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SIMULATION APPLICATIONS IN HUMANITARIAN LOGISTICS: A LITERATURE REVIEW

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ABSTRACT

Through a search in the literature, several bibliographic reviews were verified considering operational research and humanitarian logistics. Simulation is part of operational research field and have new technologies been developed. Simulation techniques make possible to represent more realistically the events brought about in disasters. Nowadays, there is a greater interest from researchers of humanitarian logistics in applying this methodology. Nevertheless, there are no studies pointing specifically to the use of simulation modeling in this area. This work aims to review papers of humanitarian logistics that apply simulation techniques to solve problems that arise in disaster situations. To accomplish this goal, papers on humanitarian logistics published in the last ten years were analyzed. A total of 111 papers were analysed and 30 their content explored in this work. From the papers selected, 73% were applied to natural disasters. The life cycle stage of disaster to which they apply are mostly response and preparedness. The techniques utilised vary mainly according to the nature of the disaster.

1 INTRODUCTION

Disasters can be natural, not natural, armed conflicts, economic crises, and others. They can happen suddenly and now more frequently, due to disordered urban growth and climate change. According to the Center for Research on the Epidemiology of Disasters, in the years 2004 to 2013, natural disasters have killed an annual average of 99,820 people, and 199.2 million people are victims worldwide. Economic damage caused by natural disasters was estimated at a ten-year annual average of US$ 162.5 billion (Guha-Sapir et al. 2015).

Disasters cause situations of social, economic, and political uncertainty. When a disaster occurs, the goal of organizations and authorities is to help the victims. This help is of vital importance, because many lives depend on it. In these cases, finding an efficient way to help the victims can make a big difference.

The humanitarian logistics is the process of planning, implementing and controlling the efficient, cost effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people. The function encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking and tracing, and customs clearance (Thomas and Kopczak, 2005).

Optimization and simulation are the major tools to address and overcome these challenges. Simulation in the area of humanitarian logistics is a methodology that is not yet widely used in comparison with others from operational research (OR). Still the dynamic technological development in simulation techniques is making its application grows in this area too.

In the humanitarian logistics literature, the paper of Hoyos et al. (2015) stands out. It provides a review of the literature on stochastic OR models, with a focus on the techniques used for the solution, but literature reviews dedicated to the specific simulation method were not found.

For all the above, this work aims to examine the literature that applies simulation modeling to improve logistics operations management in disasters. This paper is organized into four sections. The second section presents the methodological approach. In the following section, the results are presented. In the final section, the main conclusions and contributions of the research are presented.

2 RESEARCH METHODS

A systematic literature review is a means of identifying, evaluating and interpreting all available research relevant of an area (Kitchenham 2004). This systematic review includes a descriptive, a bibliometric and a content analysis. A combination of bibliometric study and content analysis allows the identification of the most important topics, approaches, and methods, as well as the most important definitions of the theme (Carvalho et al. 2013).

The main objective of this study is to identify humanitarian logistics research that apply simulation methods. In this sense, four research questions were elaborated:

RQ1 Which types of disaster were addressed?
RQ2 Which lifecycle stages of disaster were addressed?
RQ3 Which simulation techniques were applied?
RQ4 Which decision levels were addressed?

2.1 Articles collection

For this literature review, only papers published between 2010 and January 2020 were considered. There were included papers written in English. The keywords used to search were: ”humanitarian logistics” or ”humanitarian supply chain” or ”humanitarian relief chain” or ”humanitarian chain”. Keywords such as ”simulation” or ”system dynamics” or ”agent-based simulation” were used to specify the research methods inside the main topic of study. We considered the filters ”Article” as ”Document Types” during the search. The papers were collected from the ISI Web of Science and Scopus databases.

The search resulted in 54 papers from the ISI Web of Science and 57 papers from the Scopus database, a total of 111 papers, which 31 were excluded from the sample because they were duplicated. In the next phase, after reading the abstracts, the sample of 80 papers was reduced as we excluded some papers. The exclusion criteria concern the fact that certain papers, although citing humanitarian logistics, have an emphasis healthcare. Another exclusion criterion was the techniques adopted; some papers were removed from the sample because they did not actually use a simulation technique. After this analysis, 50 papers were excluded, leaving a final sample of 30 papers for the next phases of the systematic review, which are developed in the following sections. Figure 1 summarize the phases of the systematic review.

2.2 Descriptive analysis

The description of the findings and distribution of the selected papers according to its years, methodology and approach are detailed in the result section.

2.3 Category selection

To classify the papers for this study, it was used the framework adopted by Leiras et al. (2014). As the present study only refers to papers that use simulation paradigms, the categories: problem type, optimization type, and coordination perspective do not apply. The remaining categories are described below and explained in detail by Leiras et al. (2014):

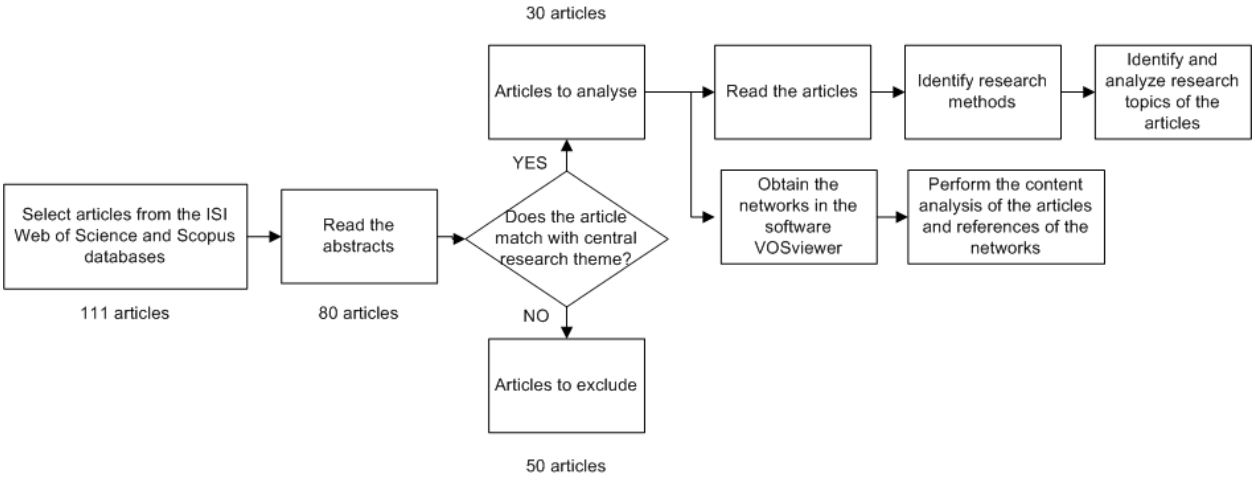

Figure 1: Phases of the systematic review

- General paper information: journal title, publication year, authors and countries of affiliation of authors.
- Disaster type: disasters were divided into natural or man-maid. The man-maid are split into sudden-onset (i.e., terrorist attack, chemical leak, etc.) and slow-onset (an economic crisis, for example).
- Disaster lifecycle stage: it is divided into mitigation, preparedness, response, and recovery. Mitigation and preparedness are different because, in the mitigation, the authorities measure risk and try to reduce it. The preparedness concerns training and methods to quickly respond to disasters.
- Research method: we used only three classifications. Empirical papers include data analysis, literature review, and other qualitative research. The analytical papers are the ones where a new method or approach is presented and it considers the modeling process. Applied are papers that contain case studies.
- Geographical perspective: the location of the analyzed area used in the case study papers.
- Decision level: the papers are divided into strategic, tactical and operational according to if its long, medium, or short term, respectively.
- Stakeholder perspective: it was divided into government, organizations (private or non-profit) and victims. The papers were fitted according to the decision makers (users) for which the models, tools, etc. were designed.

2.4 Material evaluation

The papers selected were reviewed according to their keywords and abstract at first. As there were not many papers, all were read and classified according to the list presented in the previous section.

3 RESULTS

3.1 Descriptive analysis

The analysis of the selected papers will proceed with the evaluation of the simulation techniques, the disaster types, and disaster life cycle stages used for these works. For this analysis, the 30 papers selected are evaluated.

3.1.1 Graphic analysis

In response to the research question (**RQ1**), the figure below (Figure 2) presents the number of occurrences of each disaster type, according to the publication year of the papers. One paper could analyze more than one disaster type; the occurrence of more than one disaster type by publication was observed in two papers. Each color represents a disaster type category, as presented in section 2.3. The number of publications was not large, as the results of the keywords search showed. From 2013 to 2020, the average number of publications using simulation techniques and humanitarian logistics was 3.5. 22 of the 30 papers address to natural sudden-onset disasters.

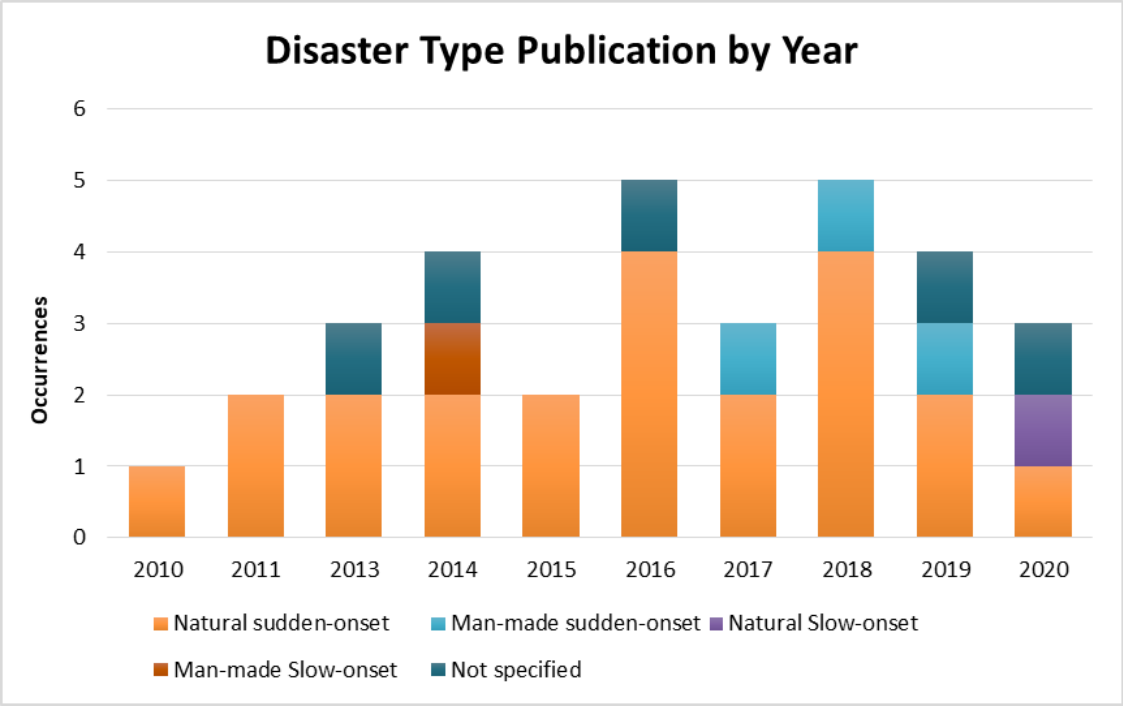

Figure 2: Publications by year according to disaster type classification

Besides the analysis of disaster types per year and by publications, the verification of life cycle stages of disasters per year was also carried out as a reply to the research question (**RQ2**). In Figure 3, one can see that the presence of the response stage is checked all the years as the larger percentage of the columns. 80% of the papers deal with response questions. The preparedness was the second disaster stage more studied, with six occurrences. Five papers included more than one disaster stage in its content. They included the presence of preparedness and response, or response and recovery.

To complement the analysis of publication per year, the comparison between disaster stages and types was created. To create this analysis, we crossed the information, to each paper, of the stages and types mentioned into it. Like the previous analysis, one paper can result in more than one type or stage. Figure 4 shows the occurrences of disaster stages to each disaster type. The stage with a higher number of occurrences was natural sudden-onset, as explained previously. The primary use of simulation was to conceive solutions to respond and prepare for this type of disaster, respectively. Five papers did not specify the disaster type used as reference, and these papers use analytical research method. The techniques used were agent-based simulation and system dynamics and had a purpose of creating methodologies that help non-profit organizations and the governments to solve general situations (Figure 4).

Concernig to research question (**RQ3**) the Figure 5 was created to show the occurrences of techniques for each disaster type. The use of discrete-event simulation and agent-based simulation highlights, compared

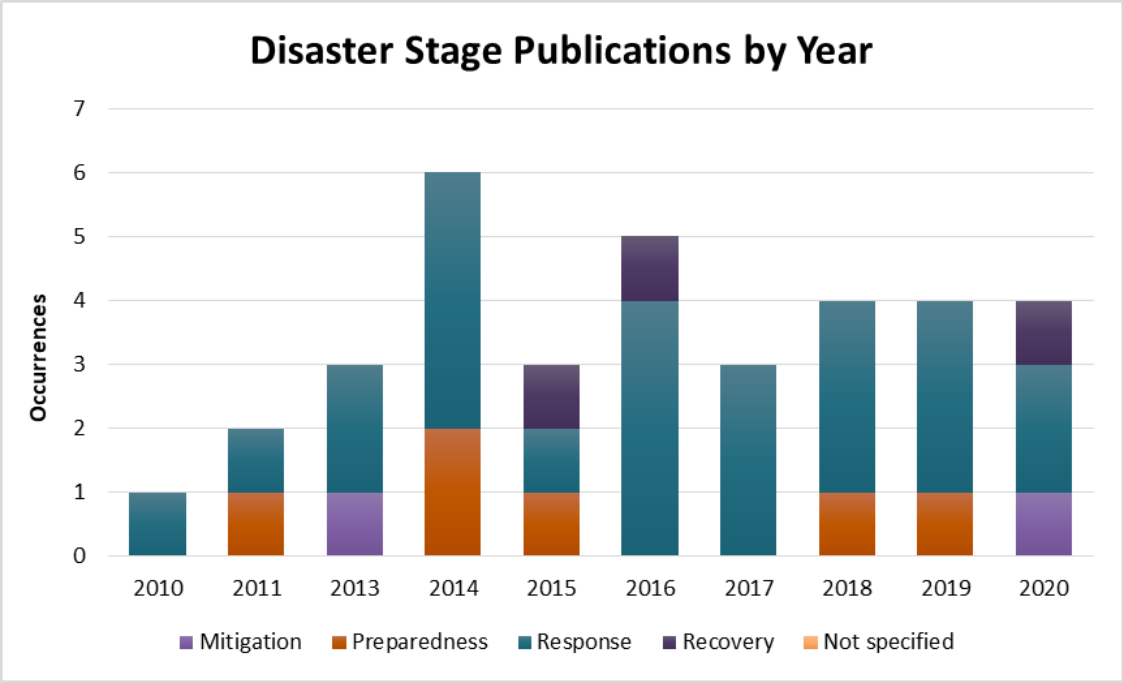

Figure 3: Publications by year according to disaster life cycle stage

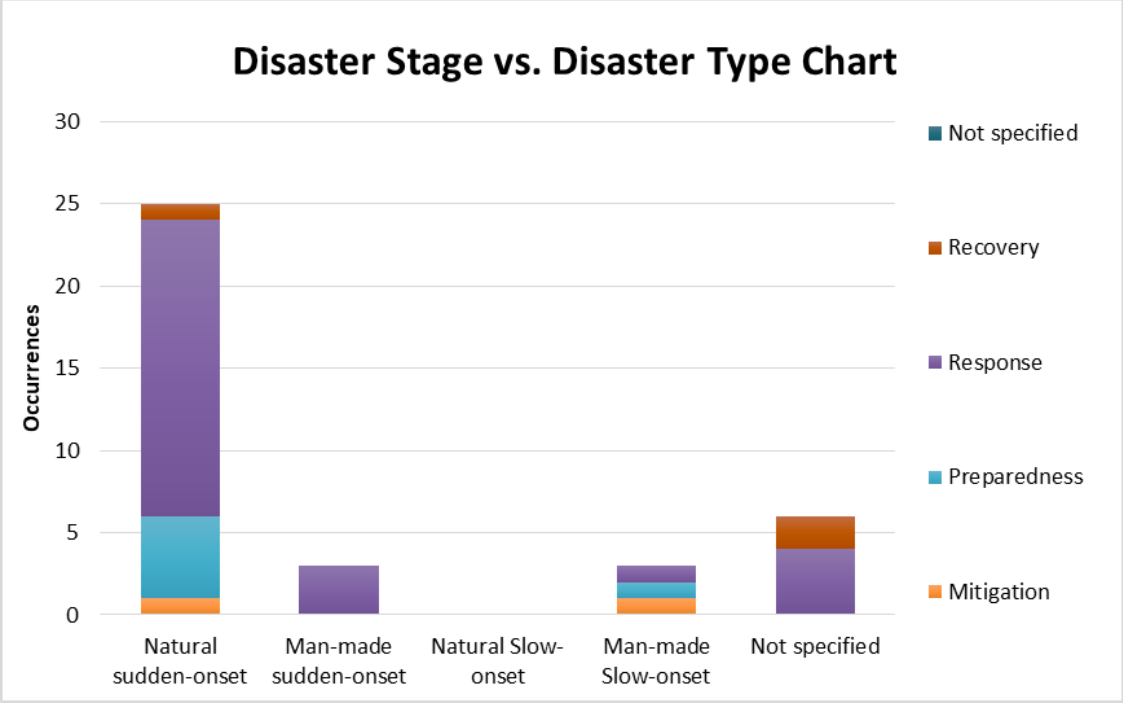

Figure 4: Occurrence of disaster stage for each disaster type

to the other techniques. The hybrid simulation is a concept used by Balcik and Krejci (2015) to describe the methodology of a paper that uses discrete-event simulation allied to agent-based simulation to create an approach to humanitarian logistics. It was verified in one selected paper. For papers that looked to

natural sudden-onset disaster, the use of system dynamics was also a suitable technique. The distribution of simulation techniques by disaster stage shows the same pattern (Figure 6).

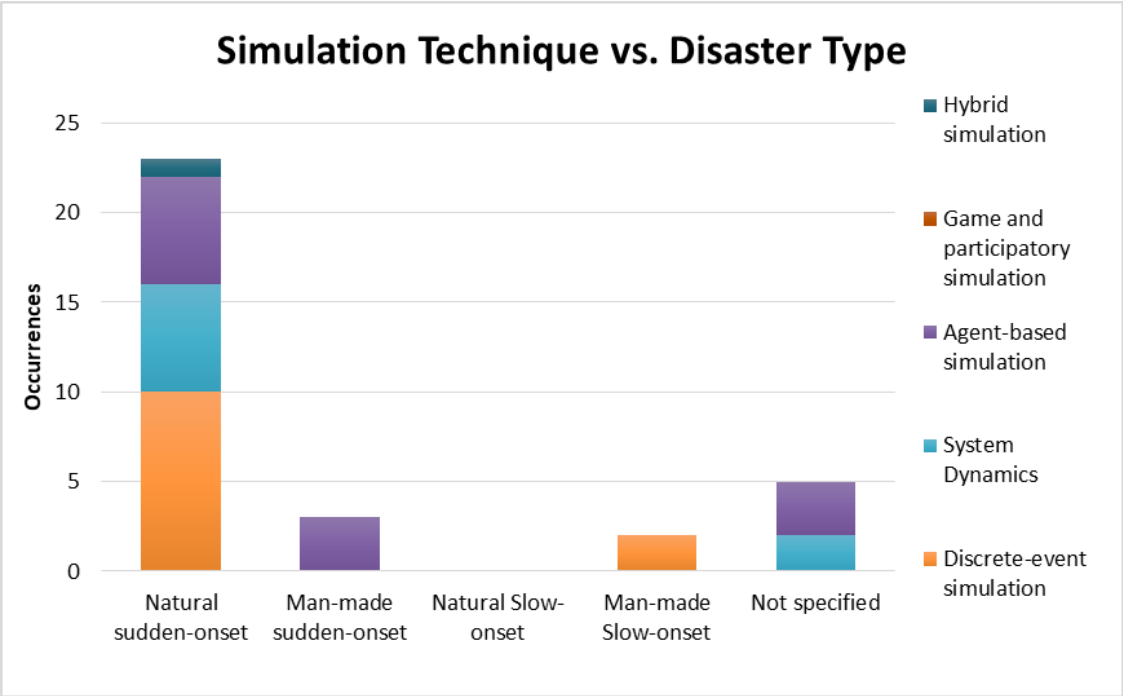

Figure 5: Simulation techniques applied to each disaster type

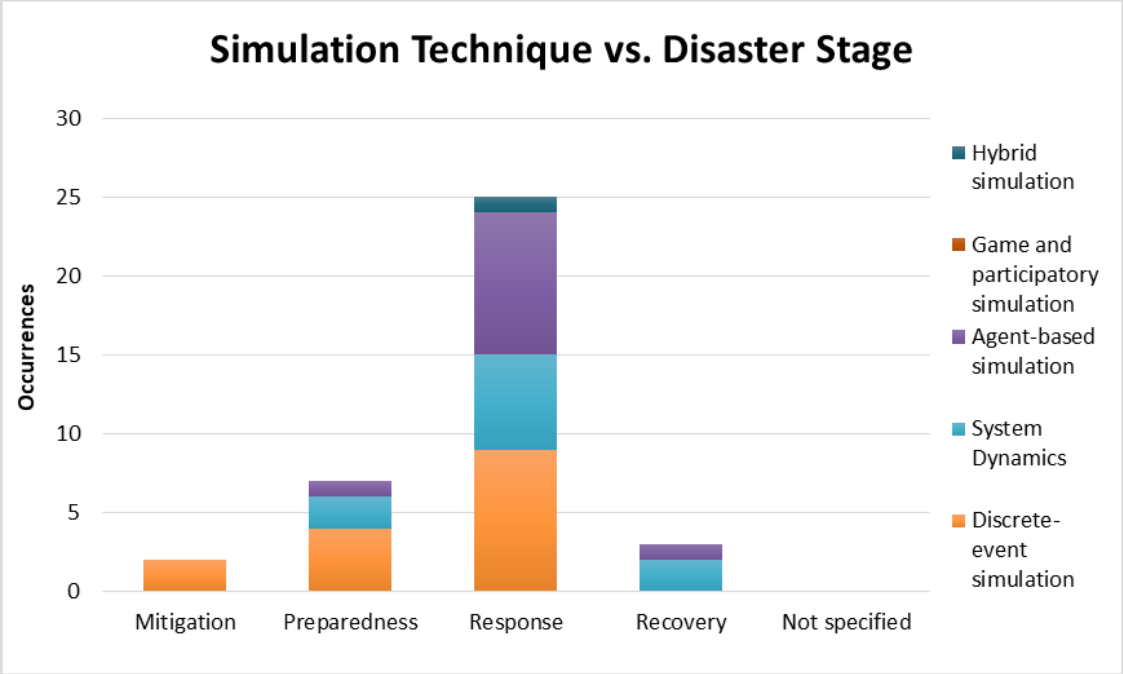

Figure 6: Simulation techniques applied to each disaster life cycle stage

The operational decisions were the most applied by the selected papers, followed by tactical and strategic ones. Answering the research question (**RQ4**), the Figure 7 presents the occurrences of all simulation techniques to each decision level. One can notice that papers with operational decisions use a large percentage of agent-based simulation, whereas tactical decisions favor discrete-event simulation. Strategic decisions also have a large presence of discrete-event simulation as technique, followed by system dynamics. The use of system dynamics was the second option with more relevance for all the decision levels.

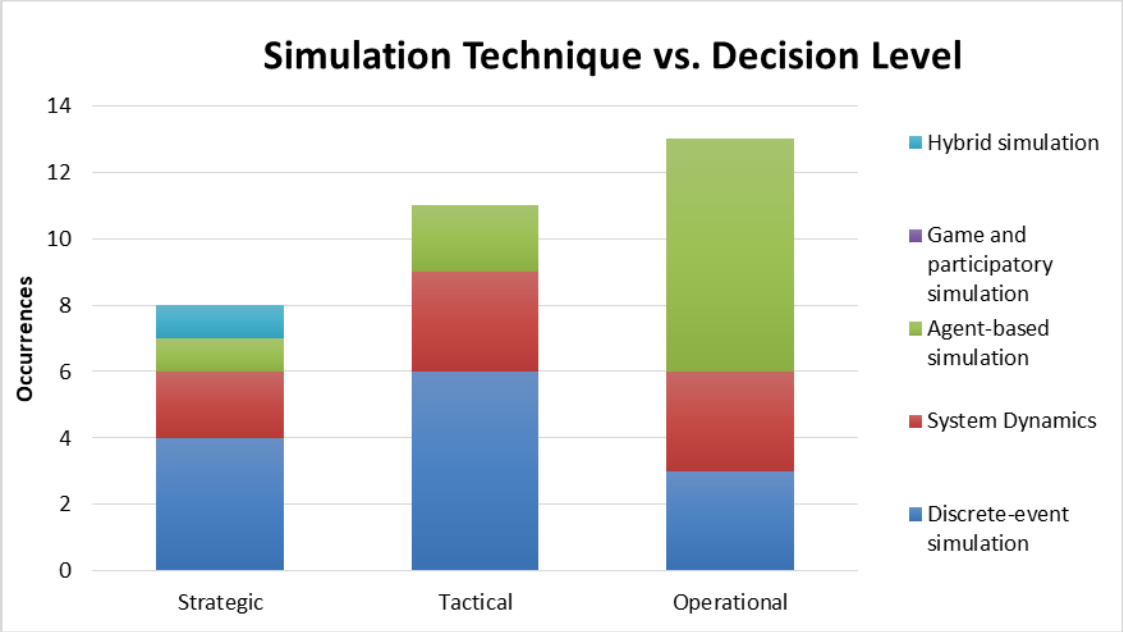

Figure 7: Occurrence of simulation techniques for papers according to their decision level

3.2 Bibliometric analysis

In this section of the research, the keyword network and the co-citation network were developed with the *VOSviewer* software.

3.2.1 The keyword network

The keyword network (Figure 8) was used to identify concepts associated with humanitarian logistics and simulation. The 30 papers selected, from the sorting process of its content relevance and publication year, were used as reference for this data cross-checking procedure. A minimum of two citations of each keyword was considered to qualify the network. The keywords mentioned together are linked, it is important to note that the larger the node, the greater the frequency of the corresponding keyword. There is a connection between humanitarian logistics and simulation. The main connections with humanitarian logistics are management, system dynamics, and model. In relation to simulation, the main connections found are resource allocation, disaster response, and logistics.

3.2.2 The co-citation network

The co-citation network (Figure 9) indicates the degree of similarity between references when displaying the documents that have been mentioned together. An analysis of this network can reveal the common interest of research groups. This analysis was also conducted with the papers selected after the sorting process.

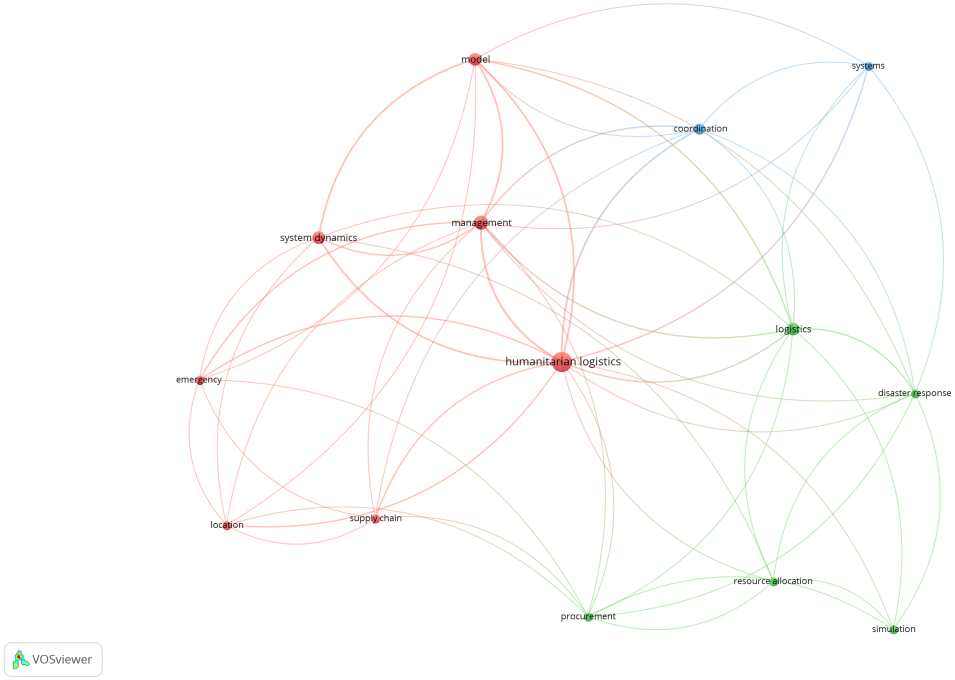

Figure 8: Keyword network

A minimum of three appointments of each paper was considered qualified for this network. The size of the node is proportional to the frequency of a cited paper. This analysis shows three defined clusters. The cluster illustrated in red is composed of classic papers of humanitarian logistics that explore the concept. The blue cluster presents papers that apply simulation techniques. In the green cluster are classified papers of operational research and simulation, mostly with stochastic problems.

3.3 Content analysis

In this section, we present a review of all those papers that apply simulation to solve humanitarian logistics problems. We evaluated nineteen papers. Eleven papers, from the sample, had a content that included optimization-simulation as the method of study.

3.3.1 Discrete-event simulation

The logistical elements involved in the distribution of unsafe food are discussed by Mohan et al. (2013). The authors describe how a discrete event simulation-based approach was used to improve the efficiency and productivity of a food recovery center that plays the central role of purchasing and assembling food for distribution. Iakovou et al. (2014) created a methodology that quantifies the impacts of risk mitigation strategies on the humanitarian logistics supply chain. A conceptual instance was taken into account using disasters such as hunger and drought as a reference; scenarios with variation in the percentage of pre-established spaces for allocating supplies in the event of disasters were analyzed.

3.3.2 Monte Carlo simulation

Applying data from reports and Oxfam America, the city of Pikini, Senegal, was studied by Green et al. (2013). They determined whether emptying latrines in a flood-prone urban slum would be a sustainable business for the local population and profitable for the private sector. The authors conducted several Monte Carlo simulations in order to determine costs, the number of effluents removed from latrines, regions of

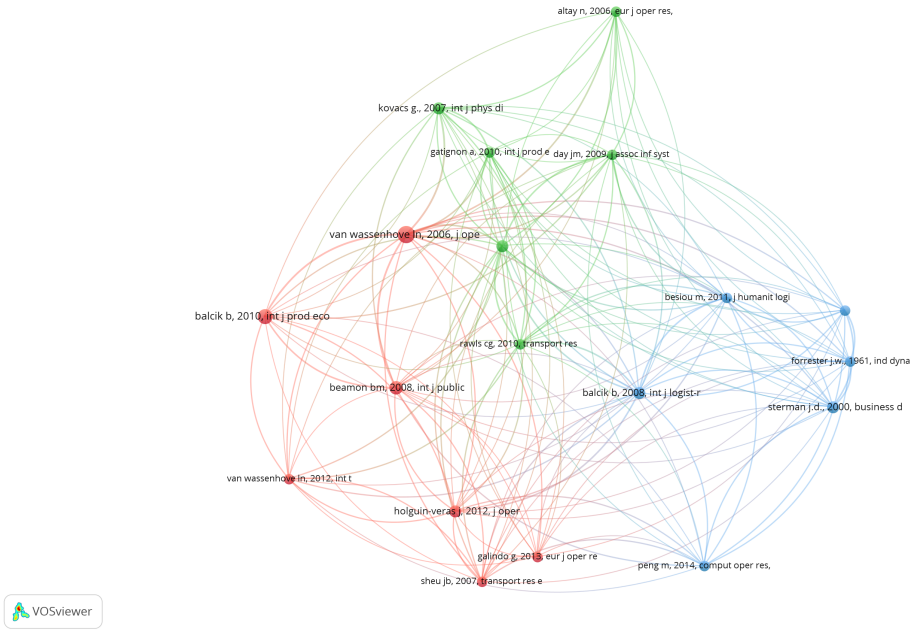

Figure 9: Co-citation network

the city to be served first, and others. Stauffer et al. (2018) studied how the supply chains of international humanitarian organizations are affected in the event of mega-disasters.

3.3.3 System Dynamics

The adequacy of the system dynamics (SD) methodology as a tool for humanitarian decision-makers to understand the effect of their decisions on humanitarian operations is illustrated by Besiou et al. (2011). They analyze field vehicle fleet management and find that the SD can accurately represent the dynamic complexity of humanitarian operations and is, therefore, an appropriate tool for studying these systems. Kunz et al. (2014) try to evaluate the effects of investing in disaster management resources; they modeling or process of delivery of therapeutic feed items ready for use during a phase of immediate response to a disaster and analysis the performance of different preparation scenarios. Besiou et al. (2014) applied systems dynamics to model vehicle supply chains (VSCs), incorporating the three different structures of VSCs that International Humanitarian Organizations (IHOs) operate, in addition to modeling the entire cycle of disasters managed by IHOs. Diaz et al. (2015) propose improvements in building materials inventory management in a post-disaster perspective; they use theoretical data to simulate the reconstruction of houses taking into account scenarios with different time ranges until the adjustment of the material stock level. An alternative disaster management model for East Java was created by Octavia et al. (2016), to reduce the response time to recurring natural disasters in the region . Initially, a model is made to assess the current situation with government data. Therefore, it is suggested to include a non-governmental organization to assist in the critical operations raised. Diedrichs et al. (2016) present a discrete model of mathematical systems dynamics to study the role of communication and logistical coordination between actors in an emergency disaster response operation and measure its impact on the number of lives saved and dollars spent. Berariu et al. (2016) aim to present a model that allows simulating the deployment of resources to meet the growing needs of products such as food and other consumables during disaster situations. The focus is on managing a suddenly increased demand (accumulation behavior) for an affected population under restricted transport conditions. A model proposed by Guo and Kapucu (2020) to engage interested

actors during disaster events to collaborate and obtain more accurate and faster results when managing these events.

3.3.4 Agent-based simulation

Altay and Pal (2014) aim to focus the humanitarian community's attention on the importance of information sharing and the role of cluster leaders in facilitating humanitarian aid; modeling and simulations based on agents have shown that clusters, if used properly, encourage a better flow of information and thus facilitate the effective response to disasters. The process of donating, receiving, and allocating goods received was modeled by Suárez-Moreno et al. (2016); they sought to present insights for coordinating donations between warehouses in a post-disaster situation. Ochoa et al. (2017) uses an agent-based approach to model and simulate dynamic human crowds, but introduces the use of specific anthropometric and socio-cultural aspects that impact individual and group behavior. Aros and Gibbons (2018) studied the effect of using different forms of communication between organizations on the response time to occurrences. Two models were created. The first is based on qualitative field research, and the second is based on data provided by FEMA (Federal Emergency Management Agency), an American institution that supports organizations that work in disasters. A prototype was generated by Wang and Zhang (2019), to check the gap between demand and supply in areas affected by disasters, given a limited time window. They used the case of the earthquake in Sichuan province to validate the model. Abualkhair et al. (2019) consider strategies for managing spontaneous volunteers in disaster relief centers affected by the convergence of volunteers and materials. They identified the most effective policies for assigning volunteers, in which performance metrics related to the average time donors and beneficiaries spend in the queue are minimized.

3.3.5 Hybrid simulation

Hybrid modeling is a combination of various simulation modeling techniques described above. Balcik and Krejci (2015) present a conceptual framework for a hybrid simulation model that can be used to study decision-making and the behaviors of humanitarian logistics actors to determine how certain coordination mechanisms allow for better efficiency and effectiveness of the relief chain over time. The ABM (agent-based simulation) component of the hybrid model allowed the representation of heterogeneous agents (donors, international NGOs, and local NGOs) and the interactions between them that led to horizontal and vertical coordination in the pre-disaster phase, via shared transport and sharing of information. The model's discrete event simulation (DES) component captured the flow of relief supplies through the post-disaster logistics system, based on the pre-disaster coordination arrangements defined in the ABM.

4 CONCLUSION

From an initial set of 111 papers, taken from the ISI Web of Science and Scopus bases, 30 papers were selected for analysis. As criteria for the selection of the first 111 papers, some keywords were used, which included combinations of simulation and humanitarian logistics. To select the 30 papers analyzed in the results of this paper, criteria as the studied problem, the nature (practical or theoretical) of the content, and the use of simulation as the primary methodology to solve the studied cases, were verified.

For the analysis of the papers, the methodology proposed by Carvalho et al. (2013) was followed, combining bibliometric analysis and content analysis.

For bibliometric analysis, the clouds of co-cited references and keywords used by the authors were created. From the cloud of keywords, it was observed that there is a little predominance of simulation in humanitarian logistics papers. This fact is confirmed by the low number of works selected for analysis, about a quarter of the total initially identified.

For content analysis, three fronts were carried out. Charts were created to summarize and identify trends in the content that has been published from 2010 to January 2020. Thus, the description of the

selected works, informing the reader more about the region studied, the type of disaster analyzed and methodologies used.

From the graphical analysis of the results, it was possible to verify that most studies focus on the response stage to natural sudden-onset disasters. Papers in which the authors sought to manage volunteers or communication among stakeholders used mainly agent-based simulation. Papers interested in material flow or supply flow use mostly discrete event simulation and system dynamics, respectively. Five papers did not specify the disaster type and use analytical research to create new approaches to be used by organizations during the preparedness and response to disasters.

A significant amount of research is also focused on the sudden-onset disaster, but in the slow-onset, few works were found. Slow-onset disasters are now potential threats for the people, like drought, insect infestations, and disease epidemics; simulation techniques can be adopted to find solutions to these problems. Another topic that has not been studied much in humanitarian logistics is the inventory management in distribution or local relief centers, mostly because of the uncertainty of supply and demand for commodities. These problems can be successfully addressed with simulation techniques; a reasonable allocation of resources, distribution relief, and inventory planning can contribute to disaster operations management. Also, research has been limited to the organizations and government perspective. Therefore, it needs further study in the evacuation and transportation of victims. It can be made with the modeling of search and rescue activities.

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