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# Simulation experiments of supply chain in a period of small and big disasters

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## Abstract

**Aim/purpose** – The aim of this paper is to present a strategy that allows companies to recover from disasters, when creating a supply chain. Furthermore, it also shows the impact on the company's resources that are used in the implementation of the strategy in case of small and big disasters. Thanks to the proposed solution, it is possible to analyze each company individually, as well as in groups, at any given time.

**Design/methodology/approach** – The results were obtained based on a numerical analysis which was performed with the use of MATLAB software. The tests were carried out separately for five companies, as each of them may expect a disaster on any different day. However, the selection of the day when crises occur is carried out in accordance with the probability determined by scientific research.

**Findings** – The research showed that companies using their resources can continue to fulfill their functions as a link in the Supply Chain despite the fact that they react differently to small disasters compared to big ones. This difference occurs since small disasters in contrast to big ones appear in every company much more often. Consequently, it is more difficult for companies to build their wealth in the case of small disasters. The advantage of the proposed approach is that one can freely test which strategy can cause the least losses for the company as well as for the entire supply chain.

**Research implications/limitations** – The analysis carried out shows that companies wishing to develop in conditions of unexpected disasters, that cannot be predicted, should regularly increase their assets because they are needed to implement a strategy

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that allows them to maintain an appropriate operational level. This approach provides tools that enable the selection of strategies with variable parameters, freely determined during the scientific research.
**Originality/value/contribution** – The paper presents a graphical analysis of the change in the value of resources of a supply chain company over one year period. Such an analysis may be useful for any company that creates a supply chain during the COVID-19 crisis period, which is an unpredictable disaster. The adoption of a Gaussian Pseudo Random Number Generator turned out to be useful as it creates crises days while simulation studies allow us to generate experiments for different data configurations. This paper provides an analysis of small and large disasters separately, which is an approach not presented in the literature.

**Keywords:** supply chain, disaster, strategy, threats, simulations.
**JEL Classification:** M21, D81, D84, C44.

## 1. Introduction

During the COVID-19 crisis, companies operate in more difficult conditions than, for example, in the crisis that ended in 2009, because the current crisis is characterized by a faster pace, hitting all sectors, including the largest employers in the world (COVID-19 and the great reset, 2020). Such conditions mean that companies, that are links in the supply chain, may not be able to meet their obligations, which will distort the results of the supply chain, negatively affecting the flow of goods and services, which is referred to as the supply risk (Zsidisin, Panelli, & Upton, 1999). Supply chains are now not only longer, due to strong competitive pressures and internationalization of companies, but they are also becoming more complex, with globalization contributing to the distant sourcing of markets. Supply chains are therefore exposed to various threats that can result in the supply chain not being able to deliver the goods on time.

Such threats include catastrophes that cause the loss of the company's ability to operate, and thus – the entire supply chain. In the literature, one can find the view that disasters, including diseases, which negatively affect the supply chain, may also have a negative impact on the regional economy or even the entire country (Martínez, Lizarraga, Cavazos, Salais, & Saucedo, 2018). For this reason, the COVID-19 crisis can also be considered such a catastrophe. Therefore, in the current epidemic conditions, any research on a disaster analysis seems to be particularly desirable. Consequently, companies deal with closed borders, factories face closure,  large supply chains are under stress as global production is halted, moreover shortages and delays occur globally (Runde & Ramanujam, 2020). In such conditions, the priority is to restore the economy to its pre-COVID-19 crisis state, which also requires the reorientation of global supply chains and their transformation into resistant chains (Runde & Ramanujam, 2020). It should be added that apart from the crisis, there may be other disasters in practice that also affect firms and entire supply chains, without any possibility of predicting them. To sum up, unpredictable disasters exist and additionally expose companies to financial and operational risks (Kleindorfer & Saad, 2005), and therefore strategies for business recovery are needed and should be examined. Epidemics belong to such unpredictable disasters (Chen, Liu, & Yang, 2015). At the same time, COVID-19 is an epidemic and therefore one can be motivated to analyze such strategies. The literature divides disasters affecting the functioning of supply chains into small and large, and they are characterized by different probabilities of occurrence (Chen et al., 2015) if one wants to use a strategy to improve the functioning of supply chains under unpredictable conditions. They reduce the operational efficiency of companies, and therefore of the entire chain. Therefore, strategies that allow each link (i.e., a firm) to recover in the event of a catastrophe, and, consequently, the entire supply chain, seem necessary. They are called recovery strategies (Chen et al., 2015). Their advantage is that they can be used in case unpredictable disasters occur.

The research problem is that there is a lack of graphical interpretation of the impact of two types of disasters on the condition of companies and the whole supply chain whereas the disasters could be analyzed separately. Moreover, the literature does not provide precise indication of the days on which disasters occur throughout the year. Thanks to the proposed approach, it is easier to separately assess the impact of both small and big disasters on the condition of the supply chain and individual companies, it also allows the development of a graphic interpretation of the effects of these disasters and their frequency. The aim of this publication is to fill the cognitive gap that results from the literature analysis. The paper analyzes the selected strategy, considering both the sequence and number of days when disasters may occur and the company's resources that can be used during the year to improve the situation, simultaneously considering both small and big disasters. The original numerical model – "a Gaussian Pseudo Random Number Generator" (called PRNG) (Thomas, Luk, Leong, & Villasenor, 2007) was used to analyze this order, because it is useful for analyzing the number of such days and the problem is that all studies failed to use it. However, the number can be calculated very precisely.

To increase the practical value of the work, there was selected such a type of strategy which can be considered as useful from the perspective of the current epidemic situation in the world,. In addition, a graphical analysis of changes in the value of resources was carried out, which was not found in the current literature prior to this paper. Moreover, all the supply chain-based studies do not use the PRNG – a tool, which makes them not as precise as they should be. To conclude, the work uses its own research carried out in the MATLAB environment and the analysis of the literature. The paper consists of four parts. The first part presents the essence of the supply chain and unpredictable disasters, the second part is devoted to the research assumption, while the third part contains research findings. The conclusions are presented in the fourth and last part.

## 2. Brief characteristics of the supply chain and disasters from the perspective of recovery strategies

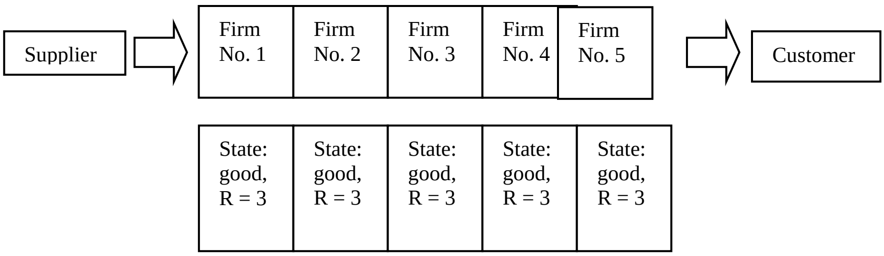
Apart from the fact that there are lots of definitions in the literature, we can assume that “a supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. Within each organization, such as a manufacturer, the supply chain includes all functions involved in receiving and filling a customer request. These functions include, but are not limited to, new product development, marketing, operations, distribution, finance, and customer service” (Chopra & Meindl, 2007). Moreover, it can be assumed that for the existence of a supply chain, cooperation of at least 3 companies is required (Mentzer et al., 2001), and the purpose of this cooperation is to satisfy the customer’s needs. Supply chains can be multielement entities, even consisting of hundreds of enterprises, if they are built for the implementation of a large project, for example a construction type project (O’Brien, London, & Vrijhoef, 2002). This is the construction supply chain which “consists of all the construction business processes, from the demands by the client, conceptual, design and construction to maintenance, replacement and eventual decommission of building, and organizations, which are involved in the construction process, such as client/owner, designer, general contractor (GC), subcontractor, supplier, consultant, etc. CSC is not a chain of construction businesses with business-to-business relationships but a network of multiple organizations and relationships, which includes the flow of information, the flow of materials, services or products, and the flow of funds between client, designer, contractor and supplier” (Xue, Wang, Shen, & Yu, 2007, p. 151). One should add that there is also a project supply chain described as “the global network (…which is…) used to deliver a project from raw materials to the final project customer through an engineered flow of information and physical distribution. A project supply chain thus involves the principal contractor who oversees the management of the project, the clients and their own clients, the suppliers and their own suppliers and subcontractors, the subcontractor and their own subcontractors" (Parrod, Thierry, Fargier, & Cavaille, 2007, p. 159).

In other words, the supply chain is an entity delivering goods to customers, and its size cannot be clearly defined, therefore its management is not risk-free. However, as mentioned previously, disasters are phenomena that cannot be predicted (Chen et al., 2015) as it is impossible to foresee all potential uncertainties (Johansen, Halvorsen, Haddadic, & Langlo, 2014, p. 567).

Thus, one of the most problematic issues for supply chains is that unpredictable disasters disrupt the flow of the mentioned goods across supply chains. Considering the current situation, these disasters should be analyzed, but from the perspective of improving the functioning of supply chains. Based on the literature one can state that such disasters should be researched on the assumptions of Martínez et al. (2018) and Chen et al. (2015) to improve operational state of companies functioning as links of a supply chain. The problem is that there is little research on these issues, additionally, these disasters are events that cannot be predicted and only these assumptions can help us apply recovery strategies supporting supply chain. From the view of these assumptions such disasters can be divided into small disasters (with probability called *pg*) and big disasters (with probability called *pf*), where $pg = 134/365$ and $pf = 17/365$ (Chen et al., 2015). This means that the researchers did not attempt to build models to predict disasters but did determine the probability of their occurrence. In other words, every day there is a disaster probability for every company in the supply chain (Martínez et al., 2018) that exposes the company to operational and financial risks (Chen et al., 2015). This breakdown helps us to understand how the disasters can be managed effectively as better management of operations in the case of a disaster will make a recovery easier (Altay & Green, 2006) and only such a breakdown of disasters allows us the use of recovery strategies. That is a model for analyzing disasters and firm resources, which can be used for development of firm operational states. One should not forget that the best firm state, called good, means that on "*t*" day a company "*i*" is fully operational, so the best situation is such that the supply chain would consist of firms in such a state. Using this recovery strategy requires own considerable resources (Chen et al., 2015), which are described as R. The higher R is, the better financial standing of the company. All in all, a recovery strategy should protect the supply chain from disruption and have a positive effect on member companies over time, increasing R while having the best firm state. One can assume that R value corresponds to the condition of companies, and simultaneously to the whole supply chain. In view of the disasters; a recovery strategy is a representation of an opinion of a company which wants to change its state to a better level after disaster. In this way all supply chain companies can improve their state and the state of the whole chain.

If the chain consists of five links, a final customer and a supplier, for the purpose of research goals it can be presented in the form of an overview drawing depicted in Figure 1.

**Figure 1.** The most important links in the sample supply chain at the beginning of the research period



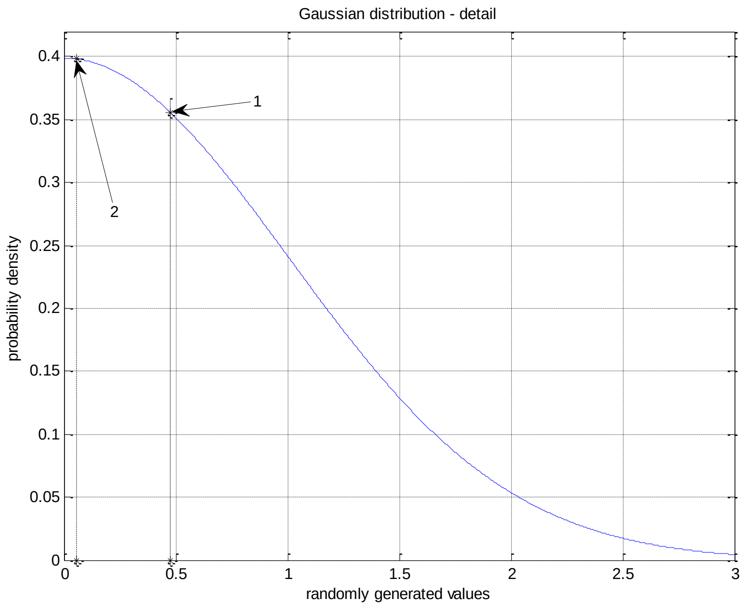

Source: Authors' own study.

A recovery strategy determines the construction of a supply chain which is that at the beginning each company can function as a part of supply chains, so it has state called "good," and has the same considerable resources (for example $R = 3$). This assumption allows us to use the research procedure whose effect for firms is such that there is a possibility of increasing resources and being fully operational.

## 3. Research assumption

This research procedure is based on the assumptions of Martínez et al. (2018) and Chen et al. (2015), but it uses a Gaussian Pseudo Random Number Generator because it enables the observation of crises individually for individual links (companies) with an indication of the number of the days of their occurrence. However, all studies which were carried out failed to use this approach. A PRNG allows the number of disasters to be determined, where The Gaussian distribution (Figure 2) is used as a basis for calculating (Cotrina, Peinado, & Ortiz, 2020) with probabilities *pg=134/365* (marked as "1") and *pf=17/365* (marked as "2").

**Figure 2.** Small disaster days for companies




Source: Authors' own study based on MATLAB-simulations.

Assuming that the highest possible state of a company is "2," then the dichotomous breakdown of disasters affecting an enterprise in the supply chain can be represented as follows:

- small disaster causes the company to reduce its state by level "1;"
- big disaster causes the company to assume the status "0."

This concept allows the company "*i*" to adopt three states on "*t*," which reflect the company's operational capability in terms of being able to function as a link in supply chains (Martínez et al., 2018):

- the first state (called good), marked as $s_i(t) = 2$ means that on "*t*" day the company "*i*" is fully operational, where $s_i(t) = 2$ is the highest state;
- the second state (called normal) marked as $s_i(t) = 1$ means that on "*t*" day the company "*i*" is not fully operational, but can perform as a member of the supply chain, where $s_i(t) = 1$ is the average state;
- the third state (called bad) marked as $s_i(t) = 0$ means that on "*t*" day the company "*i*" is barely operational, therefore it may even expect production stoppage, therefore $s_i(t) = 0$ is the lowest state.

In other words, the operating conditions of the firm can be presented using specific rules:

- $s_i(t) \in \{0,1,2\}$ where $i = 1,2, \ldots N$ and $t = 1,2, \ldots T$;
- *pg=134/365* and *pf=17/365*;
- $s_i(t) = 0$ after a big disaster;
- $s_i(t) \in \{0,1\}$ after a small disaster;
- $T = 365$, if a full year is tested.
- the company "*i*" after a disaster, wishes to reach the state $s_i(t) \in \{1,2\}$ to be able to fulfill its functions in the supply chain, so it starts to recover the required operational level while this operation is called the decision rule (DR);
- performance of the supply chain is described as $S(t) = \sum_{i=1}^{N} s_i(t)$.

The above conditions define the state of individual companies on a given day, however, to achieve the state $s_i(t) \in \{1,2\}$, strategies are desirable that will improve the status of the firm. Under such assumptions, there are three combinations of enterprise improvement:

- state $s_i(t) = 0$ increases to the level $s_i(t) = 1$;
- state $s_i(t) = 0$ increases to the level $s_i(t) = 2$;
- state $s_i(t) = 1$ increases to the level $s_i(t) = 2$.

It is easy to notice that the classification of firms, which, due to their condition, can be divided into three groups, complicates the development of strategies that will allow to raise the level of the firm. Nevertheless, they are desirable because even the level $s_i(t) = 1$ determines the state in which the chain link is operational, so if the entire supply chain will consist of links at this level, then it will also be operational. Strategies that have been developed to help a company recover from a disaster (including the entire chain), are called "recovery strategies" (Chen et al., 2015). It was assumed that to raise the level of the company to the value of $s_i(t) \in \{1,2\}$, the resources of the firm should be used. This utilization depends on the cost of upgrading the link, as this may vary. The resource consumption rules are called "resource consumption" (RC), with each company in the supply chain, starting out with the same level of resource ($R = 3$), which increases by the same amount each day, $\Delta R = 1$. An example of resource consumption (called RC1) together with the assumptions of recovery strategies, can be presented as follows (Martínez et al., 2018):

- in $t = 0$ company "*i*" owns resource $R = 3$;
- $\Delta R = 1$ after a period $t + 1$;
- $RC1 = 1$, if a company wants to increase state $s_i(t) = 0$ to $s_i(t) = 1$;
- $RC1 = 2$, if a company wants to increase state $s_i(t) = 1$ to $s_i(t) = 2$;

- $\mathrm{RC1} = 10$, if a company wants to increase state $s_i(t) = 0$ to $s_i(t) = 2$;
- if there is a day t when the company owns $R < RC1$, then the resources of it are considered as insufficient and RC rule cannot be applied, therefore its state is not changed until $R > RC1$.

Due to the purpose of the study, not all combinations of resource consumption (RC), which are 6 (Martínez et al., 2018), are shown, but the most radical – RC1, has been chosen because the COVID-19 crisis may force companies to use the resources with the highest levels. Values, and the state $s_i(t) = 1$ may not be practical enough to perform as a link in the supply chain. Not all 10 decision rules (DRs) are listed here because it is also assumed that the company is aiming for $s_i(t) = 2$, regardless of the state of other companies in the supply chain.

## 4. Research findings

Two types of experiments were carried out in the work to show the value of resources in enterprises in a graphic form, considering the number and sequence of days on which disasters may occur. This approach is intended to show the development of a company operating in the supply chain throughout the year, regardless of the condition of other enterprises in this chain. The first type of experiment relates to big disasters, and the second type – to small disasters. This division is dictated by the desire to obtain transparent results that can be presented on separate charts. In summary, the following assumptions were made in the study:

- experiments for big disasters and for small disasters were conducted separately;
- supply chain consists of five companies;
- to determine the number of disasters and the number of days in which they occur, "a Gaussian Pseudo Random Number Generator" (PRNG) was used in the MATLAB environment, where the number of attempts corresponded to the number of 365, the experiments were carried out separately for five companies, because each of them may face a disaster on a different day (with probabilities *pf* and *pg*);
- the level of resources (R) for each firm, at time of *t*, was determined based on the guidelines presented in the previous part of the work, using the MATLAB environment. MATLAB was chosen because it is a useful tool and it is based mainly on scientific and technical calculations. The program boasts that a spectrum of software solutions, called Toolboxes, can used, for example, to create and optimize neural networks or occurrence of disasters. What is more, MATLAB is totally compatible with other programming environments.

Based on the conducted experiments, the number and sequence of days were determined for each of the companies in the supply chain (Table 1).

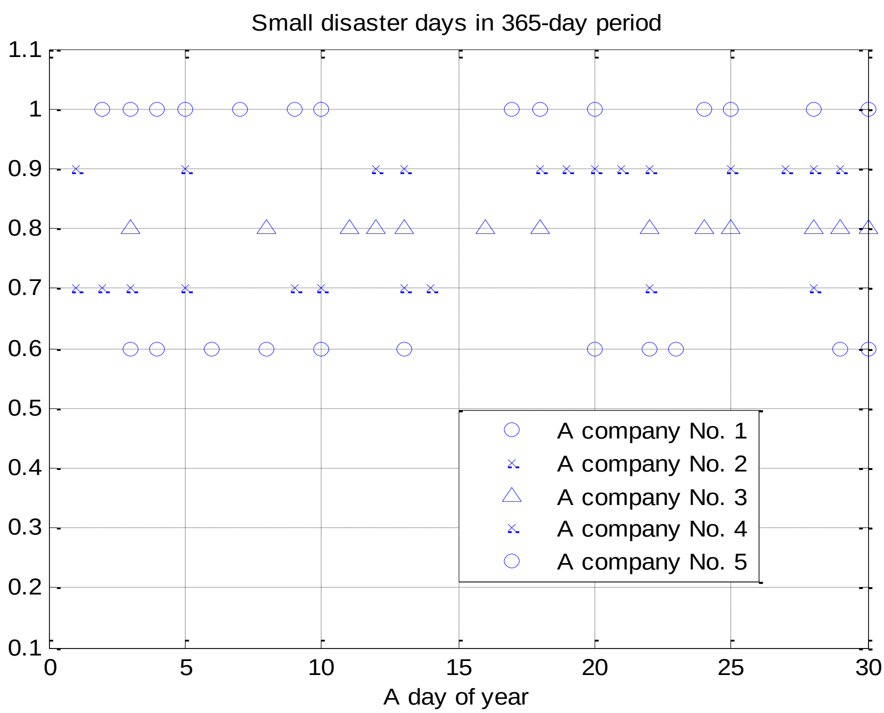
**Table 1.** Several disasters

| A company number | Number of big disasters | Number of small disasters |
|---|---|---|
| No. 1 | 18 | 136 |
| No. 2 | 15 | 106 |
| No. 3 | 17 | 131 |
| No. 4 | 13 | 126 |
| No. 5 | 21 | 137 |

Source: Authors' own study based on MATLAB-simulations.

For the sake of clarity, the number and sequence of days have been presented graphically from the perspective of small disasters (Figure 3) and big disasters (Figure 4). Values from 1.0 to 0.6 have been assigned to each of the five links in these figures to distinguish the moments of crises more easily for the selected link.

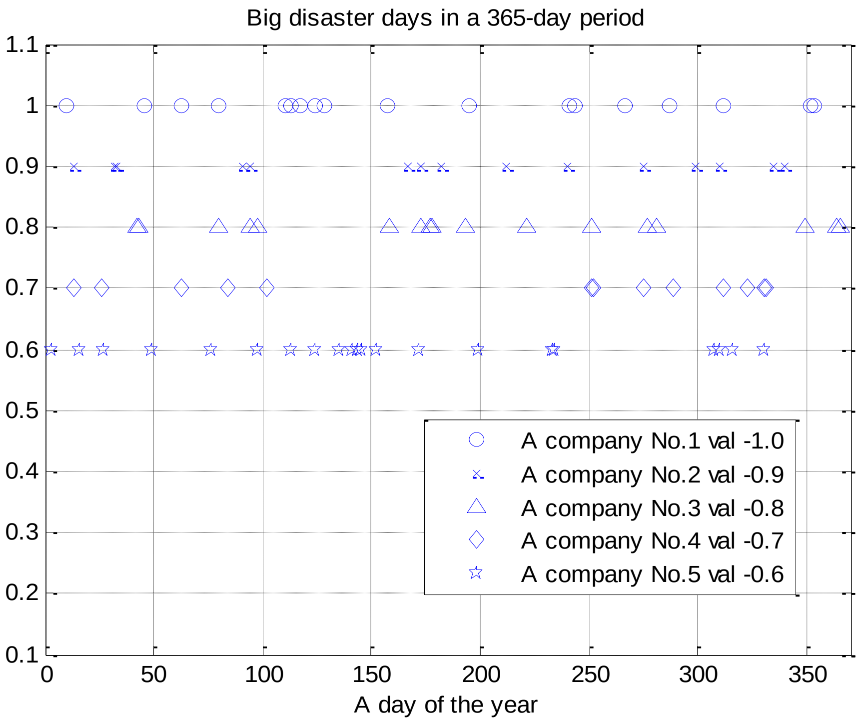
**Figure 3.** Small disaster days for companies




Source: Authors' own study based on MATLAB-simulations.

The number of small disasters was very large, therefore the period of 30 days from the start of operation in the chain was selected for the presentation. However, the number of big disasters is smaller, therefore the entire period of 365 days is presented (Figure 4).

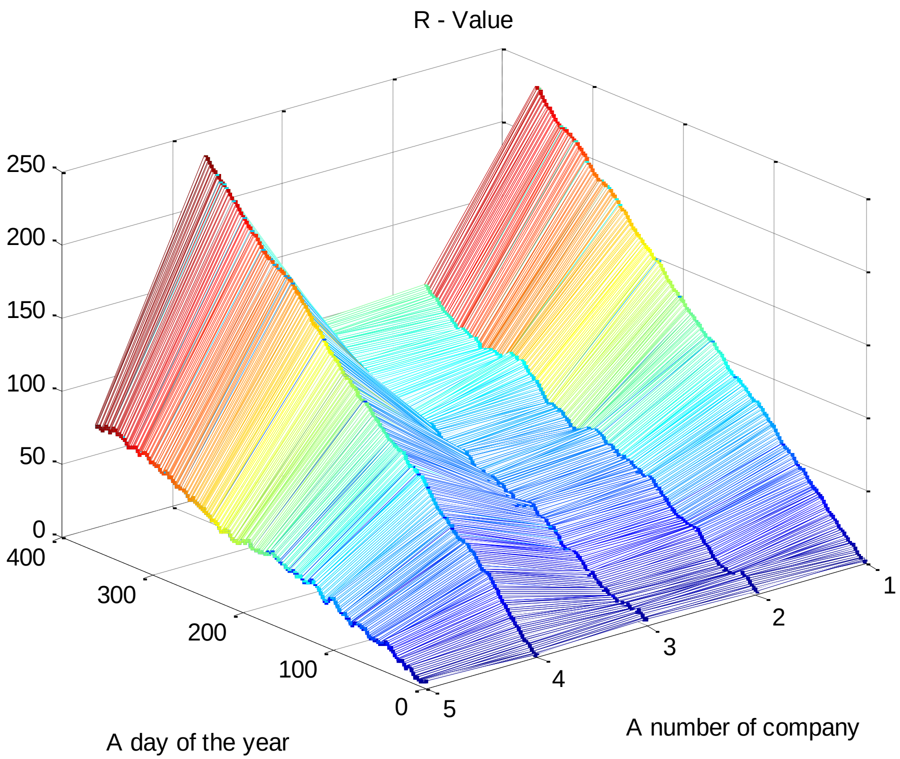
**Figure 4.** Big disaster days for companies




Source: Authors' own study based on MATLAB-simulations.

The R-value in the analyzed period is also presented separately in the form of two additional figures. Figure 5 shows the MATLAB-based calculated value of R for five companies during small disaster days in 3D dimensions, to present the surface, whereas Figure 6 outlines values of R for the same companies during small disaster days, but in 2D dimensional form. This can help assess how large the increase for each company is. Additionally, the research did not concentrate on the specific numerical data, but on the progress of R – value during a year.

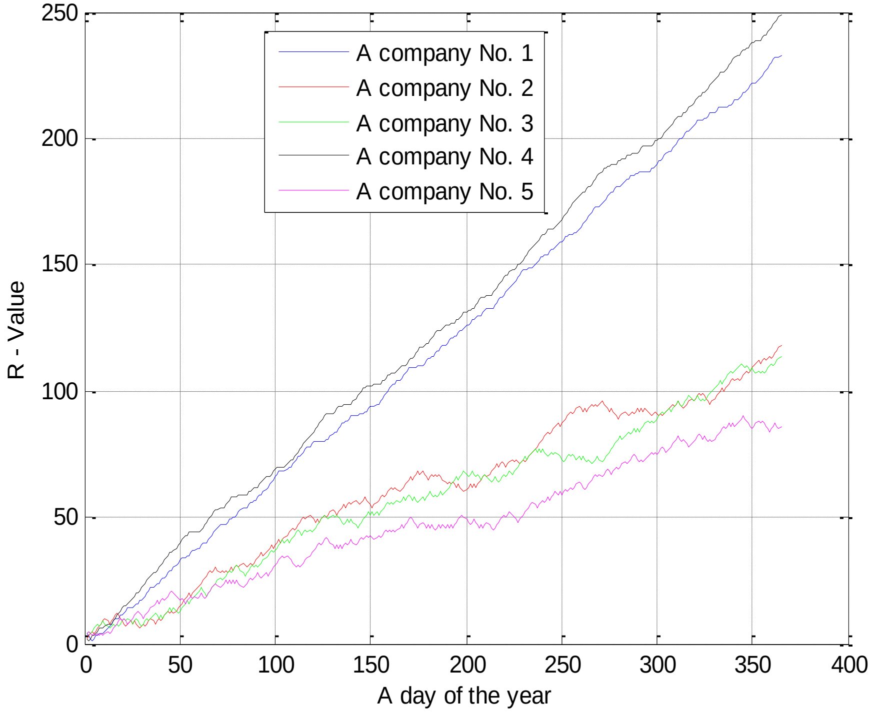
**Figure 5.** Value of R for five companies during small disaster days in 3D dimensions




Source: Authors' own study based on MATLAB-simulations.

Value of R for small disaster days changes for each company in a different way, therefore it is worth presenting the course of these values in the form of a two-dimensional chart, which was previously stated. Figure 6 presents the research results, but one must add that the methodology used in the paper allowed us to get $s_i(t) = 2$ – state, which means that in each day there is a possibility of the company being fully operational. In other words, this is a kind of beneficial strategy to keep the supply chain fully operational at the expense of resources in any company.

**Figure 6.** Value of R for five companies during small disaster days in 2D dimensions

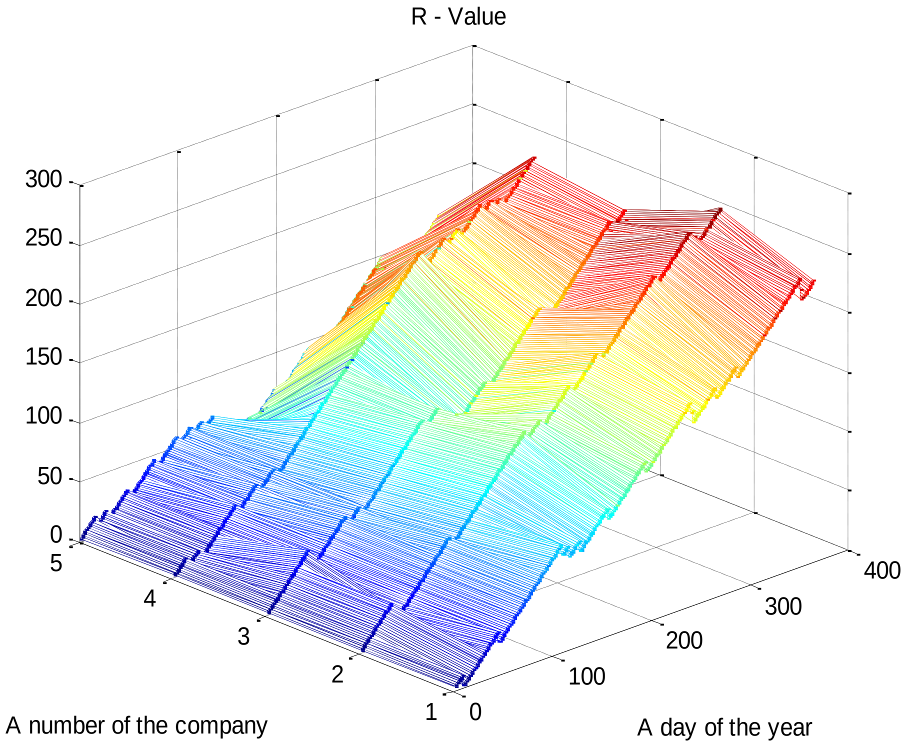



Source: Authors' own study based on MATLAB-simulations.

All in all, following the conducted experiments, it was found that companies use the strategy (DR) in the case of small disasters with different results, but thanks to it, it is possible to maintain the level of $s_i(t) = 2$ for a period of 365 days. However, such a high level is related to the fact that the enterprise must consider difficulties in increasing its assets R, therefore the differences between the assets of firms are quite large at the end of the year. In other words, no matter how much a single company would increase the R – value, it should consider an R – increase of the other supply chain companies, because after 5-year period the resources of these members could not be high enough.

Analyzing Figure 6, it can be noticed that there may be situations in which the links, despite the impact of crises, increase their resources R much more effectively (company 1 and company 4) than the others. Additionally, both the 3D dimensions figure (Figure 7) and the 2D dimensions figure (Figure 8) are added with the same aim as it has been already done but regarding big disasters.

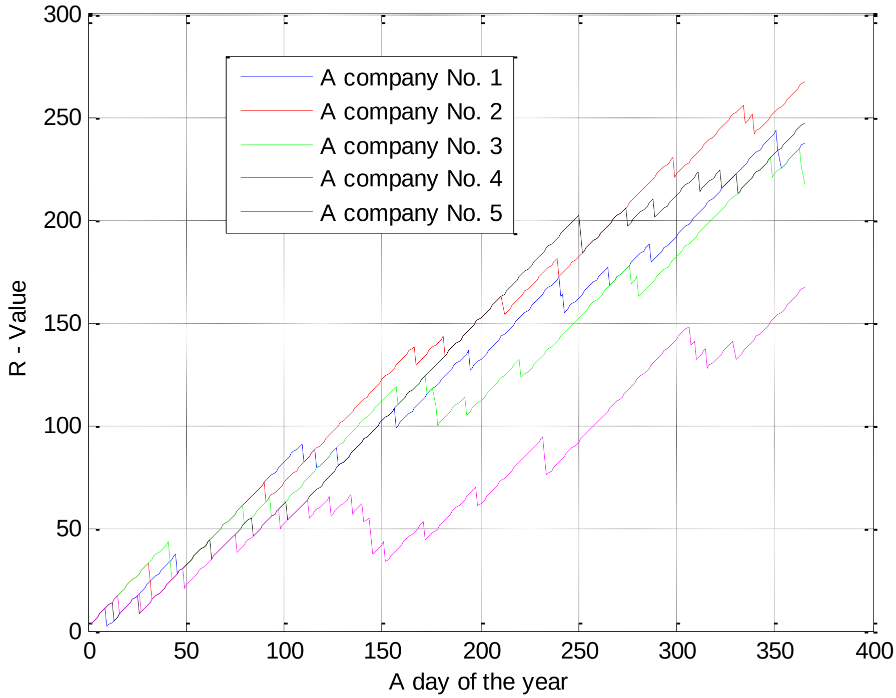
**Figure 7.** Value of R for five companies during big disaster days in 3D dimensions




Source: Authors' own study based on MATLAB-simulations.

As shown in Figure 7, it can be concluded that firms similarly increase their R – resources in the event of the occurrence of big disasters, which can be clearly illustrated by a two-dimensional diagram. The result is equally to be understood if one analyzes the above-mentioned Figure 8. It cannot be ignored that the aim of the research was to establish the difference between the development of R – values for both supply chain companies under the condition of a small disaster and supply chain companies under the condition of a big disaster.

**Figure 8.** Value of R for five companies during big disaster days in 2D dimensions




Source: Authors' own study based on MATLAB-simulations.

The consequences of the cumulative occurrence of disasters can significantly reduce the resources of the link in relation to other links (company 5), for which there is a greater uniformity of crises. Let it be mentioned that the big disaster days analyses showed that companies build their resources in a more similar way. If such a statement can be used, and therefore there are no such discrepancies as there were with small disasters. Nevertheless, the applied DR strategy also allows companies to maintain the level $s_i(t) = 2$, also in the case of big disasters. In summary, the entire supply chain can remain operational in the event of these two types of disasters, and companies will find it easier to expand their resources in the event of big disasters. The condition for maintaining the level of $s_i(t) = 2$, however, is the immediate reaction of the company to the crisis and having sufficient resources, which should always be increased every day.

## 5. Conclusions

This paper focused on the functioning of entities in the supply chain, which consists of many companies forced to conduct their activities in conditions of disasters. The paper presented a different approach used in the analysis of the impact of disasters on the quality of functioning of the supply chain. It seems that this proprietary approach can be used by other researchers in many ways. The solution shown in the paper can be treated as a unique guideline for policy-makers and researchers worldwide who want to research which strategies are more effective for small or large disasters. One should mention that these disasters cannot be predicted, and in the literature, they have been classified into big disasters and small disasters. This approach complicates the considerations that seem necessary during the COVID-19 crisis. Moreover, these disasters can occur on different days for each of the supply chain companies. Bearing this in mind, an attempt was made to use the PRNG model, which allows companies to determine the number and sequence of days during which big disasters and small disasters may occur. This approach permits the analysis of the selected strategy that can be used to improve the condition of the company. Such an approach enables individual analysis to be made for links which are subjected to crisis. The probabilities of crises are the same for all links, but the PRNG model can distribute them differently, causing different effects on the companies and the entire supply chain. No studies with a similar approach were found in the literature, therefore this study should be treated as unique. The use of the PRNG model has become the basis for the strategy analysis, thanks to which companies are able to overcome disasters. However, this strategy requires the use of specific resources, so it was determined how their value develops over a 365-day period, in supply chains consisting of five links.

As a result, the study revealed that in the case of big disaster days, companies building supply chains evenly develop their resources, whereas in the case of small disasters, some discrepancies occurred. Nevertheless, companies can be fully operational if they react immediately to a crisis, having a sufficient value of resources that should be increased every day, regardless of the condition of neighboring firms within that supply chain. All in all, this simulation approach makes it possible to average the analysis of the selected period of operation of the company as well as the entire supply chain. This allows for a precise determination of the day of the occurrence of a small and large disaster, and its advantage is the possibility of repeated experiments, which may become the basis for determining the consequences of these crises. Thus, it is possible to conduct experiments concerning the entire chain as well as a particular link, without the consequences of exposing a company to losses. Unfortunately, our simulation studies do not consider unpredictable events other than small and big disasters. Furthermore, there are no other similar studies to compare with our results. One should mention that the approach is universal, but the complexity of the problem rises with the increase in factorial consideration. Further research will be directed towards increasing the company samples to broaden and confirm the results. The discussed matter may be related to many research questions, but the paper addresses the issues of a disaster in a broader rather than a fragmentary perspective.

## References

Altay, N., & Green, W. G. III (2006). OR/MS research in disaster operations management. *European Journal of Operational Research, 175*(1), 475-493. https://doi.org/10.1016/j.ejor.2005.05.016

Chen, L.-M., Liu, Y. E., & Yang, S.-J. S. (2015). Robust supply chain strategies for recovering from unanticipated disasters. *Transportation Research, Part E: Logistics and Transportation Review, 77*, 198-214. https://doi.org/10.1016/j.tre.2015.02.015

Chopra, S., & Meindl, P. (2007). *Supply chain management: Strategy, planning, and operation* (3rd edition). Upper Saddle River: Pearson Prentice Hall.

Cotrina, G., Peinado, A., & Ortiz, A. (2020). Gaussian pseudorandom number generator based on cyclic rotations of linear feedback shift registers. *Sensors, 20*(7), 1-18. https://doi.org/10.3390/s20072103

Johansen, A., Halvorsen, S. B., Haddadic, A., & Langlo, J. A. (2014). Uncertainty management – a methodological framework beyond "the six W's". *Procedia – Social and Behavioral Sciences, 119*(19), 566-575. https://doi.org/10.1016/j.sbspro.2014.03.063

Kleindorfer, P. R., & Saad, G. H. (2005). Managing disruption risks in supply chains. *Production and Operations Management, 14*(1), 53-68. https://doi.org/10.1111/j.1937-5956.2005.tb00009.x

Martínez, R., Lizarraga, G., Cavazos, L., Salais, T., & Saucedo, J. (2018). A new objective function to simulate supply chain performance under disruptions with cellular automata [Paper presentation]. In F. Torres-Guerrero, J. Lozoya-Santos, E. Gonzalez Mendivil, L. Neira-Tovar, P. Ramirez-Flores, J. Martin-Gutierrez (Eds.), *Smart Technology. First International Conference, MTYMEX 2017, May 24-26, 2017, Monterrey, Mexico* (pp. 21-30). Berlin: Springer International Publishing. https://doi.org/10.1007/978-3-319-73323-4

McKinsey & Company. (2020). *COVID-19 and the great reset: Briefing note #26, October 7, 2020*. Retrieved from https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Risk/Our%20Insights/COVID%2019%20Implications%20for%20business/COVID%2019%20Oct%207/COVID-19-Briefing-note-26-October-7.pdf

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. *Journal of Business Logistics, 22*(2), 4. https://doi.org/10.1002/j.2158-1592.2001.tb00001.x

O'Brien, W. J., London, K., & Vrijhoef, R. (2002). Construction supply chain modeling: A research review and interdisciplinary research agenda. In C. T. Formoso, & G. Ballard (Eds.), *10th Annual Conference of the International Group for Lean Construction. Gramado, Brazil, 6-8 Aug 2002*. Retrieved from https://iglcstorage.blob.core.windows.net/papers/attachment-f9507e7c-6962-4ce9-985f-49159a1c78ec.pdf

Parrod, N., Thierry, C., Fargier, H., & Cavaille, J. B. (2007). Cooperative subcontracting relationship within a project supply chain: A simulation approach. *Simulation Modelling Practice and Theory, 15*, 137-152. https://doi.org/10.1016/j.simpat.2006.09.016

Runde, D. F., & Ramanujam, S. R. (2020, September). *Recovery with resilience: Diversifying supply chains to reduce risk in the global economy*. Washington, D.C.: Center for Strategic and International Studies (CSIS). Retrieved from https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/200904_Ramanujam_GlobalSupply_v4.pdf

Thomas, D. B., Luk. W., Leong, P. H. W., & Villasenor, J. D. (2007). Gaussian random number generators. *ACM Computing Surveys, 39*(4), 11:1-11:38. https://doi.org/10.1145/1287620.1287622

Xue, X., Wang, Y., Shen Q., & Yu X. (2007). Coordination mechanisms for construction supply chain management in the Internet environment. *International Journal of Project Management, 25*(2), 150-157. https://doi.org/10.1016/j.ijproman.2006.09.006

Zsidisin, G. A., Panelli, A., & Upton, R. (1999). Purchasing organization involvement in risk assessments, contingency plans, and risk management: An exploratory study. *Supply Chain Management, 5*(4), 187. https://doi.org/10.1108/13598540010347307