starting point for further experimental research.

The method used is based on four basic principles. It pays attention to:

- (1) anonymity—survey participants are informed of their anonymity; this means that the individual members of the expert panel are known to the researchers, but not each other. This principle guarantees the full sincerity of experts and eliminates the influence of dominant entities (authorities and strong personalities) on the decisions or opinions of others;
- (2) asynchrony—means inconsistency or inconsistency in the time of providing answers by experts; it should be understood that testing time and the rate of response are at the expert's discretion. This is conducive to the multilateral nature of the analyses undertaken;
- (3) feedback—the test is an iterative process, consisting of research rounds;
- (4) statistical response—participants are informed about the statistics of their responses and the group's responses, which allows for comparing their position with the group's opinion and changing their statement.

The research method was used to investigate and describe the attribute characteristic of disruptions in the functioning of contemporary supply chains. The planned empirical study was conducted in a correspondence version in 2021 (May–September). The entire research procedure was carried out without experts meeting. The experts invited to the study were selected on purpose. It should also be emphasized that the selection of experts does not reflect a random sample of any given population.

Experts from the business community who empirically deal with the subject and management of supply chains were selected for the study. They have extensive practical knowledge of the subject. All experts have higher education and a minimum of 12 years of work experience in the area of logistics and supply chains.

## 5. Research Results

Analyzing the respondents' statements, it was indicated that the most common disruptions faced by contemporary supply chains occur in several categories. Those are:

- barriers related to COVID-19—lock-down of regular stores with the constant operation of e-commerce, which distorts the sales forecast and the dynamics of changes in demand,
- human resources—the lack of a sufficient number of qualified employees able to effectively cooperate with technical solutions, and the thoughtlessness of a new generation of logistics specialists,
- material resources—periodic increase in the availability and lack of raw materials on the market, such as granulates, electronic parts and high raw material prices, no availability of containers from China, the need to adapt multilanguage packaging, and the need to care for ecological aspects, shortening the life cycle of the product,
- technical resources—imperfection of the supporting IT systems, IT problems regarding data compatibility, e.g., between SAP ERP and the external DRP system,
- financial resources—cost savings leading to low-quality logistics services, poor quality of services provided by some carriers, and, on the other hand, an increase in the prices of transport services.

Hence, sources of disruptions are both external and internal.

Disruptions violate the established orderly course of affairs and processes. They can also be called a bottleneck, the negative effects of which spread to the entire supply chain and the functioning of individual participants in this supply chain. Since disruptions and unforeseen events are equated with disturbance, disorientation, and confusion, often even with the chaos and a break or delay and downtime, it is worth looking at the attribute characteristics of disruptions indicated by experts that occur in modern supply chains.

Most often, in the expert study, it was indicated that disruptions in the supply chain occur every day (Figure 3). It can be guessed that the more extensive the supply chain, in terms of the number of participants and geographic scope, the greater the frequency and variety of disruptions that occur. It should also be noted that over time, the continuous functioning of the supply chain and despite the growing experience of all participants in the supply chain, the processes of its participants may be more and more disrupted.

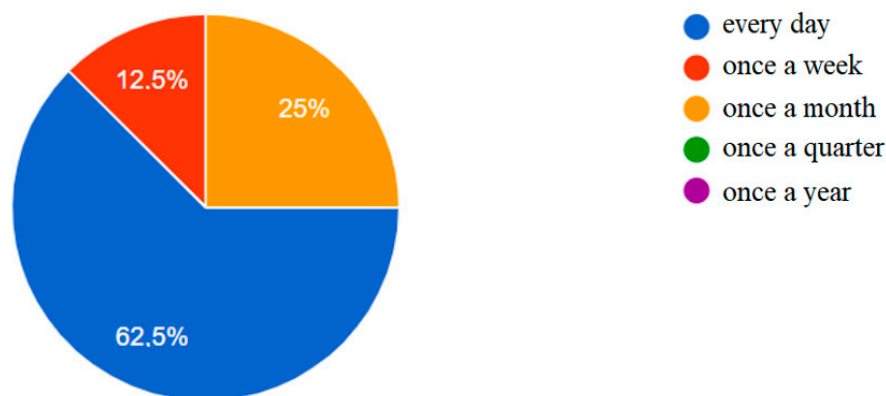


**Figure 3.** Frequency of supply chain disruptions.

Taking into account the research conducted before the pandemic [37], a clear increase in the frequency of disturbances can be observed. In the area of disturbances occurring daily, there was an increase of as much as 33, and in the area of disturbances occurring once a month, there was an increase of 15.2%. These are disturbing values because they relate to a double-digit increase. On the other hand, a decrease in the frequency of occurring disturbances once a week by 8.3% was observed.

An important attribute of disturbances in the supply chain is the duration of the disturbance (Figure 4). In the expert study, the distribution of the disturbance duration is evenly distributed between the medium and long-term reduction of the supply chain power (37.5% each). The duration of the disruptions is very important information in the analysis and evaluation of the supply chain reliability. The longer the disruption duration, the greater the real losses in the entire supply chain.

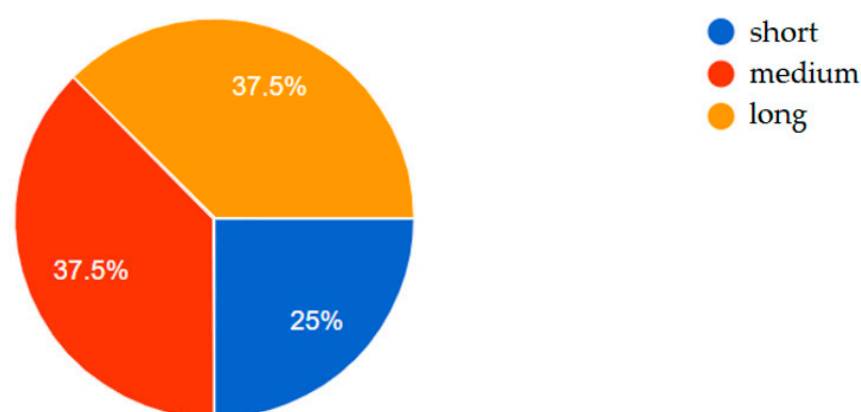


**Figure 4.** Duration of supply chain disruptions.

The high frequency of disruptions in the supply chain would suggest that they are standard, and therefore repetitive, disruptions for which it is easy to prepare and adequately deal with. Unfortunately, this assumption could not be more wrong. Experts indicate that non-standard disruptions dominate the supply chain (Figure 5). They are characterized by non-standard solutions, which often require unconventional solutions from all participants in the supply chain. Unfortunately, the non-standard nature of disturbances has a negative effect on their duration. Classification of the supply chain disruptions indicated by experts

in the area of the critical disturbance (red area) and the area of the unacceptable disturbance (orange area) confirms the need for immediate corrective action and even consideration of the need to suspend logistics processes in the supply chain. Immediate disturbances reduction measures are needed. In the event of disturbances from the acceptable area (green area), periodic observation and monitoring of the disturbances are required, with the possibility of postponing or suspending activities that would contribute to the disturbance.

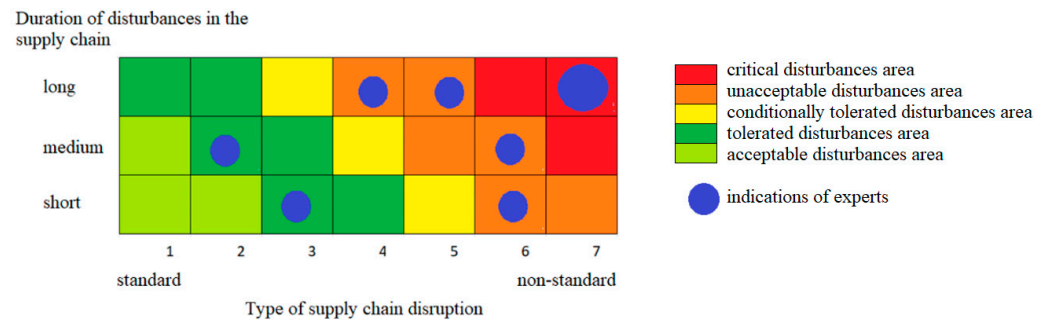


**Figure 5.** Duration of the supply chain disruption and its type.

It is also important to know whether the disruption causes a complete suspension of the supply chain or only its partial capacity reduction. In the case of a partial limitation of the supply chain power, it is also worth determining how big the limitation is and how extensive its impact on other participants in the supply chain is. It should also be emphasized that the duration of the disruption that completely suspends the supply chain is relatively longer than the duration of the disruption partially limiting the power of the supply chain.

Estimating the probability of disruptions is one of the basic elements of disruption management. The correctly performed estimation will allow you to be better prepared for disruptions, unforeseen or unplanned, that may have significant effects on the functioning of the supply chain and all its participants. In the study, experts were asked to estimate the probability of the identified disturbances. Even though their opinion may be subjective and experience-based, still such estimates are useful from a utilitarian perspective showing the perceived or expected probability of disruptions and justifying the strategies developed or to be developed to avoid disruptions or/and minimize their consequences.

As many as 75% of experts indicated that disruptions in the supply chain were likely (Figure 6). The analysis shows that experts identify many unplanned disruptions and anticipated negative events. Some disturbances occur randomly, for which they have defined a high probability of the disturbance and its consequences. The increased likelihood of disruptions increases when dealing with a global supply chain when the JiT strategy and its variants are used in the supply chain. The likelihood of disruptions also increases with the growing popularity of supply chain outsourcing.

When analyzing disruptions in the supply chain, the severity of disruptions is also taken into account and estimated. The severity of a disturbance is defined as the strength or effect of the disturbance. The level of severity of a disruption in the supply chain may vary for different participants, from acceptable to unacceptable to intolerable. Often, the influence factor may be critical for one of the participants in the supply chain and another of little or no importance.

In the study, 50% of experts pointed to the serious severity of the disruptions in the supply chain (Figure 7). This means a serious threat to maintaining business continuity in the supply chain. At the same time, it means a level of disruptions that is unacceptable and requires constant monitoring. As many as 25% of experts observe the severity of disruptions in the supply chain at a critical level. This should be understood as disruptions requiring immediate action to reduce the level of these disruptions.

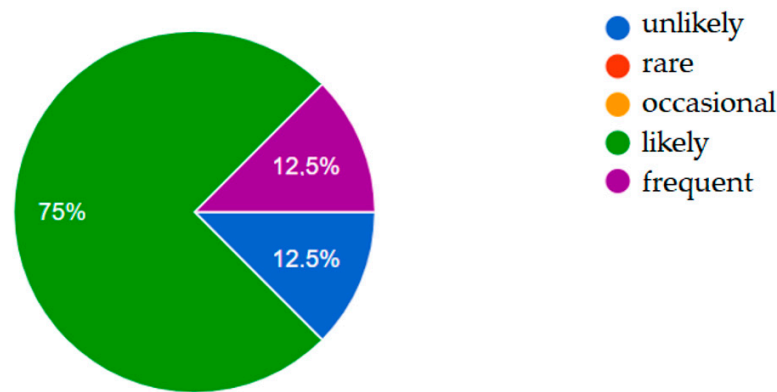


Figure 6. Probability of a disruption in the supply chain.

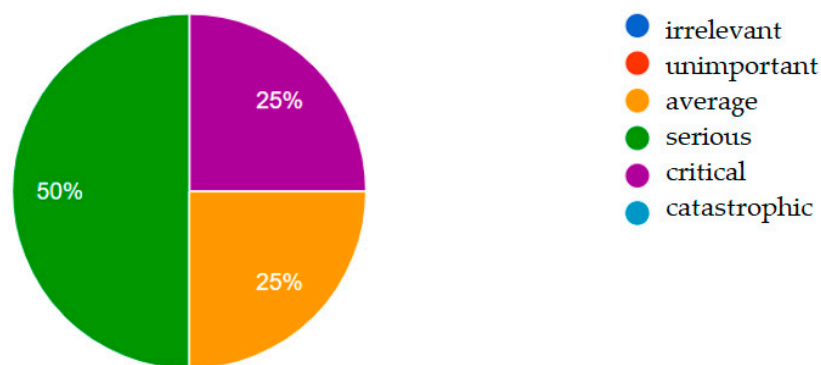


Figure 7. The severity of the disruption in the supply chain.

Experts note the impact of non-standard disruptions in the supply chain on the high level of severity of these disruptions (Figure 8). The strength of their impact is so great that they should be described as intolerable, threatening the proper functioning of the supply chain. Most of the disturbances identified by experts that occur in the supply chain are in the area of critical disruptions (red area) and unacceptable disruptions (orange area). This confirms the need for immediate corrective action, which will significantly reduce the disruption level.

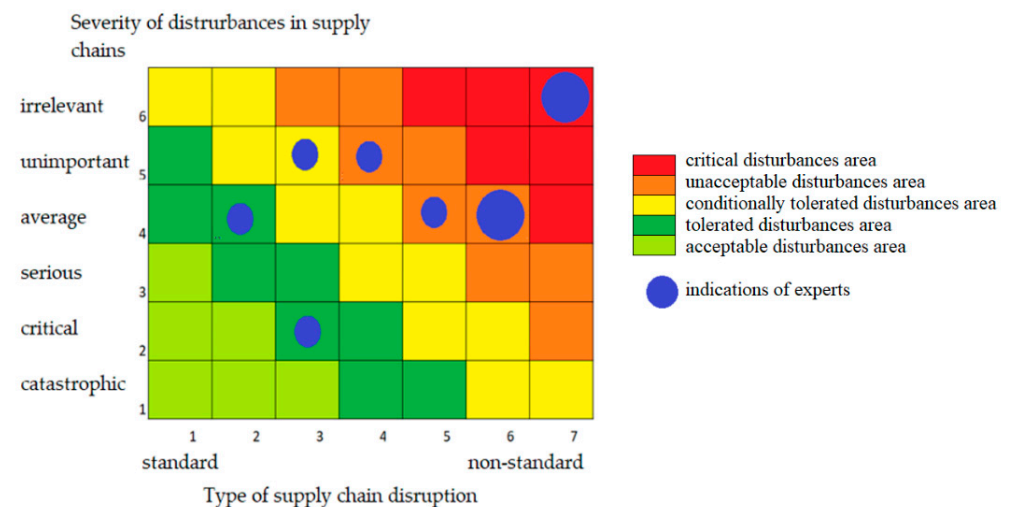


Figure 8. Impact of the type of disturbance on the severity of the disturbance in the supply chain.

Disruptions in the supply chain are also characterized by the estimated costs associated with the elimination of the disruption (Figure 9). Both direct and indirect costs can be

indicated here. Experts indicate that the cost of eliminating supply chain disruptions may exceed the average level, reaching high (37.5%), very high (12.5%), and even extremely high (12.5%) levels.

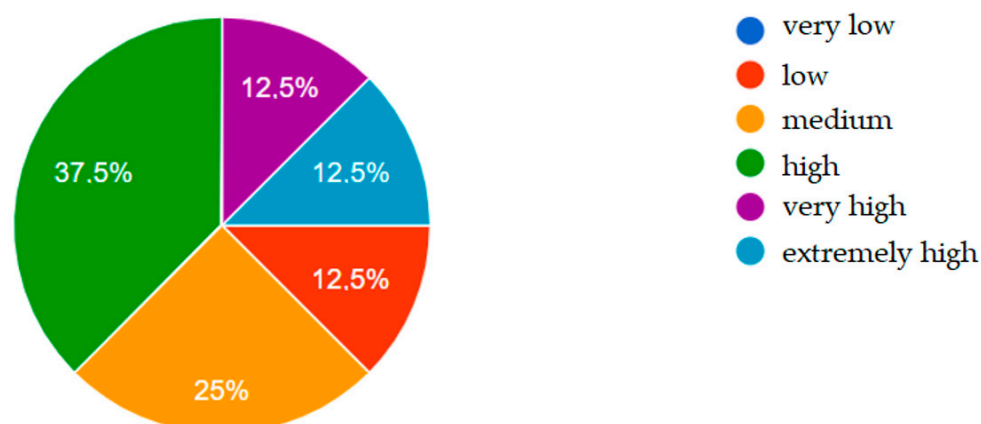


**Figure 9.** Estimated cost related to the elimination of a supply chain disruption.

The elimination of disturbances can be done in two ways: applying negative feedback, and using feedforward (forward) when the disturbance is monitored and it is possible to compensate the process input before the effects appear on the process output. However, the cost of eliminating interference is high, very or extremely high (Figure 10). It has been observed that the higher the severity of disturbances, the higher the cost of eliminating these disturbances. In the case of interference elimination, it is necessary to minimize the interference severity.

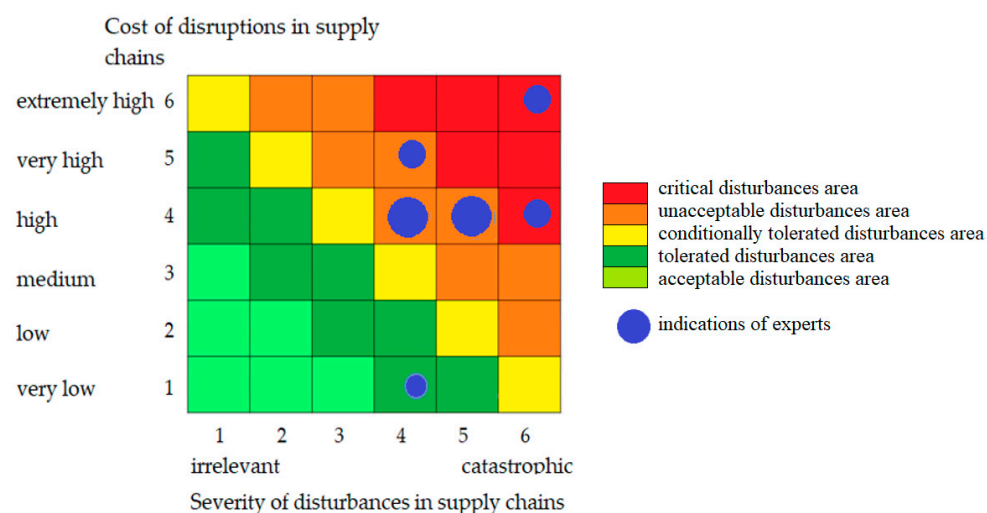


**Figure 10.** The severity of disruptions and the cost of disruptions in the supply chain.

Again, it can be observed that the identified disturbances indicated by the experts refer to the critical and unacceptable. Rapid actions to minimize and eliminate disruption are required. Studies on the subject should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

## 6. Discussion

Four levels of dealing with supply chain disruptions have been identified. We can distinguish (1) acceptance, (2) avoidance, (3) reactivity, and (4) protection. Half of the surveyed experts indicate that protection against disruptions is the most effective form of eliminating the disruptions associated with disruptions in the supply chain (Figure 11).

In this sense, a proactive supply chain will adapt in advance and in a predictive manner, constantly subordinating its efforts to prevent negative impacts and disruptions. This means that it will be constantly redesigned in search of solutions. The effectiveness of this disturbance coping strategy depends on the effectiveness of the analysis of weak signals in the environment and the accuracy of anticipation. On the other hand, 25% of experts indicate that reactivity strategies are effective, i.e., a tendency to react intensively to disturbances and adapt. In this sense, a reactive supply chain will adapt to the current, often increasingly severe, disruptions. Supply chain reactivity can restore capacity after a disruption, which will bring greater levels of resilience to actors in the supply chain and bring it to a more stable equilibrium.

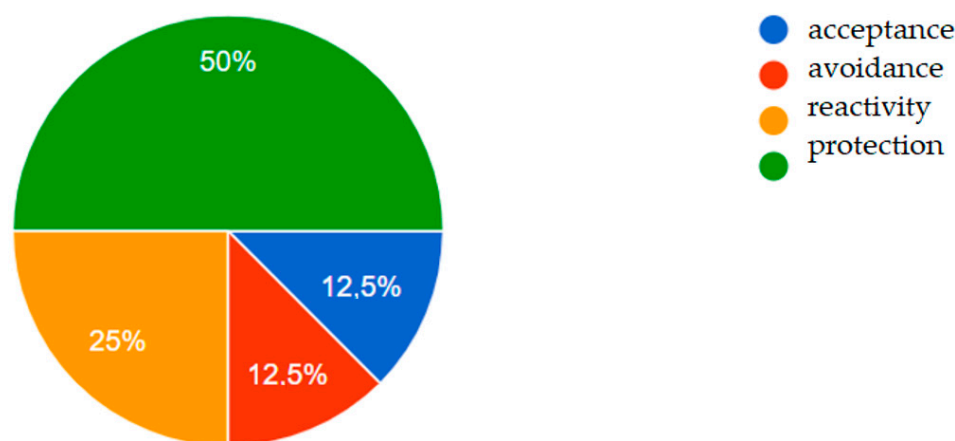


**Figure 11.** Strategies for dealing with supply chain disruptions.

Attention was also paid to the avoidance strategy (12.5%), which consists in not starting or continuing the actions related to the disturbance. Unfortunately, this method is negatively assessed by experts. In most cases, the use of avoidance strategies has the negative consequences of not taking action. As a result, it may have negative effects in the form of a breakdown and paralysis of the functioning of the supply chain. Experts also point to the possibility of using an acceptance strategy (12.5%). It is based on a passive response to disturbance, based on the necessity to accept (or ignore) and bear all consequences resulting from the possible occurrence of a disturbance.

Experts' indications confirm that changes in the environment and in the global economy increase the frequency and scale of shocks caused by disturbances. Our research confirms the qualitative results of the McKinsey report, where respondents report that their industries (automotive, pharmaceutical, aerospace, computer, and electronics) have experienced significant disruptions for a month or more. Shorter disruptions are even more common [38].

Based on the expert study, the following trends were observed:

- the frequency, dynamics, and variety of disruptions in the supply chain are increasing,
- disturbances dominating are:
  - of a non-standard nature
  - of medium and long-term duration
  - with a force of impact so great that they should be referred to as intolerable disturbances that threaten the proper functioning of the supply chain.

It was also observed that:

- the higher the severity of disruptions in the supply chain, the higher the cost of eliminating these disruptions,
- the higher the severity of disruptions in the supply chain, the more non-standard and unconventional nature of these disruptions,
- the higher the severity of disruptions in the supply chain, the longer the disruptions will last.

Supply chain resilience increases as the ability to eliminate disruptions increases and the susceptibility to disruptions decreases.

The opinions of the experts will be used in further stages of the research, focused on resilience development strategies.

## 7. Conclusions

The supply chain should be durable, meaning it should be resilient to sudden changes, and it should be viable. This is possible by monitoring and responding to disruptions. The conducted research resulted in obtaining answers to the questions posed in the research. The attribute characteristic of disruptions in the functioning of supply chains was identified and then verified by an expert method.

The contribution of the paper is presenting the research results proving that the identified global changes resulted in changing characteristics of disruptions in supply chains, their scale, time range, and repeatability. The novelty of the research is the consequence of the novelty of the global changes.

Supply chain resilience increases as capacity increases and as susceptibility to disruptions decreases. Shaping the resilience of the supply chain should be based on: (1) analysis and identification of weak points in the supply chain, which make it more susceptible to disruptions, and (2) development of the supply chain capabilities that will enable the anticipation and overcoming of disruptions.

Further work in this area is necessary. It seems justified to research opportunity of quantifying the impact of disruptions (and thus determination of measures and indicators) on the functioning of supply chains. It is equally important to identify participants in the supply chain responsible for the disruptions that have occurred and to develop a system or scheme of settlements between individual participants in the supply chain for causing disruptions. The last important element of further research is finding ways to counteract disturbances and their effects and developing the framework for supply chain resilience. The next research step will be the search and development of a forecasting system. A description of events and the relationships between them can be the basis for such prediction. Describing a given situation with the help of elements and their features, we obtain a set of variables. The task will be to find out which variable affects the other variable and how. By analyzing the results using appropriate statistical tools, it will be possible to predict how one variable will change concerning the other. The forecasting system will allow for achieving a state of sustainable resilience of supply chains through transparency, sustainable development, awareness, and security.

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