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APPLICATION OF CRISIS MANAGEMENT METHODS AND TECHNIQUES DURING A SEISMIC SEA WAVE (TSUNAMI)

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Abstract:
Research background: Every year the natural disasters kill or affect millions of people and cause gigantic economic damages. Although it is impossible to eliminate these natural disasters at all, it is possible to mitigate their impacts partly – by effective rescue works implemented in these cases. The impact of these risk events depends on several factors, such as the economic development of the country or locality, and especially on predictability (early warning).
Purpose of the article: These activities also include a plan for the deployment of aid distribution centers after a crisis event occurs. The study focuses on the analysis of disaster management events and their development in recent years. On the basis of these findings, it is concluded that for perfect organization it is appropriate to determine the location of the relief distribution centers using mathematical methods.
Methods: A multiple objective model is proposed to select relief distribution centres and channels. Thanks to the optimization carried out, it can be easier to provide the necessary help in a timely manner, which is reflected in lower losses of life and property. Optimization model contains three minimization objective functions – following (1) the number of distribution centres in total, (2) the number of distribution channels in total and (3) total distance between distribution centres and channels. The model also contains four constraints.
Findings & Value added: Based on the investigation and performed normalization of values, it is advisable to minimize the number of distribution channels, as this purpose function provides the best results. The findings can be applied in tsunami-prone areas to reduce the impact of this natural disaster on the number of deaths, the number of people affected, and the costs associated with rescue efforts.

Keywords: crisis management; disaster management; optimization; relief distribution; tsunami

JEL Classification: H12; C6; D81

1. Introduction

Natural disasters with a significant impact on the Earth and human society become a regular occurrence in current world. These are extreme phenomena caused by environmental factors and climate change (Hidalgo and Baez, 2019). Similarly, Cappelli et al. (2021) state that there may be a dependency between climate change and the occurrence of catastrophic events, especially in the case of wildfires and extreme temperatures. However, according to them, the dependence between the occurrence of catastrophic events is much stronger with countries with significant income inequality, while this inequality increases future vulnerability. According to Saeed and Gargano (2022), natural disasters are adverse events that can often result in injury, property damage, or even death. Natural disasters are increasingly serious and have an impact on the financial situation (Sapulveda-Velasquez et al., 2023). According to Cooke et al. (2022), natural disasters are specific in that they have a direct or indirect impact on humans, fauna and flora. This fact is confirmed by Matsuda et al. (2023), who state that natural disasters have a serious impact on human health and social functions. Among other things, they have a negative impact on infrastructure, and economic and social activity (Kljucanin et al., 2021).

According to Centre for Research on the Epidemiology of Disasters (CRED) and its international disasters database EM-DAT, since 2000 almost 1.5 million people have died as a result of natural disasters, about 3.8 billion people have been affected and total damages have amounted to 2.4 trillion USD. The processing and recording of relevant data in the databases of the given organization is carried out with high accuracy, and any missing information is supplemented in accordance with appropriate statistical methods (Jones et al., 2022). As Coppola (2011) says, the number of natural disasters has increased in recent 20 years compared to the previous time period. The reason for this is the fact that the Earth is constantly evolving, which causes a number of changes. These changes arise due to natural processes and development, but also to human activity (interventions). According to Li et al. (2021), human activity and people in general fundamentally influence the environment, which is one of the most important factors in our lives. In connection with the increasing impact of natural disasters, the need for effective and efficient operations has become a major problem to solve in the disaster management area. Sahil and Sood (2021) argue that due to frequent natural disasters, different countries are focusing on programs and research that can influence these devastating effects. However, there are no comprehensively known and consistently applied tools in the world.

The aim of this article is to propose a multi-criteria relief distribution optimization model that can be applied in affected areas after the impact of the tsunami wave. The given model is based on data that was created based on the coastal dispositions of countries in South East Asia. The proposed model contains a total of three objective functions and four constraints, which decide on the appropriate number of distribution centres, distribution channels and the distances between them.

1.1 Natural disasters

The power of impact of any natural disaster depends on many factors, such as place of event and its economic maturity, location of relief distribution centres, preparedness, type of natural disaster, use of early warning systems and other (Pathirage et al., 2014). According to Khairuddin et al. (2022) this is an unavoidable phenomenon that has an impact on the entire affected location. In China, natural disasters have even been proven to have devastating effects on social and economic development (Wang and Zhao, 2023). This is confirmed by Agarwal et al. (2023) who argue that land use is being reduced and this is leading to more natural disasters that affect socio-economic factors. Floods are the most common type of natural disaster. Floods thus bring the greatest economic burden and it is very difficult to prepare for them, as well as for other natural disasters (Arshad et al., 2020). They occur almost worldwide and have enormous impacts on population health. Of course, these impacts include drowning, but the transmission of viral diseases may also increase (Yavarian et al., 2019). According to Yu et al. (2022), it is crucial to evaluate flood disasters and analyze the causes of these disasters. Only then to examine the consequences that the floods brought with them. They often arise as a side effect of another catastrophic event (storms, underwater earthquakes, volcanic activity) and proportionally affect a high number of people. Storms and hurricanes "due to a good predictability even less affecting people" anyway are most often accompanied by rainstorms and floods causing more casualties than the storm itself (Haddow et al., 2011). Floods and storms together have occurred most often since 2000 and they represent over 70 % of all natural disasters (Ritchie and Roser, 2019). Earthquake is almost every year the deadliest type of natural disasters. According to Latupeiris and Pujianto (2020), earthquakes have similar consequences to floods, including fatalities and material losses. In less developed countries, where it has repeatedly struck in recent years (for example, Nepal or Haiti), it has a fundamental effect on labor migration, especially among men (Shakya et al., 2022). An effective way to reduce losses and risk is to increase awareness of the issue and thereby increase the ability to respond effectively to earthquakes (Wei et al., 2020). The reason for a low predictability, significant settlements in risk areas and accompanying side effects (tsunami) in the case of underwater earthquake. According to Ebisuzaki (2021), strong earthquake vibrations are amplified by secondary submarine landslides. These abnormal landslides and high waves are associated with a longer time horizon compared to typical events (Katsumata et al., 2021). Usually, droughts occur in the same areas (e.g. India) and have major effects on a number of people. Volcanic activity is well predictable and therefore affects only a small number of people even if causes extensive damages. Even so, it has a negative impact on the population, and it is therefore important to carry out assessments related to volcanic activity (Liu et al., 2020). Allende et al. (2020) argue that volcanic activity has a significant negative effect on the growth and survival of flora.

Table 1: Natural disasters 2017 to 2022

Year	**Floods**	**Storms**	**Droughts** (incl. extreme temperatures)	**Earthquakes**	**Volcanic activity**	**Wildfires**
2017	126 (41.7 %)	127 (42.1 %)	10 (3.3 %)	22 (7.3 %)	2 (0.7 %)	15 (5 %)
2018	127 (42.3 %)	95 (31.7 %)	41 (13.7 %)	20 (6.7 %)	7 (2.3 %)	10 (3.3 %)
2019	194 (52.3 %)	90 (24.3 %)	37 (10 %)	32 (8.6 %)	4 (1.1 %)	14 (3.8 %)
2020	201 (54.3 %)	127 (34.3 %)	14 (3.8 %)	16 (4.3 %)	4 (1.1 %)	8 (2.2 %)
2021	223 (53.3 %)	121 (28.9 %)	18 (4.3 %)	28 (6.7 %)	9 (2.2 %)	19 (4.5 %)
2022	176 (47.7 %)	108 (29.3 %)	34 (9.2 %)	31 (8.4 %)	5 (1.4 %)	15 (4.1 %)
Average 2017-2022	175 (49.2 %)	111 (31.2 %)	26 (7.3 %)	25 (7 %)	5 (1.4 %)	14 (3.9 %)
Average 2002-2021	168 (47.9 %)	104 (29.6 %)	35 (10 %)	27 (7.7 %)	6 (1.7 %)	11 (3.1 %)

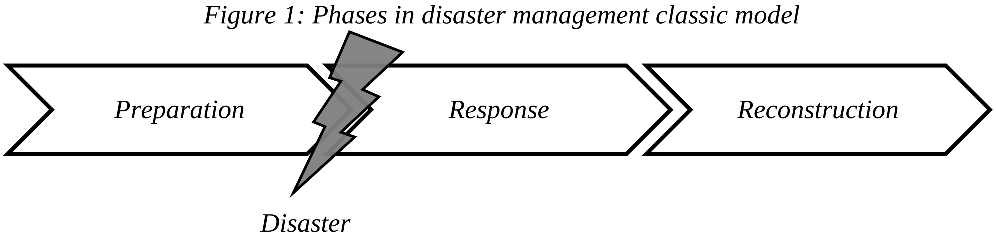
Source: authors (processed on the basis of data from the EM-DAT database at CRED)

Perhaps the tsunami wave which accompanies the undersea earthquake and volcanic activity has the most devastating impact. It takes only from a few minutes to hours for the entire process, from the emergence of the danger to the impact in the vulnerable zone. The earthquakes and tsunamis in the Indian Ocean (2004) and in Japan (2011) are the biggest events since 2000. The earthquake and tsunami in Indonesia in September (4,340 deaths) was the largest natural disasters in 2018. Table 1 shows the number of natural disasters by type since 2017 to 2022 (Yaghmaei, 2023). Tsunami waves are not captured because they are always a side effect of another devastating disaster.

1.2 Phases in disaster management

According to Kovacs and Spens (2007) the model of disaster management consists of three consecutive phases, which together constitute a closed-circuit cycle. The preparation phase forestalls the disaster while the following response and reconstruction phases are implemented after the disaster occurrence. The term cycle above refers to the situation when preparation begin with the gradual end of the reconstruction phase. The whole described system is shown in Figure 1.

Figure 1: Phases in disaster management classic model



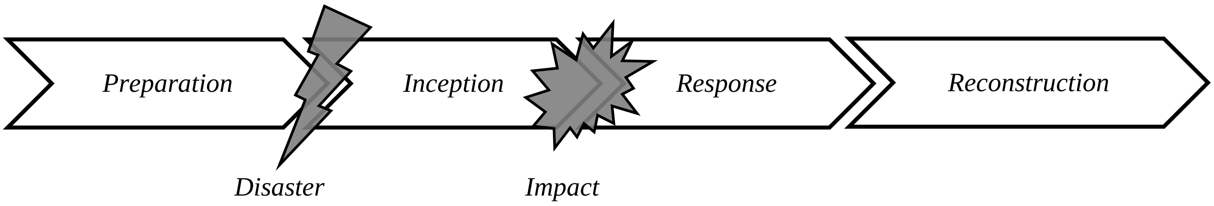
Source: Kovacs and Spens (2007)

Furthermore, the strategies and activities allocated to each stage are briefly presented.

- Preparation phase – Based on Coppola (2011) the preparation phase covers steps that lead to reducing the risk and overall impact of natural disasters. During the preparation phase first aid supplies and pre-positioning strategies for relief distribution should be made (Ozdamar and Ertem, 2015). According to Van Wassenhove (2006) trainings for emergency situations should be taken by locals.
- Response phase – Takes place shortly after a disaster, includes first aid to injured people and creation of crisis plans. The response phase usually lasts from 12 hours (Ahmadi and Tootooni, 2015) up to few days (Cao et al., 2017) based on activities allocated. Alexander (2002) formulates a similar model and states that the response phase covers finding victims, providing lifesaving assistance and transportation of these people to hospitals or provisional medical facilities.
- Reconstruction phase – Comes with a quietening of the situation after the response phase. Reconstruction phase has strategic goals and covers reconstruction works that lead to get back to normality as soon as possible (Hoyos et al., 2015). Ozdamar and Ertem (2015) states that this phase closes the disaster cycle because allocated activities proceed to the first phase.

The idea of the given system was developed by Chamrada and Subrt (2020), who created a new phase, called the “Inception phase”. The inception phase includes the time span between the occurrence of the disaster and the impact. Its beginning is defined by the moment when an early impact is confirmed (it is established that the event will hit a certain location) and its end comes at the moment of impact (the first loss of property or lives). The inception phase follows on from the preparation phase and at the same time precedes the response phase, as shown in Figure 2.

Figure 2: Phases in disaster management developed model



Source: Chamrada and Subrt (2020)

In professional literature, this period of time can only be encountered exceptionally, when it is usually referred to as "Preparation" or "Pre-Impact" (Alexander, 2002), but it is still not clearly defined in catastrophe timeline. The duration of the inception phase is highly variable, however, it is similar for individual types of disasters. According to Chamrada and Subrt (2020), based on 323 investigated events, it takes about 2 minutes in the case of earthquakes, about 1 hour in the case of tsunamis, and about 10 hours in the case of wildfires. The impact of floods and storms can be predicted in days, and the impact of extreme temperatures, droughts and volcanic activity can be identified even longer ahead.

It is worth mentioning that there is a number of other views on the system of Phases in disaster management, many of which are explained on the cycle system. Graphical representation in closed cycle format is mentioned by Balamir (2022), who points out the limits of the simplified model and suggests its extension. Against this, Bosher et al. (2021) opposes the cyclical concept, which significantly and inappropriately simplifies the system of managing catastrophic events. They present the development of disaster risk management phases by means of a helix in a two-axis graph, which evaluates the necessity and utilization of (1) resources and (2) efforts depending on the time development.

1.3 Problem description

According to Caunhye et al. (2012) the disaster management uses relief distribution centres for warehousing and prepositioning. The main distribution centres are constructed during the preparation phase for permanent use and they are usually located in a safe zone (out of the affected area). A network providing relief distribution as a result of humanitarian aid (medicals, water, food, etc.) arises in these centres and during the response phase distribution channels are provisionally built in the nearby area of them. Distribution channels are used to evacuate people and to provide humanitarian aid in the lowest level. They are built exactly in or close to the affected area.

Relief distribution centres are supplied a long time before crisis situations. The location of the warehouses and possibilities for making stock items available must meet the risk of (expected) catastrophic events (Safeer et al., 2014). The selection of points for distribution centers and foreseen distribution channel locations must take into account the possible infrastructure failure due to disaster (Torabi et al., 2013).

The current problem is therefore to identify the appropriate number of distribution centers and distribution channels as well as the distance between them and to the demand points in affected areas. Optimization will allow a proper allocation of rescue forces to individual areas. As a result, relief would be provided to the maximum number of injured people in a minimal number of relief distribution places.

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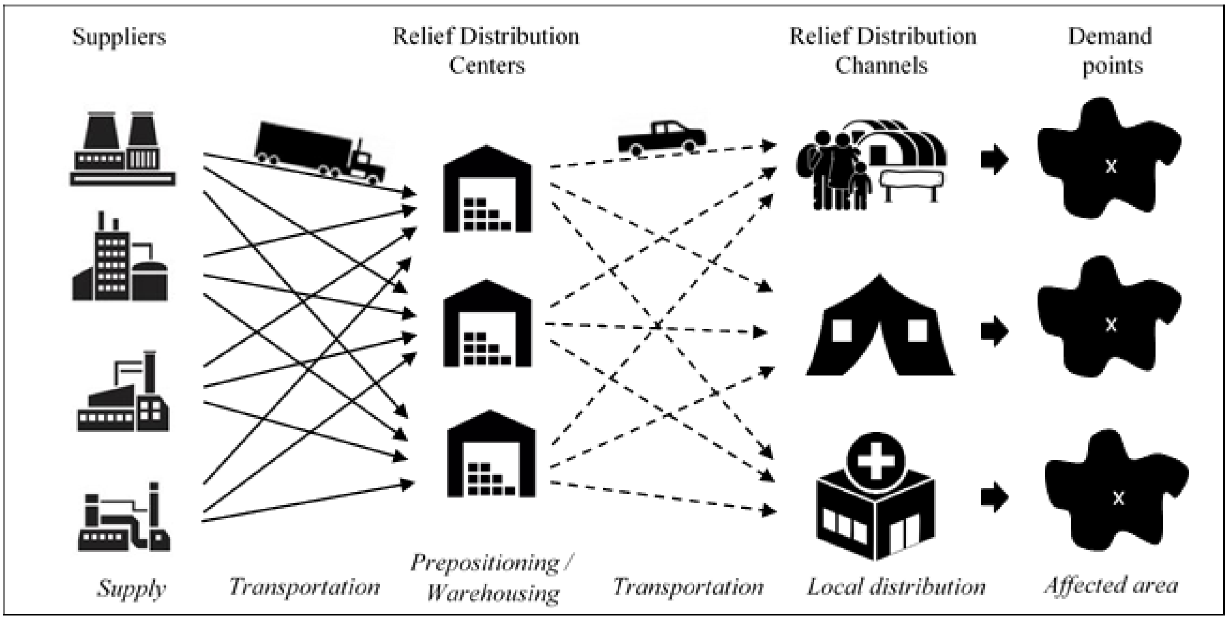
Figure 3: Relief Supply Network



Source: author

2. Methodology

In this paper, we propose a decision support model that could be used during operations in disaster response phase as a result of the tsunami wave. The model consists of 3 main objectives: (1) minimization of the number of relief distribution centres; (2) minimization of the amount of distribution channels; (3) minimization of the total distance between mentioned points. The model also includes the sets of variables, parameters and decision.

In the model, we focus on one area which represents a part of the third world country by the scope of the relief provided. The lenght of the defined area is equal to in its coastline. It may represent (1) industrial area; (2) urban agglomeration; (3) tourist resort; (4) uninhabited natural area and/or its combination. In our situation, the model is universal. Anyway there is a population that needs to be evacuated.

The model parameters values were randomly generated, but they correspond to the real and actual values.

The mathematical model consists of 3 minimizing objectives, 3 sets describing distribution centres, distribution channels and demand points, 4 groups of binary decision variables and parameters concerning the distance between centres and channels.

$$MIN \sum_s x_s \quad (1)$$

$$MIN \sum_t y_t \quad (2)$$

$$MIN \sum_s \sum_t c_{st} a_{st} \quad (3)$$

$$\sum_{t=1}^{n} b_{tu} \leq 3, for \ \forall \ u \quad (4)$$

$$a_{st} \leq x_s, for \ \forall \ s, t \quad (5)$$

$$b_{tu} \leq y_t, for \ \forall \ t, u \quad (6)$$

$$y_t \leq \sum_s a_{st}\ , for\ \forall\ t \quad (7)$$

where objectives
$O1(1)$ is minimization of distribution centres in total
$O2(2)$ is minimization of distribution channels in total
$O3(3)$ is minimization of total distance between distribution centres and channels

where sets and parameters
s is the distribution centres set
t is the distribution channels set
u is the demand point set
c_{st} is "cost" distance between distribution centres and distribution channels

and where decision variables
a_{st} {1 if part of solution; 0 otherwise}
b_{tu} {1 if part of solution; 0 otherwise}
x_s {1 if distribution centre is open; 0 otherwise}
y_t {1 if distribution channel is open; 0 otherwise}

Equations (1) – (7) define the aforementioned model. Formula (1) minimizes the number of distribution centers that must be created in the area. Formula (2) minimizes the amount of distribution channels created to provide aid. The units of formulas (1) and (2) are calculated in absolute values of the total number of aid distributing entities. The minimization of the total distance between the distribution centers and the channels is included in equation (3), with values quantified in transportation costs.

Constraint (4) limits the maximum number of assigned demand points to one distribution channel up to 3. Constrains (5), (6) and (7) ensure the flow only from centres that are open.

3. Results and Discussion

Within the solution of the given optimization model, each of the objectives was solved individually, and therefore independently of other objective functions. The obtained results are shown in Table 2. A prepared dataset was used for the implementation of the calculation, the data of which reflect the arrangement, fragmentation and general disposition of the coasts of countries in South East Asia.

Table 2: Results for optimization of each objective

Solved for	Value O1	Value O2	Value O3
O1	1	6	47,100
O2	2	2	45,100
O3	2	6	32,500

Source: author

From the results in Table 2, the minimum values in the relevant column and row can be seen on the main diagonal. This fact in itself testifies to the correctly performed optimization in the given problem with minimization objective functions. The mentioned solutions propose the creation of one to two distribution centres and two to six distribution channels. The minimized distance then takes on values from 32,500 to 47,100.

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Based on the data obtained, it is appropriate to normalize the values, whereby all variables will take on values ranging from 0 to 1 (including values). The newly obtained values are shown in Table 3.

Table 3: Results for optimization of each objective (normalization of values)

Solved for	Norm. Val. O1	Norm. Val. O2	Norm. Val. O3
O1	0	1	1
O2	1	0	0.863
O3	1	1	0

Source: author

Table 3 shows the normalized values of the objective function, which in most cases reach extreme values of O and 1. The only exception is objective function O2, normalized according to the value of objective function O3. It reaches a value of 0.863. Zero values on the main diagonal then show the optimal solution of individual objective functions. A value of 1 then indicates the greatest distance from the optimal solution.

Table 4 shows that objective 2 leads to the best results in the situation when the model is solved for each objective individually. The optimal value is highlighted in bold.

Table 4: Accumulation of normalized data

Solved for	Sum Value
O1	2
O2	**1.863**
O3	2

Source: author

The optimal solution of the normalized values reaches 1.863, which is the smallest of the listed sums. This value was obtained by objective function O2, which had a relatively low value when minimizing the total distance between distribution centres and channels.

It is worth mentioning that the model is limited in its scope, where it only focuses on the number of relief distribution centers, the number of relief distribution channels and the distance between these objects and demand points. Although the model is insufficient in the context of the entire disaster management, it appropriately reflects one of its key components. Implementation of the proposed conclusions can lead to increased effectiveness of time pressure and crisis activities. It is important to note that our solution does not work with real numbers but approximate estimates. These estimates are specific to the South East Asia region (a frequent site of tsunami disaster events).

It is also appropriate to compare this model with similar research by other authors. Banomyong et al. (2009) propose a model and hierarchy of implemented activities after the impact, whereby the basic system of regional, provincial and local support centers should be created within 3 hours, and the control and coordination body within 13 hours after the impact of the disaster. Basic support should be delivered within the specified 13 hours, more complex support within 37 hours. Their study is based on data from the 2004 Tsunami that struck Thailand. A similar study is presented by Ilabaca et al. (2022), who analyze the situation in the city of Iquique, Chile. They also focus on the time availability of help, which can be delivered within 4 to 7 hours thanks to the more developed urban infrastructure. Patrisina et al. (2018), who created a two-stage mixed-integer programming model applied in a 3-tier of a relief distribution network, also dealt with the issue of relief distribution sites in the event of a tsunami. However, the objective functions of their model focused exclusively on the distances between distribution centers and affected areas and reflected the different fragmentation of the coast. It should be noted that the mentioned case studies and expert outputs do not directly reflect the number of distribution centers or distribution channels created, but focus on the time of delivery of aid. This is explained in the model presented by us using the third objective function – formula (3). They also often take into account other and further constraints of the proposed model.

The model should be expanded in next studies involving more variables (factors). It is necessary to think about the idea of whether it is appropriate to cumulate survivors in Relief distribution channels or if it is better to transport them to Relief distribution centres. Both cases have their pros and cons. In first case (Relief distribution channels) there is a raising risk of epidemic threats in the closed population, but the group is isolated from the rest of the world. The negative is also the dependence on constant supplies (food, water, medicals, etc.) from distribution centres. However, according to Ekici and Ozener (2020), in general a key factor in the success of humanitarian aid is fair and rapid distribution, because in the case of delayed and unfair deliveries, people affected by a natural disaster can suffer and die. In second case (Relief distribution centres) the survivors must be transported immediately after the disaster to other place. However, the costs in time decreasing and distribution channel naturally expires due to the loss of meaning. Depending on this fact, proper logistics planning is necessary, including the transportation of injured persons who have been affected by the situation to hospitals or temporary clinics (Niyazi and Behnamian, 2022).

With the use of early warning systems, tsunamis can be predicted (after an earthquake or volcano eruption) a few minutes to hours before impact in the vulnerable area. This time horizon can be used for initial analysis. It is also possible to start with rescue activities and preparations before the impact of the wave. However, for example, Relief distribution channels cannot be built due to the risk of immediate flooding. When dealing with a natural disaster, it is crucial to consider all relevant components and thoughtfully evaluate which approach would be most appropriate for the circumstances.

4. Conclusions

Natural disasters should not be taken lightly, and it is necessary to know both the theoretical and practical basis of the issue of destructive realities. Properly set processes can eliminate the impact of natural disasters and loss of life and property.

Overall, this study recommends a proposed model that identifies distribution centers and channels that have the potential to improve the effectiveness of crisis management in places where natural disasters occur frequently. The implementation of the proposed solutions could shorten the reaction time and guarantee a faster distribution of aid to the affected networks. Regardless, it is essential to note that the model works with assumed values and could be additionally extended by various elements that influence the dynamics during emergencies. Further research could help to refine this approach and materialize it in the surveillance of catastrophic events and to ensure a faster and more effective response to these crises. On the basis of theoretical data, it is good to emphasize that states, corporations, but also smaller entities throughout the world try to ensure the greatest possible protection and elimination in the event of a natural disaster.

The shorter investigated time horizon and especially the lower quality of processed data is the limit of the work, while there is still proctor for the further implementation of the research, where the data of an older nature could be applied and compared with the current time of the development of natural disasters. The implementation of further research can also compare the individual countries of occurrence of natural disasters and evaluate the differentiation of the consequences of natural disasters. The comparison of approaches can then lead to the identification of correctly chosen crisis management strategies and the creation of preventive and effective measures in the event of a sudden occurrence of natural disasters.

In the article, they are used both of a theoretical and practical nature, which can be used for further research, not only in the field of natural disasters, but also in risk management of other hard-to-influence situations on a global scale. The achieved results can be applied to all areas and the contribution of the work is not only from a theoretical but also a practical point of view. Within this fact, it is possible to state that the goal of the work was fulfilled.

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