A Review of System Dynamics Models Applied in Social and Humanitarian Researches

Fahimeh Allahi, Sander de Leeuw, Ehsan Sabet, Ramez Kian, Lorenzo Damiani, Pietro Giribone, Roberto Revetria, Roberto Cianci

***Abstract*— Over the past decades, the number of disasters has been on the rise, including earthquakes, war, flood and other incidents that cause destruction of society, such as education and health services. Forecasts show that over the next 50 years, natural and manmade disasters are expected to increase five-folds both in the number and impact. Therefore, there is a need for effective and efficient disaster support actions during emergencies. This compels humanitarian organizations to improve the effectiveness and efficiency of their approaches and facilitate decision making in resolving such complicated problems characterized by numerous parameters. Besides, humanitarian organizations face situations with multiple critical events, inadequate funding, limited time to plan and react, and operating in increasingly challenging circumstances. Useful approaches for tackling problems in such dynamic conditions require methods and tools that take into account uncertainty and enable managers to evaluate the dynamic complexity of such systems, to facilitate decision making. Among the large amount of decision-aid tools for humanitarian organizations, System Dynamic (SD) is a method used for the evaluation of complex system behavior and for presenting the effect of decisions over time in an easy-to-use model. This method has been applied in humanitarian problems, and this paper aims to present a review of the most relevant humanitarian publications associated with system dynamics. This literature review is a structured review of the papers published since 2003 onwards. The finding of this research can be used to facilitate further research in developing the system dynamic methodology for humanitarian organizations and to present the essential requirement of SD tools for modeling complex environments.**

***Index Terms*— Complex systems, Decision-making, Humanitarian, Literature review, System dynamic.**

F. A. Author is visiting PhD student at Wolfson Department, University of Loughborough, UK (e-mail: f.allahi@ lboro.ac.uk).

S. d. L. Author is Associate professor of Logistics & Operations Management at the University of Amsterdam, Department of Information, Logistics and Innovation, School of Business and Economics, de Boelelaan 1105, 5th floor, 1081 HV, Amsterdam, Netherland (e-mail: sander.deleeuw@ntu.ac.uk).

E. S. Author is with the University of Loughborough, UK (e-mail: e.sabet@lboro.ac.uk).

R. K. is with the University of Loughborough, UK (e-mail: r.kian@lboro.ac.uk).

L. D. Author is with Genoa University, Via Opera Pia 15, 16145 Genoa, IT (e-mail: Lorenzo.Damiani@unige.it).

P. G. Author is with the University of Genoa, Department of Mechanical Engineering, Via Opera Pia 15 16132 Genoa IT (e-mail: Piero@itim.unige.it).

R. R. Author is with the University of Genoa, Department of Mechanical Engineering, Via Opera Pia 15 16132 Genoa IT (Phone Number: +393207982156; e-mail: Roberto.Revetria@unige.it).

R. C. Author is with the University of Genoa, Department of Mechanical Engineering, Via Opera Pia 15 16132 Genoa IT (Phone Number: +390103532895; e-mail: cianci@dime.unige.it).

I. Introduction

The Red Crescent Societies and the International Federation of Red Cross (IFRC) introduce a disaster as "a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources" [1]. It is necessary here to clarify exactly the explanation of an emergency situation by [2]: "Disasters evolve into crises as their complexity increases and they interact with other vulnerability factors demanding a response that challenges the traditional response mechanisms and capabilities." Millions of people around the world are affected by the direct consequences of natural and man-made disasters, which have become one of the most significant problems of human life according to the report by the Centre for Research on the Epidemiology of Disasters (CRED) [3].

Nowadays, the number of disasters is increasing causing the disruption of local infrastructure and population, poverty, diseases, ecological disruption, loss of human life, human suffering, and deterioration of health and health services [3, 4]. It also leads to situations with forced migration-related crises such as refugees, internally displaced people and PoC (Protection of Civilians) camps [5] leading to a state of deprivation and suffering [6].

It is necessary to quickly support sufferers after the occurrence of disasters in various ways, such as protecting injured people, allocating resources, supplying meals assistance, shelter and medical care [7]. Therefore, the demands have increased for disaster response operations of humanitarian organizations, donors, governments, non-government, and all the relief organizations to assist the affected countries and reduce the disaster's impacts. Critical management of the factors that influence effectiveness in disaster response in international humanitarian organizations is essential, initiating the improvement of operational skill to better face disasters [1]. Moreover, this is complicated by humanitarian organizations suffering from poor funding, and insufficient opportunity to organize and behave correctly in crisis situations.

II. System Dynamic Review

System dynamics is a modeling and simulation methodology that has been introduced for the first time by Jay. W. Forrester in 1958 at the Massachusetts Institute of

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Technology [8] which emphasized the multi-loop, multistate, and nonlinear features of the feedback systems in human life. The SD model can be displayed graphically by applying a mixture of simulation and circumstances modeling to develop both perception and modeling [9]. Furthermore, it can be applied to systems with several factors, high range of uncertainty, casual obscurity, and complexity adjusted with the requirement of humanitarian organizations.

The SD approach presents administrators with a collection of tools that can support their knowledge in complex environments including causal mapping to think systemically and interpreting the dynamic complexity, and simulation modeling [10] to evaluate the outcomes of interactions between variables and improve comprehension of complex systems [11].

In the field of system dynamics, [12] and [13] have provided two robust literature reviews on the present simulators. Complex dynamic systems have been reviewed by [11] and 33 empirical studies in the view of dependent and independent variables have been evaluated by [13]. The investigation of problems involving interacting feedback loops has presented that it is required to solve them by system dynamic [14] and [5].

Some of the benefits of dynamic modeling [15]:

• Discovers probable emergent characteristics of a system: dynamic models provide a way to investigate emergent behavior because such models can cover these real-time spans at the time of model runs.

• Prepares quantitative assessments of qualitative ideas: system dynamic models allow the user to convert qualitative understanding into a quantitative style which most systems are just recognized at a qualitative level.

• The most important parameters can be identified in a system dynamic: a lot of inputs should be recognized to understand their impact on the output; however, it's really difficult to monitor all of them. SD model allows evaluation of the impact of each input on the output and ranking them, then by sensitivity analysis, it can be decided to choose high ranked input.

• By means of SD models, the long-term effects of decisions on a defined humanitarian system can be predicted.

• SD tool can be effectively used to assist humanitarian decision making and provides managers with a set of tools that can help them learn in complex environments [16].

In particular, SD is a method to improve learning in complex systems within humanitarian-related projects, especially large infrastructure projects. However, learning about complex dynamic systems requires more than only technical tools to create mathematical models. Because these tools are applied to the behavior of human as well as physical and technical systems [11].

According to [17], models can be considered and used as a basis for experimental investigations at lower expenses and in less time than trying changes in actual systems.

III. Humanitarian and System Dynamics

When a disaster affects population and people's vulnerability [18], the sequence forces people to handle damages, and an assistance demand from humanitarian organizations, public agents, and other donor's is asked for the affected region and reduce impacts [19]. Recently, disasters and any occurrence that produce the disruption in the environment happen increasingly [20] and cause serious effects on different aspects of human life. Beside, related humanitarian support expected much more as well due to unplanned famine, poverty, diseases, climate change [21], which generate more migration-related crises such as refugees, internally displaced people and PoC camps. Accordingly, a universal demand of disaster assistance procedures raised during emergencies which are incited donors and humanitarian organizations to develop the benefits of their methods and decision making in modifying such complex problems. These findings have forced managers of humanitarian organizations to recognize the complexity of these parameters, understand the demand and desired response to a disaster [22], and discover how to manage complex aid performances. Beneficial knowledge in such dynamic situations needs convenient tools that empower managers to demonstrate the dynamic complexity in a system and to develop decision making. System dynamic is a strength tool in the evaluation of complex system behavior and demonstrating the effect of donor's decisions on humanitarian subjects in developing an easy-to-use model. Furthermore, the interrelations among the observed and reviewed phenomena could be visualized by means of appropriate tools such as SD [23]. When system dynamic and modeling the complex situation are properly understood, humanitarian organizations can extract the maximum benefits from their available resources in their efforts to attend the victim demand [21]. Modeling the organizational dynamics in emergency situations would enable better understanding of the human behaviors to improve humanitarian's performance. Therefore, SD enables the causal relationships to be quantified and tested more explicitly and rigorously. Donors could improve their systems analyzing skills which allowing them to better learn the dynamic complexity of humanitarian systems in SD modeling. Furthermore, SD models can be developed by the accurate collection of variables and factors and as a result, the effects of current decisions can be observed clearly.

The beneficiary of system dynamic has been discussed on analyze of humanitarian assistance as a complex and dynamic system involving multiple 'actors' which could manage to improved comprehension, better implantation in the humanitarian organization and useful in understanding the system behavior [24]. In addition, humanitarian assistance has been suggested as a complex and dynamic system, rather than analyzing problems in a piecemeal way or exploring solutions concerning single characters, may present magnificent insight into efficient ways.

The key in the literature reviews is to extend the search to the most probable and relevant literature related to research questions [25]. In the following the research procedure is described. To prove reliability of database source of presented research, online databases by implementing various related subjects and different journals have been considered. Two broadly used electronic databases such as Scopus and Science Direct have been involved. These

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databases exist between the largest in terms of the set of published papers with multiple subjects, including SD in humanitarian. In addition, the forward and backward search have been applied to the captured papers and consideration of well-known journals published by Springer, Wiley, and Thompson have been regarded. Furthermore, the time horizon of the search is from 2003 to 2018, because of the lack of using SD in the humanitarian subject before 2003 [26]. To search for papers, multiple search terms and keywords such as "system dynamic in humanitarian logistics", "system dynamic in disaster", "system dynamic in emergencies", and "system dynamic and social researches" have been implemented. Regarding papers which applied system dynamics in the humanitarian subject, all papers that were not related to humanitarian filed have been excluded such as papers in health, hospital or construction management subject. Following eliminating unrelated papers, the search resulted in 20 papers (Table I).

It should be considered that in recent years, several attempts are proposing to investigate the application possibilities of systems dynamics in various humanitarian fields (e.g. [27] and [28]). This distinction is further exemplified in [26] which has developed an SD model to provide insights into the complex web of causes included feedback loops and non-linear relationships and can lead to disaster and valuable lessons for organizational learning.

Reference [29] captured human behavior during flood emergency evacuation process and the dynamic interactions among model components using a computer-based model by SD approach. Furthermore, in 2005, Survey such as that conducted by [30] has presented the need for a system dynamics in humanitarian and discussed properties of complex systems. It mentioned that dynamic modeling is a relatively new technology that is little known in the academic, business, and nonprofit communities. The presented SD method in the research, simulated the impact of the strategic business decisions on the financial well-being of the Social Purpose Organization (SPO). Two limitations have been concerned in the research; first, the results are unique to the specific context of SPO, second, the process for managing this type of research might be different for a large Non-Profit Organization (NPO) or for a for-profit organization.

In 2008, [31] has demonstrated an improvement of complex system's features and declared that it allows a fundamental knowledge of the different factors capable for producing the dynamic complexity in humanitarian relief systems and is a significant step in the management of the complex crisis. Besides, the proposed SD method describes an opportunity to model various phenomena in humanitarian relief and to support manager's design more effective policy interventions in the long run. Also, [32] have presented a system simulation of coal mine safety, a complex socio-technical system, by SD approach and analyzed the kinds of unsafe behavior of employees in the coal mine accidents.

In the following, reference [27] in 2011, declared that system dynamics can capture the complexity of humanitarian systems and can improve humanitarian decision makers to predict the effect of their decisions on the system performance over time. The well-defined issue of field vehicle fleet management in humanitarian organizations is used to illustrate an application of SD for humanitarian operations. Although, the authors present an example of over three years of research, but less well-defined subsystem in the humanitarian sector which can be analyzed using SD method to the benefit of the overall humanitarian relief operation.

To obtain a relevant and dynamic decision-support in 2013, [33] proposed an SD method for decision-makers to resolve the crisis based on performance evaluation, in addition to the essential experience they undergo. The research included limitation such as focusing on general crisis management and performance assessment concepts, mainly on humanitarian applications.

Besides, [34] modeled the delivery process of ready-to-use remedial food items by system dynamic method during the immediate response phase of a disaster and find that pre-positioning inventory provides positive outcomes for the beneficiaries, but at extremely high costs. However, neglected various parameters which are relevant to the overall process of providing humanitarian relief in reality and focusing on a single disaster, single country, and single organization are supposed to some of the research's limitation.

In 2014, [35] proposed a system dynamics model to analyze the behaviors of disrupted disaster relief supply chain by simulating the uncertainties. The author has presented the system dynamics as a popular approach to study such problems for its ability to deal with high levels of uncertainty, causal ambiguity, and complexity. Nevertheless, questionnaire has not been used to collect expert's opinion for logistic planning.

In addition, preliminary, the marketing activities in the nonprofit sector has been modeled by system dynamic in the research of [36] in 2014. The research illustrated potential benefits provided to nonprofit organizations by the application of the system dynamics approach in the field of strategic planning. Also, the proposed SD model created an awareness of circular relationships between the observed variables - starting with the problem, leading to solutions and returning to the problem itself. Though, the dynamic relationship between thee constructs should be further analyzed taking into account the non-linear relationship between the variables in the system and time lags in mutual influences.

Furthermore, reference [37], applied the SD model for the forecasting, prioritization, and distribution of critical supplies during relief operations in case of a hurricane event.

In 2015, a considerable amount of papers has been published on system dynamic in humanitarian. The effectiveness of the system dynamic technique has been exemplified in a report by [38] that enable stakeholders to experience playable system dynamic models linking geoinformation which is an innovative approach to immerse disaster managers to be more effective and providing innovative ways to accelerate learning to better design and implement humanitarian work.

The systems thinking paradigm can be seen in the case of the [23], [39], and [40] which presented in a manner that emphasizes its adequateness and applicability in

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Humanitarian Logistics (HL) research. The presented systems thinking paradigm in the case of [23], making the logistics systems in general and HL-systems in particular more sustainable. The method has been included suggestion of taking into account interdependent research questions at once by regarding the uncertain relationships among the system' components, which could be different items, belonging to various levels such as objects, organizations and natural. This could offer a hopeful starting point for dealing with the increased complexity of these days' knowledge management in humanitarian.

Reference [40] allows analysis of complex problems in decisions and information effects on capacity and the role of the media and donors in humanitarian process. But, the paper hold some limitation such as the selected variables and the presented simulation were drawn from the literature, and just one type of disaster was investigated.

In addition, reference [41] aimed to enhance the range of examples of system dynamics applications in humanitarian logistics with the objective of minimizing the response time during disaster emergency response. The faster the response time of each humanitarian logistic stakeholder, reduce the risk of fatalities. Reference, [42] attempted to propose an SD model to study the role of communication and logistical coordination between actors in an emergency disaster which breaks down a complex problem into a set of variables and parameters that can be easily modified as needed. Although, the effects have been studied qualitatively, and the proposed original SD model provides a first attempt to quantify them. Beside, training of decision-makers on flood response by means of SD model has been seen in the case of [43] in 2015. This case study confirms the capability of system dynamics (SD) model to capture the complex components. However, the research limitation is all influencing variables has not been considered due to the variety of flood events. In the following, [44] developed a dynamic balanced scorecard model for humanitarian relief organizations' performance management. The developed model attempts to describe the relationships between strategic resources and how these resources relate to the humanitarian organizations' goal in providing an appropriate response to the beneficiaries. Although, the research comprises the limitation which is solely based on relevant existing literature, therefore further practical research is needed to validate the interdependencies of performance indicators. Finally, [45] has suggested an SD model for effective debris management under different disaster scenarios to develop better disaster planning for recovery.

Table I presents most of the relevant reviews about humanitarian publications associated with system dynamics and explained the purpose of each publication about system dynamic as well.

Table I Review of system dynamic paper in humanitarian

No	*Year*	Author(s)	Title	Applied system dynamic in humanitarian
1	*2003*	David L. Cooke	A system dynamics analysis of the Westray mine disaster	Presents a system dynamics analysis of the 1992 Westray mine disaster in Nova Scotia, Canada. The value of simulation is its ability to capture a ''mental model'' of the safety system, which can stimulate discussion among safety experts as to the systemic causes of a disaster.
2	*2005*	Jennifer S. Tucker et al.	Dynamic Systems and Organizational Decision-Making Processes in Nonprofits	Propose a system dynamic modeling process which facilitates organizational learning as leaders and use the insight gained from adopting a systems approach to make effective strategic decisions. The SD simulated the impact of the strategic business decisions on the financial well-being of the SPO.
3	*2005*	Slobodan P. Simonovic and Sajjad Ahmad	Computer-based Model for Flood Evacuation Emergency Planning	Develop a computer-based model for capturing human behavior during flood emergency evacuation process (movement of people from the region under the threat to safety) using an SD approach.
4	*2008*	Paulo Gonçalves	System Dynamics Modeling of Humanitarian Relief Operations	Presents an SD methodology to represents an opportunity to model different phenomena in humanitarian relief and to help managers design more effective policy interventions in the long run.
5	*2009*	LI Xian-gong et al.	System Dynamics Simulation of Coal Mine Accident System Cause	Analyze the kinds of hazards and unsafe behavior of employees in the coal mine accidents of China by system dynamics simulation method from organizational and management perspective.
6	*2011*	Maria Besiou et al.	System dynamics for humanitarian operations	Present the preliminary findings of an applied SD model to analyze a well-defined subsystem of humanitarian operations, field vehicle fleet management.
7	*2013*	Carine Rongier et al.	Towards a crisis performance measurement system	Propose a dynamic decision-support system to support the stakeholders in making accurate decisions while carrying out a performance evaluation of the activities that run during the crisis-response process.
8	*2013*	Nathan Kunz et al.	Investing in disaster management capabilities versus pre-positioning inventory: A new approach to disaster preparedness	Evaluate the effects of investing in disaster management capabilities through system dynamics modeling. The delivery process of ready-to-use therapeutic food items has modeled during the immediate response phase of a disaster.

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9	*2014*	Min Peng et al.	Post-seismic supply chain risk management: a system dynamics disruption analysis approach for inventory and logistics planning	Apply a system dynamics model to analyze the behaviors of disrupted disaster relief supply chain by simulating the uncertainties associated with predicting post-seismic road network and delayed information.
10	*2014*	Ljiljana Najev Čačija	Preliminary empirical analysis of the relationship dynamics between marketing activities and fundraising success in nonprofit organizations	Presents the initial results of the application of a system dynamics methodology to modeling the marketing activities in the nonprofit sector.
11	*2014*	Y. Cruz-Cantillo	A system dynamics approach to humanitarian logistics and the transportation of relief supplies	Develops an SD model for the forecasting, prioritization, and distribution of critical supplies during relief operations in case of a hurricane event.
12	*2015*	Pablo Suarez	Rethinking engagement: innovations in how humanitarians explore geoinformation	Offers an innovative approach to immerse disaster managers in geoinformation: participatory games that enable stakeholders to experience playable system dynamic models, decisions and consequences in a way that is both serious and fun.
13	*2015*	A. Remida	A Systemic Approach to Sustainable Humanitarian Logistics	Presents a systemic approach, which take into account the economic and social dimensions of sustainability and the increasing complexity of logistics systems within disaster relief operations that emphasizes its applicability in Humanitarian Logistics (HL) research.
14	*2015*	Otávio Costa et al.	A system dynamics analysis of humanitarian logistics coordination	Demonstrate an SD simulation to analyze the interactions between media, donors and humanitarian organizations in response to an abrupt natural disaster, such as tsunamis and earthquakes.
15	*2015*	J. Voyer et al.	Understanding Humanitarian Supply Chain Logistics with System Dynamics Modeling	Present an SD model referring to humanitarian response to a natural hazard, but they do not focus on conflicting needs resulting from the stockpiling behavior of the population and the needs for conducting relief operations.
16	*2015*	Danilo R. Diedrichs et al.	Quantifying communication effects in disaster response logistics, A multiple network system dynamics model	Propose a discrete mathematical SD model to study the role of communication and logistical coordination between actors in an emergency disaster response operation, and to measure their impact on the number of lives saved and dollars spent.
17	*2015*	Romana Berariu et al.	Training decision-makers in flood response with system dynamics	Present an SD model to train decision-makers on flood response by providing them the possibility to analyze and evaluate different scenarios.
18	*2016*	Tanti Octavia et al.	Coordination of Humanitarian Logistic Model Plan for Natural Disaster in East Java, Indonesia	Develop a detail coordination SD model in humanitarian logistic in Indonesia.
19	*2017*	Ali Anjomshoae et al.	Toward a dynamic balanced scorecard model for humanitarian relief organizations' performance management.	Propose a conceptual framework for the development of a Dynamic Balanced Scorecard (DBSC) for humanitarian organizations, with a focus on cause-and-effect relationships among KPIs of the humanitarian supply chain.
20	*2018*	Jooho Kim et al.	A framework for assessing the resilience of a disaster debris management system	Apply a system dynamics approach to evaluate the debris removal performance for a resilient community.

IV. Conclusion

System dynamic for the humanitarian subject is critical, in terms of securing donor funding, accountability and improving the relief mission (saving lives and reducing human suffering). The dynamic behavior of complex systems simulation problems in the disaster events, include a wide number of quantitative and qualitative variables, non-linear relationships between the variables and feedback interaction among them and action taken by the humanitarian organizations and donors responsible for the emergency occurs. SD approach has the ability to capture particular features of the human and environment behavior and relations during the emergency and to simulate it in an easy-use simulation model which makes it a powerful planning and analysis tool aimed at preventing the loss of life and the minimization of material damage and provide system users with a better understanding of the dynamic behavior of systems. In this review, the aim was to assess and review publications in the humanitarian field applying SD model. It can be helped to gain a better perspective about the use of this method in the humanitarian subject. A set of 20 papers were selected and reviewed which in general, useful information about the concentration of publications on SD model can be observed from this research and a new outlook has been opened about the possible applications of system dynamics to donor's organizations. The most obvious finding to emerge from this research is that System dynamic can be a valuable tool in the complex systems; nevertheless, lack of implementing SD approach is clearly observed in the studies and the quantity of research is still limited in this field. The proposed literature review aims to encourage further research in applying the system dynamic for humanitarian organizations and presents the essential requirement of SD tool for reliable modeling of the complex

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