System Dynamics Modeling Of Relief Logistics

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ABSTRACT

Earthquake crisis management is a continuous process that includes pre- and post-earthquake measures, and are in needs of integration. The optimization models that have been presented in the literature, due to the large dimensions of the model and the existence of computational constraints, only one phase of the earthquake crisis have considered and hence security, cultural, and social constraints are not taken into consideration.

In the proposed model using system dynamics technique, an integrated model is introduced. Influential factors were identified through review of past research and interviews with experts. Aftre developing cuasal diagram and the stock and flow diagram mathematical modeling of the problem were in order. Once the simulation of model using Vensim software was satisfaction scenario analysis were started. If the values of the variables after the crisis are optimal, the value of the variable “Coorporation and coordination between the parties involved” improves by 85% and the value of the variable “Organizational Performance “improves by 63%. However, if the values of the variables before the crisis are in the optimal state, the mentioned values will increase by 89% and 86%, respectively. When the values of the model before and after the crisis are simultaneously optimal, the values of these variables will increase by 98 and 160 percent, respectively.

The proposed integrated model includes forecasting risk and preparations in the first phase while at the same time considers actions during the earthquake phase and then in the response

phase. These all together are causing to develop a model in an optimal way. The effect of training on improving the performance of the healthcare network can also be seen.

Keywords: Earthquake, Crisis, Humanitarian Relief, Systm Dynamics

INTRODUCTION

Business collaboration is increasingly being considered by researchers and management professionals. Responding to events that affect individuals, communities, and businesses often involves responding to different organizations. Humanitarian aid are part of a service-based industry, so interaction and relationships with people are necessary and further increase management complexity. Humanitarian aid management is a business that still seems to remain in an efficient model with a focus on cost reduction (Petrudi, S. H et al 2020).

In this article, in Section 2, we review the history of humanitarian aid supply chain and logistics research, including the characteristics of the humanitarian supply chain and relief logistics concepts and their challenges. In the following and in section 3, the research method is presented and we examine the problem modeling method using the dynamic system technique and express the dynamic hypothesis, causal diagrams, flow accumulation diagrams and validation methods of dynamic system models. In Section 4, the model is implemented and by designing 4 scenarios, the values of variables that can be adjusted by the organization or cannot be changed externally are discussed. Finally, in Section 5 the conclusion is presented.

RESEARCH BACKGROUND

Review of past research by Adriana .L (2014) shows that the research metod of most researchers in humanitarian relief articles has been in four ways: practical, fundamental, analytical and conceptual. A study by Adriana .L (2014) in the field of research and cases shows that most of the studies in the field of humanitarian relief have been done by analytical methods. Researchers have also provided formulations for different types of problem that are examined separately in different phases as follows:

In the predictive phase, articles such as Cozzolino, A. (2012) examines the basic needs in the early moments of the crisis and states the need to create integration in the chain.Titaya .S(2016) studied the effect of building regulations on the amount of damage to buildings and main infrastructure at the time of the earthquake.

In the preparation phase of Bozorgi-Amiri, A et al (2012), presented a model in crisis situations and taking into account uncertainty. Zhang, J., et al (2019) have examin the balance between the budget and the reliability of the relief network in the earthquake crisis. Goncalves, .P. (2008) has performed a dynamic model of humanitarian aid in the response phase.

Görmez, N et al (2011) presented a scenario planning model in crisis. Many articles have been done in the response phase. In his research, Besiou, M., et al (2011) has mentioned the application of dynamic modeling in the field of transport fleet management (as one of the subsystems) in the humanitarian aid. Diabetes et al. Khanmohammadi S. et al (2018) in their research have proposed a system dynamics simulation model that characterized the dynamics of the post-earthquake recovery process of a hospital. The model determines the impacts of component damage and resource shortage on the quality of services that are provided by the hospital. Hamdan, B et al (2019) have presents a robust two-objective optimization model that is resilient to natural disaster scenarios The study by Petrudi, S. H. et al (2020) is an attempt to provide a comprehensive framework for the challenges of humanitarian model management in a case study of the Iranian Red Crescent Society (IRCS). The purpose of the study Sigala, I. F et al (2020) is to examine the design principles in enterprise resource planning systems for humanitarian organizations to enable agile, adaptive and balanced (Triple-A) humanitarian relief capabilities and digitization of humanitarian operations.

Due to the review in various sources in recent years, limited articles have been presented by domestic and foreign researchers in the field of developing a dynamic logistics model of humanitarian aid. Therefore, there is a very good ground for expansion in the selected topic.

MODEL STRUCTURE

Each feedback system has a closed boundary at which the desired behavior is generated. When creating a system dynamics model from the feedback system, a model maker must clearly define the model boundary. The model boundary includes all the components in the final model. Table 1 shows the key variables in modeling the research problem. A time horizon of 60 months or 5 Years, is considered to allow sufficient time for feedback loops to function.

Table1: Extracted Variables

Item no.	Variables	Before the disaster		After the disaster	
		Forecast	Readiness	Reaction	Repair
1	Unpredictable demand		*	*	
2	Delivery time rate			*	
3	Infrastructure and access to affected areas			*	*
4	Sanctions and restrictions on cooperation	*	*	*	*
5	Number of aid workers and humanitarian volunteers			*	
6	Use of technology	*	*	*	*
7	Budget needed to finance crisis management	*	*	*	*
8	Amount of relief goods			*	*
9	Organizational Performance	*	*	*	*
10	Allocate support resources	*	*	*	*
11	Cooperation and coordination between the parties involved	*	*	*	*
12	Political crises			*	*
13	Protection laws	*	*	*	*
14	Educational system and practical exercises		*	*	
15	Inadequate training rates for injured people in post-accident relief		*	*	*
16	Media and information sharing			*	*
17	Efforts to raise awareness among the people	*	*	*	*
18	Distance between installations		*	*	
19	Integrated systems for collecting aids	*	*	*	*
20	Cost management systems	*	*	*	*
21	Mortality rate			*	*
22	Allocation of costs, benefits and risks between the parties involved			*	*
23	Earthquake intensity			*	*
24	Psychological and cultural situation of the people of the region	*	*	*	*
25	Population density	*	*	*	*
26	Vulnerability of buildings and the status of geological faults	*	*		

27	International aid			*	*
28	Level of training people to deal with earthquakes	*	*	*	*
29	Vulnerability of communication network and information exchange	*	*	*	*
30	Security and physical protection status	*	*	*	*

Drawing Model

After reviewing the proposed criteria and evaluating them using experts' opinins, the criteria transferred to the causal model of the relationships among them, hence Figure 1 was created. After that, the relevant causal diagram is converted into a stock and flow diagram. All key variables of state, rate and auxiliary that are specified in the previous section are employed to generate the stock and flow diagram considering the inter-relationships between them.

In an earthquake event, many factors are influential. In this article, based upon the results obtained in the history of the subject literature, the mentioned factors are extracted from numerous articles (mentioned in the list of sources) and after interviews with the elite, irrelevant factors have been removed and Table 1 has been compiled as the constituent factors of the final model. As shown in Figure 1, using dynamic system modeling, it is easy to show the integration and effect of different phase variables, but this is not possible in optimization models and this is one of the initiatives used in solving rescue issues are used in this article.

The final model is based upon the classification of activities and their impact on each other in the pre-earthquake and post-earthquake phases. First, the activities of each phase of the earthquake crisis are identified and its relationship to the variable that affects it is established by drawing lines. Then in the form of flow diagram, three variables "*Organizational Performance* ","*Cooperation and coordination between the parties involved* "and"*Budget needed to finance crisis management*", are considered as Stock variables and other variables are considered as Flow variables. Finally, by evaluating the amount of Stock variables in different scenarios, the final results are extracted.

For example, the "enactment of protectionist laws" factor can affect the "allocation of support resources" factor, and on the other hand, the more support resources are allocated, the more the "amount of relief goods" will definitely increase and cause the next phase. Earthquake victims will receive more opportunities in the earthquake and will eventually "improve the efficiency of the organization." In the same way, all the factors shown in Table 1 will be related to each other, which can be accurately observed in the causal diagram (Figure 1).

It should be noted that explaining all the relationships in the model, given the limited number of pages of the article was not possible.

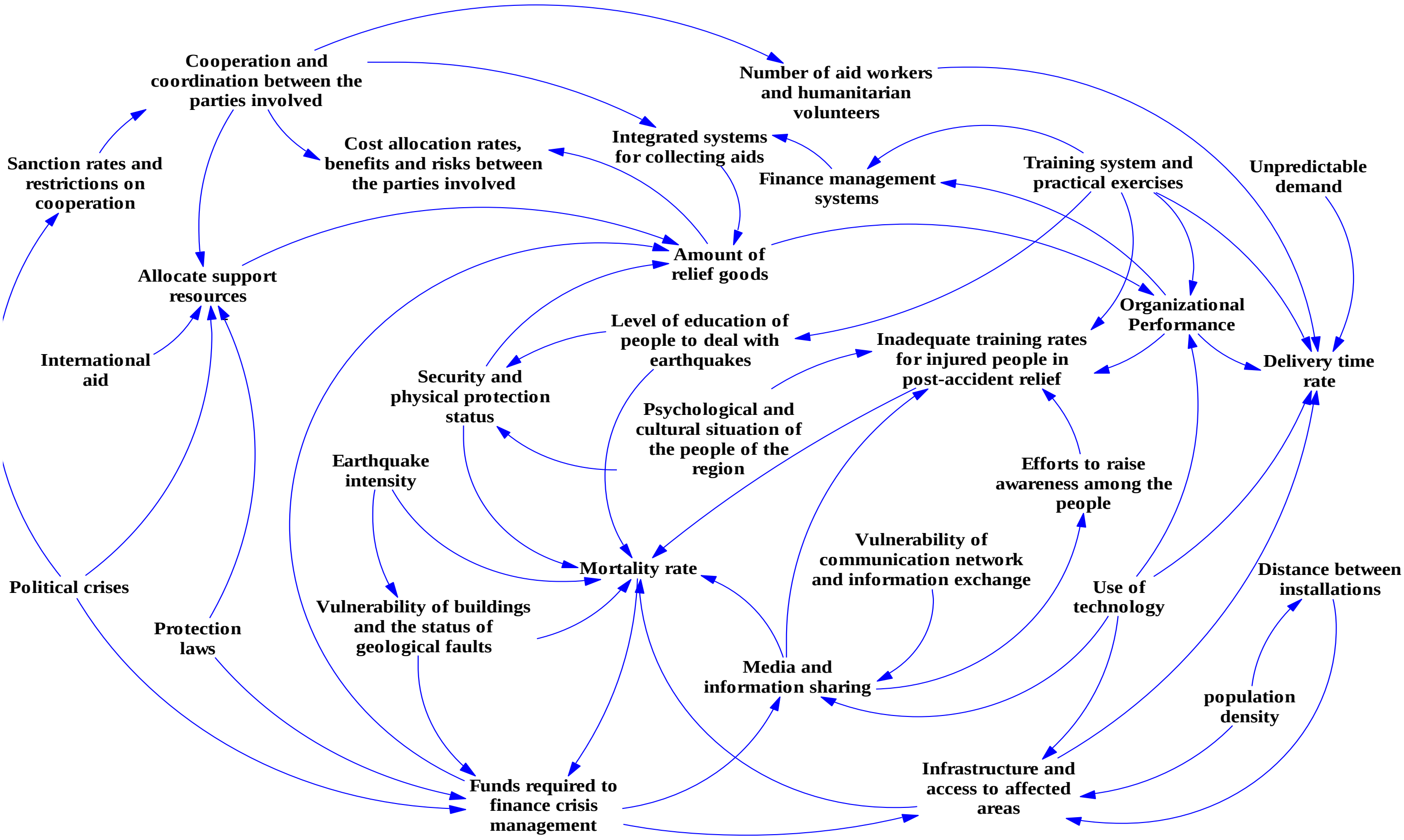

Figure 1: The causal model of the relationshi

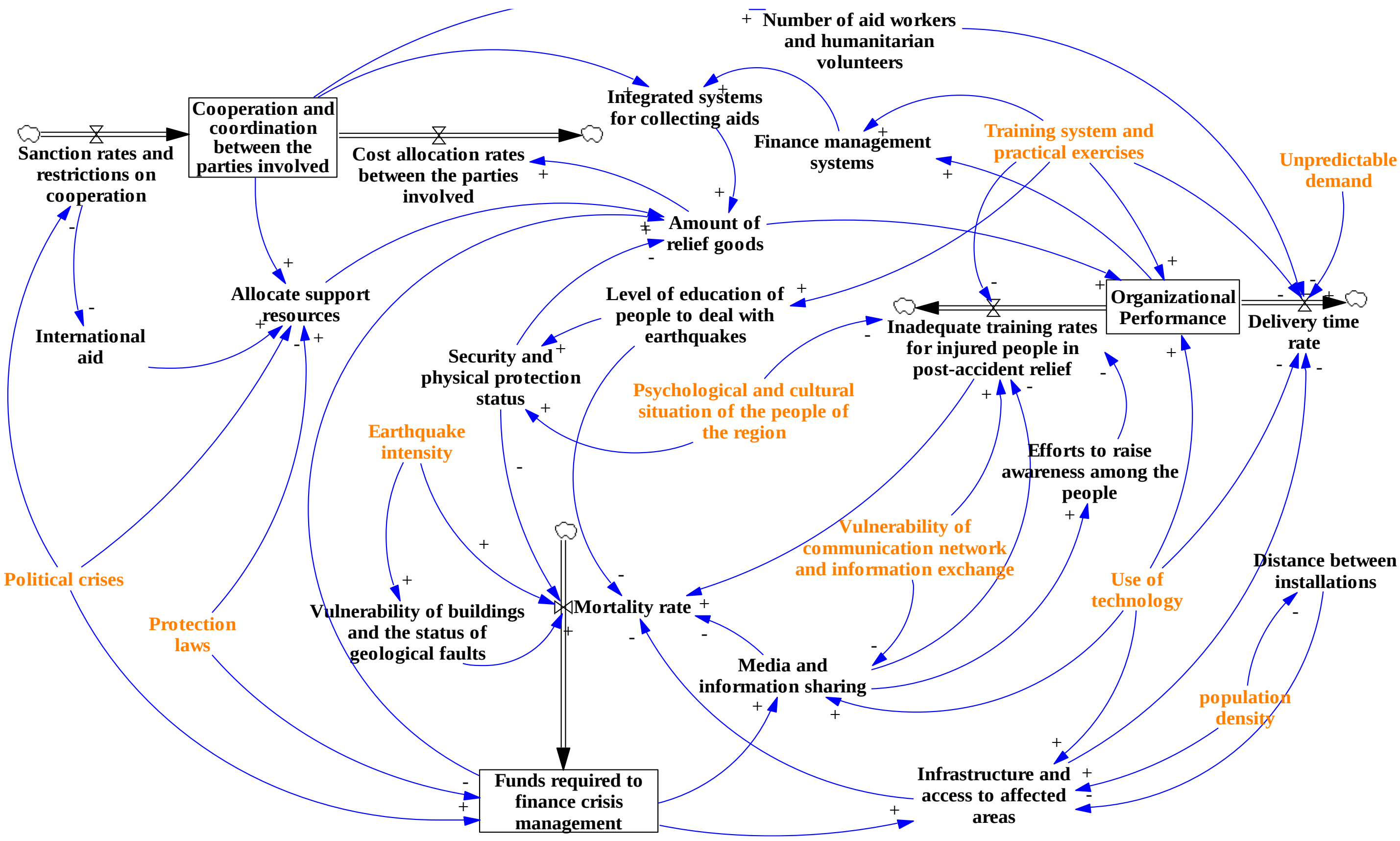

Figure 2: Flow mode diagram of the research problem model

RESEARCH MODEL CIRCLES

In this research, the method of cause and effect and finally its conversion into a flow chart has been used to model and show the relationships between influential factors. As mentioned before, the factors presented in Table 1 are examined and the cause-and-effect relationships and finally the flow diagram of the state, auxiliary and rate variables are determined, of which 3 important loops of the model are shown in Figure 3, 4, 5.

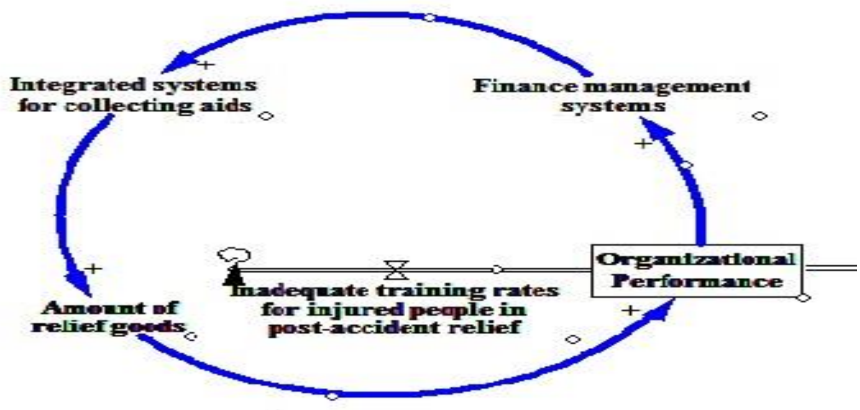

Figure 3 -Important rings of the model (**Loop1)**

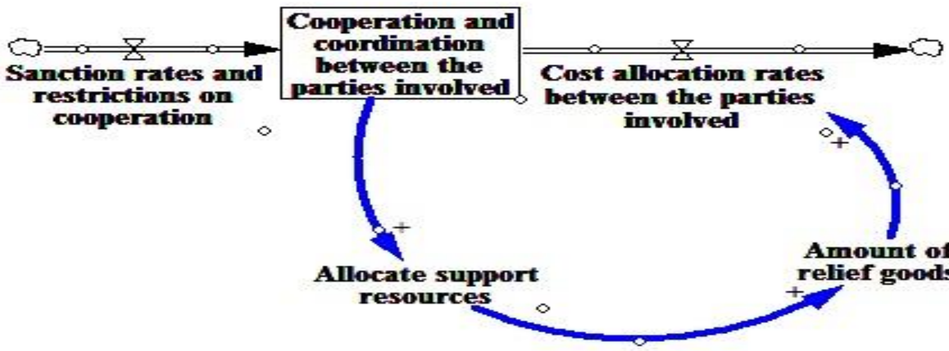

Figure 4 -Important rings of the model (**Loop2)**

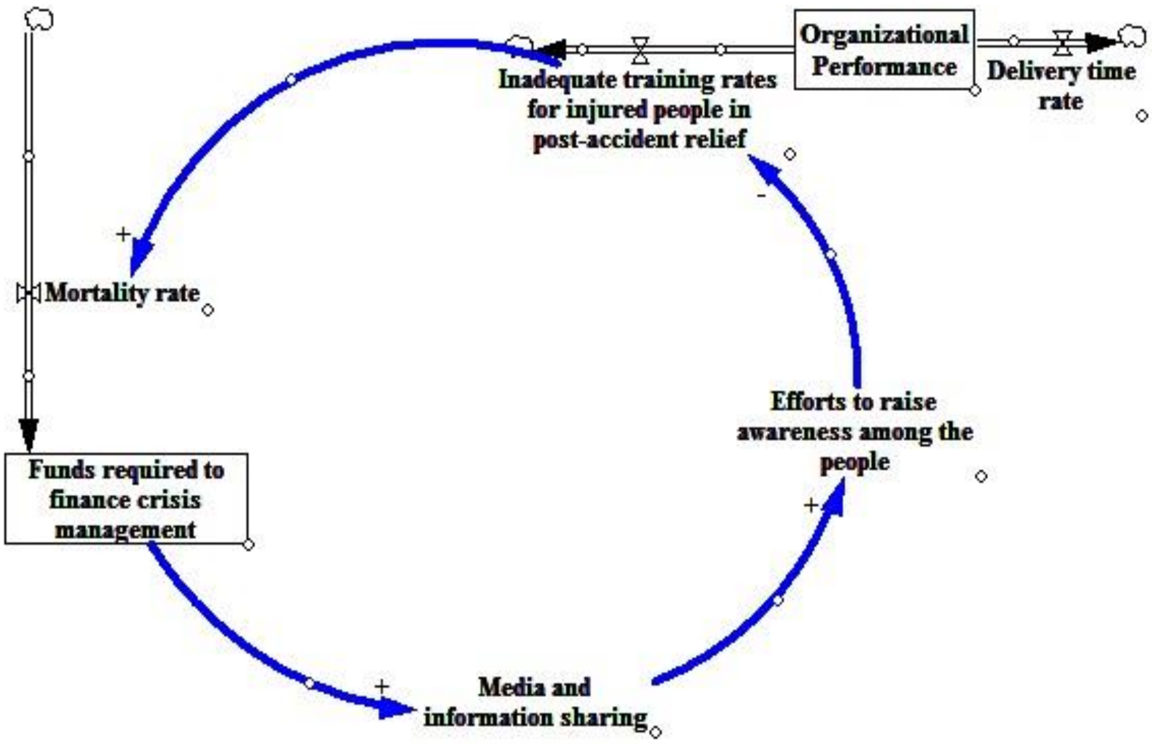

Figure 5 -Important rings of the model (**Loop3)**

In loop 1, based on Balcik, B et al (2008) organizational performance can have a positive impact on cost management. With the improvement of cost management, the system of collecting aids also improves. FelÃcio Agostinho, C. (2013) in his research has shown that the better the system works and the more successful it is in collecting aids, the more the amount of relief goods increases, because one of the executive plans of this system is to collect relief goods. Finally, according to one of the important goals of the organization, which is to cover relief goods to help victims in the humanitarian relief supply chain, so increasing the amount of relief goods has improved the performance of the organization.

In loop 2, based on the research of Petrudi, S. H. H et al (2020). It is clear that with the increase of cooperation and coordination between the parties involved in the chain, the allocation of support resources also increases.

In loop 3, it can be seen that the greater the budget resources for financing crisis management, the wider the sharing of media and information can be, and the greater the sharing of media and information, the greater the awareness among the people. As this awareness grows, the rate of inadequate training for injured people in post-disaster relief decreases, and eventually the mortality rate decreases due to this decrease and increase in risk-taking capacity. the chart below clearly shows that pre-earthquake training and exercises affect mortality rates, the amount of aid collected, the state of security and physical protection and the cost of crisis management, which ultimately affect the performance of the crisis management organization. Improves in the face of real earthquakes.

BOUNDARY ADEQUACY TEST:

This test examines whether there are factors affecting the model or not. As previously mentioned, the factors studied in this study have been determined through previous studies and expert opinion. Therefore, the importance of these factors in these two sources has been confirmed. Also, in the next step, to determine the necessity of these parameters, by eliminating some of these important factors, the system behavior is evaluated. The model outputs after removing each of these factors are shown below.

Figure 7 shows the effect of eliminating the "political crisis" factor. This factor affects the cooperation and coordination between the parties involved. Deleting this variable means ignoring it in the simulation (not the absence of this variable in the real world). This shows the need to consider all the variables and the relationships between them once again. If this variable is not taken into account, the system shows a virtual performance reduction that is far from the real situation

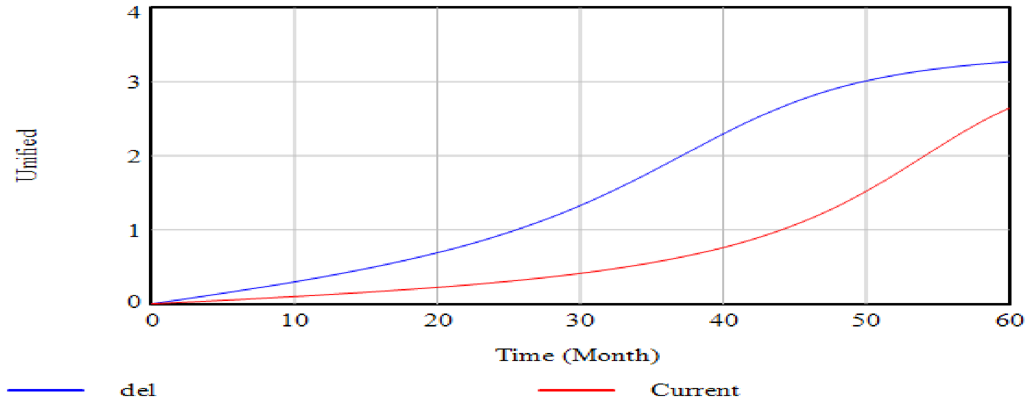

Figure 6: The effect of eliminating the cause of political crises on cooperation and coordination between the parties involved

This figure indicates that if there are no political crises in the model, the rate of sanctions and restrictions on cooperation will decrease, and as a result, due to this decrease, the ability to cooperate and coordinate between the parties involved will increase. These results are shown in two graphs. Figure 7 shows the effect of removing the "use of technology" factor.

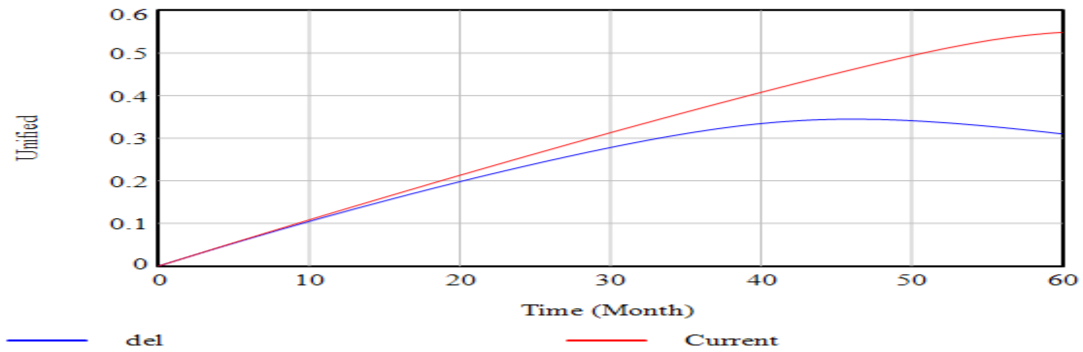

Figure 7: The effect of eliminating the factor of technology use on organizational performance

This variable affects the organizational performance factor. Ignoring this factor also shows a virtual reduction for organizational performance. One of the ways to increase organizational performance, is to use technology. This figure also shows that eliminating this factor reduces organizational performance.

Limit Conditions Test

In this test, we examine the behavior of the model in the condition that the inputs of the model are in the limit condition that is when they are at their lowest or maximum limit. In this study, it is considered whether the model is stable in these conditions or not. In the border adequacy test section, the status of variables in the infinite state (maximum value) was examined.

-Situation one: Political crises are at their lowest (Figure 8).

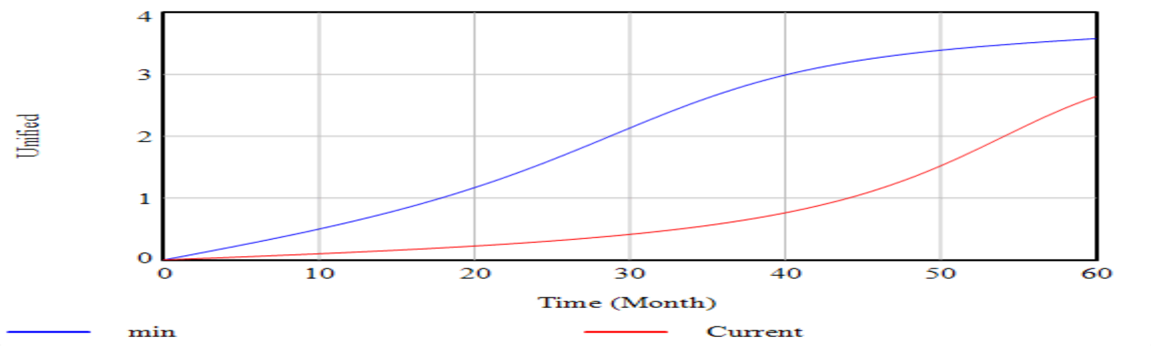

Figure 8: Model behavior in some cases of political crisis

If political crises subside, there will be nothing but increased cooperation and coordination between the parties involved. In other words, the less political crises, the easier and less restrictive they become due to the reduction of political pressures, cooperation and coordination between the parties involved, and as a result, they increase significantly.

Second situation: the use of technology is at its lowest point (Figure 9).

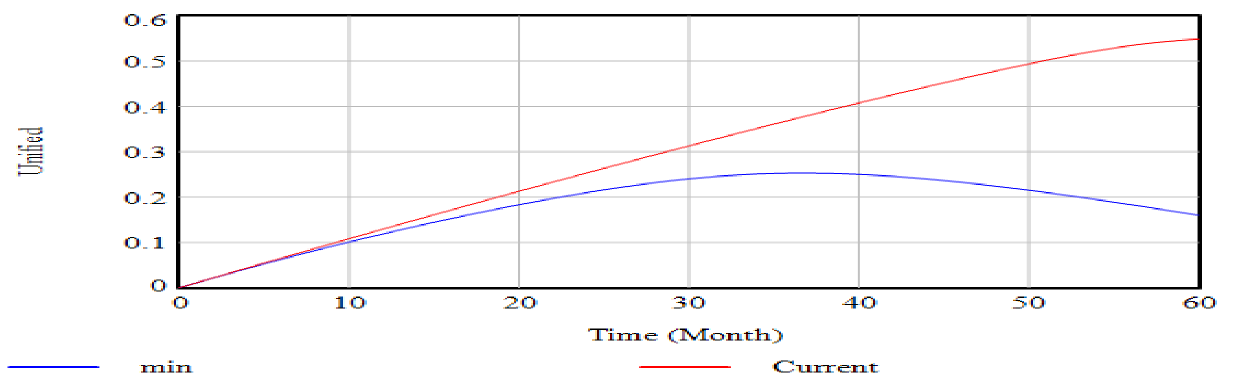

Figure9-Model behavior in cases of limited use of technology

If the use of technology tends to go down, as shown in this figure, and according to the research of Willner and Zafeiridis, organizational performance also goes down.

Description of Scenarios

In the last step after analyzing the model factors and determining the extent and type of its effect on the main factors and variables of the research, it is time to define different scenarios, by determining the different values of the group of effective indicators, the path Build smoothly to achieve practical strategies. In this research, according to the opinion of experts and according to some official articles, the factors that have a great impact on the state variable and rate variables have been determined and by determining different values for these effective indicators, based on the research objectives 4 scenarios are considered. It should be noted that in all stages of this research and the use of research data, this data has been unified through the use of standardization methods.

Scenario 1: The purpose of this scenario is to identify ways to improve resilience for relief organizations and the community before dealing with disasters. This scenario includes frameworks such as improving the education system and practical exercises, the use of technology, the level of education of people to deal with earthquakes, efforts to raise public awareness, cost management systems, the budget required to finance crisis management and other variables. The designated part of this section is defined in the parameters table to improve pre-crisis operations of the earthquake and the preparedness phase so that future strategies can be defined by examining the role of these factors. In emergencies, private organizations as well as government officials need to coordinate in real time to create an effective response. When there is no coordination, catastrophic failure results occur. To prevent these inconsistencies, pre-disaster strategies need to be developed. Variables set for this purpose in this model are the same education system and practical exercises, use of technology, level of education of people to deal with earthquakes, efforts to increase public awareness, cost management systems, budget required to finance crisis management And the other variables specified for this section are in the parameters table.

Scenario 2: The second phase is related to the post-disaster phase. This phase is also divided into two parts. Reaction or response and repair. To save lives and minimize destruction, it is necessary to take action before, during and after the disaster. In the response phase, delivery time is a very important factor. It depends mainly on the preparedness of the community or the authorities through education and awareness of the available equipment and resources.In the second part, actions that are taken immediately after a disaster or as a result of a severe impact, need to be An exceptional measure is to save the survivors and meet their basic needs until the situation normalized.

Scenario 3: This scenario is a combination of the two previous scenarios (**Figure** 10, 11). In this scenario, by simultaneously changing the variables related to both previous scenarios, the conditions are examined. in this scenario, the impact of influencing factors on the pre-disaster relief supply chain (education system and practical exercises, use of technology, level of education of people to deal with earthquakes, efforts to increase public awareness, cost management systems, the budget required to finance crisis management and other variables identified in this section in the table of parameters) and the factors affecting the post-disaster relief supply chain (variables such as the number of humanitarian aid workers and volunteers, integrated fundraising systems, allocation of support resources, cost allocation rates, benefits and risks between stakeholders, amount of relief goods and international assistance) on the variables of the state, is cooperation and coordination between stakeholders and organizational performance, are evaluated simultaneously.

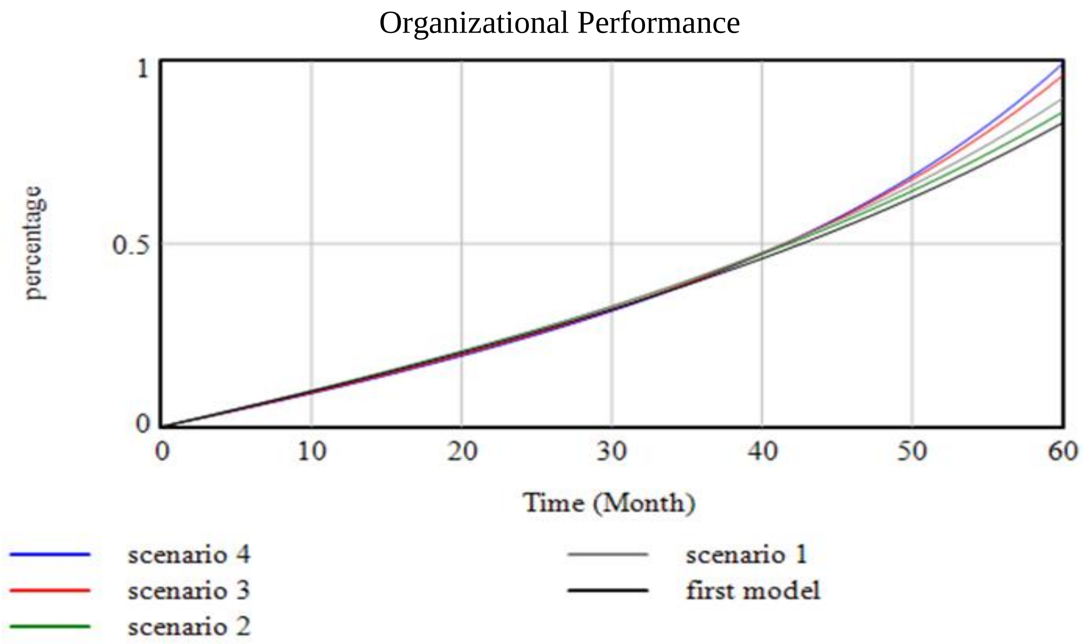

Figure 10- The effect of executing scenarios on state variables

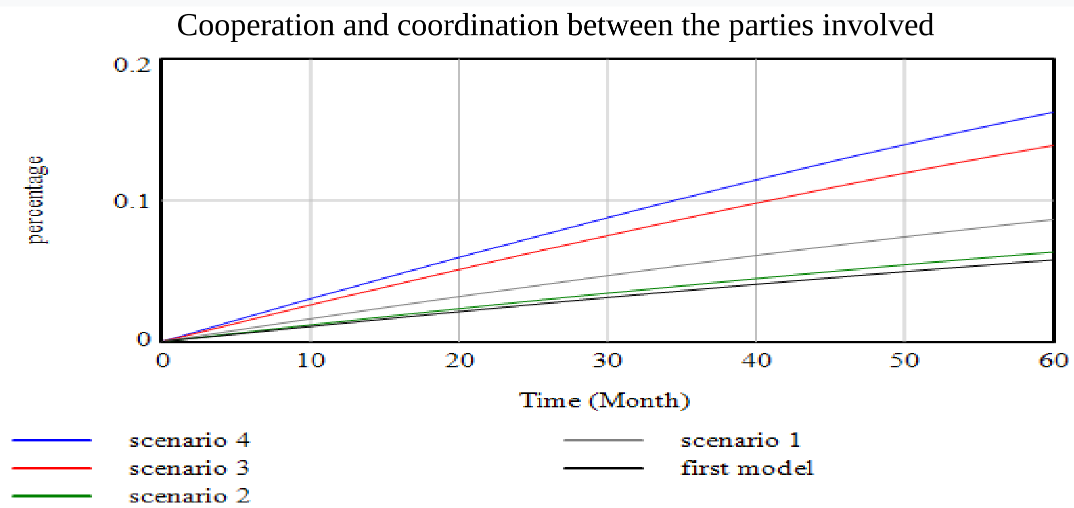

Figure 11- The effect of executing scenarios on state variables

Scenario 4: in this scenario, in addition to the variables in the third scenario, by changing the values of the variables of security and physical protection, it is examined whether this variable also affects the conditions or not. In this section, the effective variables before and after the disaster along with the variables of security situation and physical protection are evaluated simultaneously. According to the images of the scenarios (**Figure** 12), it is interesting to note that when the security and physical protection status variable is in good condition, even considering the need for primary resources shown in the previous scenarios, the amount of resources required during and it decreases sharply after a crisis occurs, which reduces the percentage of the budget needed to finance crisis management by nearly 30 percent.

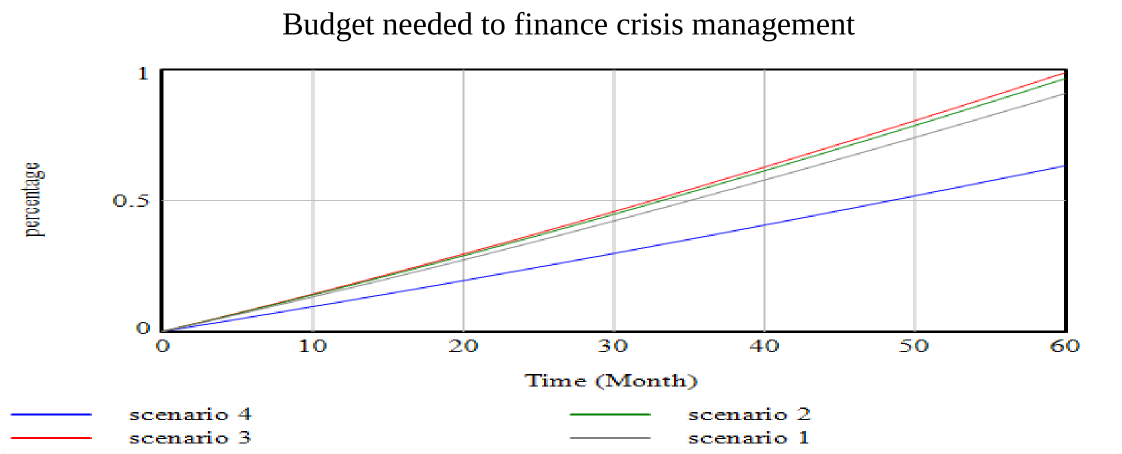

Figure 12- The effect of executing scenarios on state variables

Analysis of Results

In this research, important components of the humanitarian aid chain are addressed and a humanitarian approach model is introduced with a new approach (using system dynamics approach). The results of this study are discussed below.

1) Considering that Scenario 1 is higher than Scenario 2 in Figure 10, 11 it is concluded that the improvement of pre-earthquake operations is preferable to the improvement of post-earthquake operations, which means that if prepared before the occurrence, Crisis, even if the conditions are not right after the crisis, the situation of the chain is better than when there is no readiness, but the conditions after the crisis are better. These graphs show that if only the values of the chain variables are optimal after the crisis, the amount of cooperation and coordination between the parties involved is approximately 85% and the amount of organizational performance variable is 63% higher than before the implementation of optimal policies. However, if only

the values of the variables related to the chain before the crisis are in the optimal state, the values of these variables will increase by 89% and 86%, respectively.

2) When the chain has appropriate planning and strategies for both pre-crisis and post-crisis, scenario three and its related diagram show that the status of the two main variables, namely cooperation and coordination between the parties involved and the performance of the organization are in better condition than the previous two modes. Scenario 3 shows that if the values of the variables related to the chain before and after the crisis are simultaneously optima, the variables of cooperation, coordination and organizational performance are 95 and 140%, respectively, before reaching the values.

3) If there are appropriate strategies for both situations before and after the crisis in the chain, there is another variable that if it is in better conditions, the two variables of cooperation and coordination between the parties involved and the performance of the organization in the situation is better. This variable is the state of security and physical protection. This result shows that a more successful chain can maintain the security of the execution process. If the values of the variables related to the supply chain before and after the crisis, and the variables of security situation and physical protection are simultaneously in optimal condition, the variables of cooperation, coordination and coordination between the involved parties and organizational performance according to Scenario 4 are 98 and 160%, respectively. It increases before the optimal values are reached and before the strategies are implemented, and the percentage of the variable budget required to finance crisis management decreases by nearly 30%.

4) Considering the comparison of different scenarios, Scenario 4 will ensure the highest level of cooperation and coordination between the parties involved and organizational performance, and will lead to the creation of a more appropriate humanitarian relief supply chain. These results indicate that in order to achieve a more appropriate humanitarian relief supply chain,

the best decision is to implement three strategies simultaneously in ongoing projects based on prioritization. Therefore, this research shows that among the strategies defined in future plans, it should implement the three mentioned strategies.

Different policies can be adopted to achieve optimal values for these variables. Policies such as designing training systems needed for aid workers and the general public, implementing integrated management systems at the heart of technology-based and electronic systems, funding strategies such as creating public support campaigns and collecting humanitarian aid before and after a disaster, and other policies.

Scenario 4 has been implemented and the amount of variables of cooperation and coordination between the parties involved and organizational performance will increase by 98 and 160 percent, respectively, and the percentage of the budget variable required for financing crisis management is also reduced by nearly 30%.

CONCLUSION

In this article, by implementing system dynamics in the humanitarian aid supply chain. We sought to solve the existing problem. To achieve this first the previous studies and the diagnosis of the problem gap were reviewed and then by determining the research variables the model was designed. After implementation and validation the scenario was developed. Using the model of continuous correlation dynamics and interaction between different phases of earthquake crisis over time was investigated for the first time. Actual constraints that have not yet been considered in quantitative optimization models. Social, cultural, and security constraints were examined in this model. Decisions related to the distribution of facilities and services were evaluated simultaneously with location decisions in the anticipation preparation and response phases. The effect of different policies of legal and insurance systems and its relationship with the preparation phase was examined by the relevant variables. Different educational and cultural policies were also examined in the response phase. In future studies, crisis management strategies can be examined when changing the variables imposed and unmanageable by the organization.

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