Pontifícia Universidade Católica
do Rio de Janeiro

Luiza Ribeiro Alves Cunha

Modelling the Dynamics of Humanitarian Operations

Tese de Doutorado

Thesis presented to the Programa de Pós-graduação em Engenharia de Produção of PUC-Rio in partial fulfillment of the requirements for the degree of Doutor em Engenharia de Produção.

Advisor: Prof. Adriana Leiras

Co-advisor: Prof. Paulo Gonçalves

Rio de Janeiro
August 2022

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Bibliographic data

Cunha, Luiza Ribeiro Alves

Modelling the dynamics of humanitarian operations / Luiza Ribeiro Alves Cunha ; advisor: Adriana Leiras ; co-advisor: Paulo Gonçalves. – 2022.
168 f. : il. color. ; 30 cm

Tese (doutorado)–Pontifícia Universidade Católica do Rio de Janeiro, Departamento de Engenharia Industrial, 2022.
Inclui bibliografia

1. Engenharia Industrial – Teses. 2. Operações humanitárias. 3. Revisão sistemática da literatura. 4. Survey. 5. Estudo de caso. 6. Dinâmica de sistemas. I. Leiras, Adriana. II. Gonçalves, Paulo. III. Pontifícia Universidade Católica do Rio de Janeiro. Departamento de Engenharia Industrial. IV. Título.

CDD: 658.5

Acknowledgements

I have a lot to thank my advisor Adriana Leiras, who accompanied me since the first semester of the Masters and showed me the steps to be followed until now. May our paths continue to meet from now on.

My co-advisor Paulo Gonçalves, who presented me to System Dynamics, received me in Switzerland and contributed to my academic growth. Thank you for your availability and participation.

To the PUC-Rio institution, my home for the last ten years, for the excellent study environment and the great professionals, this work would not have been possible without them.

To all professors and staff from PUC-Rio Department of Industrial Engineering (DEI), and to all professors from Systems Dynamics courses I took, who made this academic challenge more pleasurable.

To my family, for encouraging my personal and professional growth through the necessary support for my education. Thank you for always being by my side. Especially to Maria, who turned my life upside down, and made me grow immensely during my Ph.D.

Finally, I thank the examining board and everyone who is interested in the topic of Humanitarian Operations and who, in this thesis, have the opportunity to study an interesting and relevant subject further.

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) – Finance Code 001.

Abstract

Cunha, Luiza Ribeiro Alves; Leiras, Adriana (advisor); Gonçalves, Paulo (coadvisor). **Modeling the Dynamics of Humanitarian Operations.** Rio de Janeiro, 2022. 168 p. Tese de Doutorado – Departamento de Engenharia Industrial, Pontifícia Universidade Católica do Rio de Janeiro.

Research in Humanitarian Operations (HO) has attracted the attention of academics and practitioners by applying analytical tools to improve response to beneficiaries. Different studies suggest that the integration of traditional practices and theories of logistics and operations management (OM) in the complex context of disasters would benefit the humanitarian supply chain. One of the most recognised techniques in OM is simulation, being System Dynamics (SD) a method capable of model simplified representations of realities and gain valuable insights into situations of dynamic complexity. In this context, this thesis aims to analyse the complexity of HO through SD. The thesis presents a systematic literature review (SLR) to identify the state of the art of the subject, delivering a taxonomy, a framework, and a research agenda. Then, two complex and dynamic operations are modelled through SD. The first operation involves collecting and distributing donations to the vulnerable population from Rio de Janeiro, Brazil, amid the COVID-19 pandemic. As a result, we demonstrated that: (i) increasing access to cleaning products in communities can significantly reduce COVID-19 transmission; (ii) food donations can increase the population's affordability; (iii) accessibility increases by 20% in vouchers/cash donations compared to all in-kind donations. The second one is the Brazilian operation to receive, shelter, and internalise Venezuelans. Since the flow of Venezuelans to Brazil has grown and, the pandemic aftermath presents itself as a concern for the operation capacity, Operation Welcome is modelled to understand the bottlenecks for its scalability. As a result, we demonstrate that: (i) the internalisation process is a bottleneck as, in addition to logistics, it is necessary the socio-economical insertion (through job vacancies, for example); (ii) shelters capacity is an operation bottleneck, as it defines a queue of needing assistance Venezuelans waiting to be sheltered.

Keywords

Humanitarian Operations; Systematic Literature Review; Survey; Case Study; System Dynamics.

Resumo

Cunha, Luiza Ribeiro Alves; Leiras, Adriana; Gonçalves, Paulo. **Modelando a Dinâmica de Operações Humanitárias.** Rio de Janeiro, 2022. 168 p. Tese de Doutorado – Departamento de Engenharia Industrial, Pontifícia Universidade Católica do Rio de Janeiro.

Pesquisas no campo de Operações Humanitárias (Humanitarian Operations - HO) vem atraindo a atenção de acadêmicos e profissionais ao abranger o estudo de diversas ferramentas analíticas visando a melhora da resposta aos beneficiários. Diferentes estudos sugerem que a inserção de práticas e teorias tradicionais de logística e gestão de operações (Operation management – OM) - incluindo simulação, otimização, probabilidade e estatística - no contexto de desastres beneficiaria a cadeia de suprimentos humanitária. Uma vez que desastres são eventos complexos, graves e dinâmicos, com recursos humanos e materiais limitados, muitos stakeholders envolvidos e alto nível de incerteza de informação, a capacidade de gerir operações se faz necessária. Uma das técnicas mais comumente reconhecidas em OM é a simulação, sendo o método de Dinâmica de Sistemas (System Dynamics – SD) capaz de modelar representações simplificadas de realidades e obter informações valiosas sobre situações de complexidade dinâmica. O método fornece um conjunto de ferramentas, como mapeamento causal e modelagem de simulação, e permite avaliar os resultados de curto e longo prazo de decisões. Nesse contexto, a presente tese visa estudar a complexidade de HO através de SD. Para isso a tese conta com uma revisão sistemática da literatura (Systematic Literature Review – SLR) a fim de identificar o estado da arte, entregando uma taxonomia, um framework e uma agenda de pesquisa. Em seguida, duas operações são apresentadas, demonstrando a modelagem através de SD em contextos humanitários distintos e de alta relevância. A primeira operação estudada consiste na coleta e distribuição de doações para a população na base da pirâmide (Bottom of the Pyramid – BoP) do Rio de Janeiro, em meio a pandemia de COVID-19. Realizamos uma *survey* e obtivemos 2155 respostas dos beneficiários. Os dados também foram obtidos diretamente com as organizações envolvidas na operação. Como resultado, demonstramos que aumentar o acesso a produtos de limpeza nas comunidades por meio de doações pode reduzir significativamente a transmissão do vírus SARS-CoV-2. Ademais, mostramos que as doações de alimentos podem

aumentar a capacidade da população vulnerável de arcar com as necessidades, aliviando o estresse causado pela pandemia nesta parcela da população. Ademais, demostramos que quando todas as doações são na forma de vouchers/ dinheiro, a acessibilidade aumenta em 20% em comparação com todas as doações físicas. Resultados que podem servir de base para formuladores de políticas ajudarem as comunidades vulneráveis, especialmente durante crises nas quais os recursos são escassos e devem ser explorados de forma eficiente. O segundo estudo consiste na operação do governo federal Brasileiro para receber, abrigar e interiorizar Venezuelanos no Brasil. Como o fluxo de Venezuelanos para o Brasil tem crescido e as consequências da pandemia se apresentam como uma preocupação com a capacidade da operação, a Operação Acolhida é modelada a fim de entender os gargalos de sua escalabilidade. Como resultado, demonstramos que: (i) o processo de interiorização é um gargalo, pois além da logística, é necessária a inserção socioeconômica dos Venezuelanos (por meio de vagas de emprego, por exemplo); (ii) a capacidade dos abrigos é um gargalo da operação, pois define uma fila de venezuelanos precisando de ajuda esperando para serem abrigados.

Palavras-chave

Operações Humanitárias; Revisão Sistemática da Literatura; Survey; Estudo de Caso; Dinâmica de Sistemas.

Summary

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1
Introduction

Disasters cause human, material, economic and/or environmental losses when disrupt the activities of a society exceeding the affected community recovery capacity by its means (without external assistances) (Natarajarathinam et al. 2009; Leiras et al., 2014). Major disasters marked the 21st century, as the September 11, 2001, terrorist attack on the United States, 2005 Hurricane Katrina, 2005 Pakistan earthquake, 2008 Myanmar cyclone, 2010 Haiti earthquake, the ongoing COVID-19 pandemic, and migratory movements of Syrians, Venezuelans, and Afghans due to economic, social, and political crisis.

Once disasters have hit and will continue to impact society, affecting daily life, the interest to understand how to manage them increases (Altay and Green, 2006). Thus, the rescue efforts and support activities involved in delivering relief supplies at the affected area to the right people in the shortest possible time, minimising the disaster impacts, is known as Humanitarian Operations (HO) (Leiras et al., 2014; Mishra et al., 2019), being the conduction of an HO efficiently and effectively a critical element of a disaster relief process (Leiras et al., 2014).

The earliest papers on HO were published in 2006. Van Wassenhove (2006) raised the debate that the logistics used in the private sector can be applied to improve the performance of logistics in response to disasters, considering the particularities of the humanitarian context. Similarly, the Operations Management (OM) field has expanded with the increasing importance and complexity of business operations function (Choi et al., 2016). Altay and Green (2006) emphasise the growing need to study operation-related issues, in addition to the logistics and supply chain management, in response to disasters. Since these pioneering publications, the number of papers has increased in quantity and relevance - see, for example, Natarajarathinam et al., (2009) and Leiras et al. (2014) for literature reviews on humanitarian logistics and supply chain management; Kovács and Spens, (2007), Balcik et al., (2008), Kovács and Spens, (2009), and Holguín-Veras et al., (2012) for identifying challenges, planning and carrying out logistics

operations in disaster relief (post-disaster operations); Balcik et al. (2010) for coordination in humanitarian relief operations; Van Wassenhove and Pedraza-Martinez, (2010) and Celik et al. (2012) for operation research and management sciences (OR/MS) applied to humanitarian field.

OM research focuses on applying analytical techniques, including simulation, optimisation, probability, and statistics (Choi et al., 2016). Altay and Green (2006) highlight operations research techniques and methods such as decision theory, systems dynamics, multi-criteria decision making, and expert systems, frequently published in traditional operation research journals. In HO field, one of the most recognised techniques is the simulation, by providing support for carrying out experiments in the real world, facilitating the understanding of physical processes, information flow, decision making, and helping to prepare humanitarian aid workers (Galindo and Batta, 2013; Mishra et al., 2019).

HO are dynamic and complex. Dynamic complexity arises for several reasons, such as: (i) systems are constantly changing, and those changes occur at many time scales; (ii) the systems are tightly coupled once the actors in the system are connected and interact with one another; (iii) systems are adaptive since the decision rules of the agents in complex systems change over time; (iv) systems are governed by feedbacks (because of the tight couplings among actors, our actions feedback on themselves); (v) systems are nonlinear, presenting effects rarely proportional to cause; (vi) systems are characterised by traded-offs (the long-run response of a system to intervention is often different from its short-run response); (v) systems are counterintuitive, once cause and effect are distant in time and space (Sterman, 2001). Therefore, in HO context, (i) the location and timing of the next disaster are unknown, causing a high degree of uncertainty, and a constant change in operations; (ii) involved stakeholders need to operate with extreme resource constraints (human and material) in environments where information may not be reliable, under scarce time resources (Celik et al., 2012; Besiou and Van Wassenhove, 2021); (iii) rash decisions due to unknown timing and location, extreme resources constraints, few available information makes decision-makers in HO systems change their decisions over time; (iv) systems in HO are governed by feedbacks (e.g., the number of people assisted and unassisted after the occurrence of a disaster creates a gap between assisted population and population needing help, this gap influence HO response so that more affected population can be assisted);

(v) systems in HO can also be nonlinear (e.g., the increase in early warning performance, and the trust of populations in early warning systems); (vi) trade-offs in HO normally usually deal with the number of people saved (e.g., short response time to a disaster result in more people saved, while long response time leads to less people saved); (v) HO systems can also be counterintuitive (e.g., humanitarian development programs can be established believing it to be the best way to respond to a crisis, but they may have setbacks such as dependence of the assisted community). Thus, once HO are dynamic and complex, it is imperative to understand that our mental models for studying such complexities are flawed. Failures happen because complex systems are policy resistant; that is, the system's complexity in which we are embedded overwhelms our ability to understand them (Sterman, 2001). System Dynamics (SD) allows the creation of simplified representations of realities through models that are capable of represent the main dynamics of a system and gain valuable insights into situations of dynamic complexity. Thus, SD is a promising tool to be used in modelling HO (Sopha and Asih, 2018; Besiou and Van Wassenhove, 2021), and the most predominantly simulation technique in the context (Mishra et al., 2019; Yale et al., 2020).

Therefore, considering the progress of using SD simulation modelling, in the HO context and the importance of HO to prepare to a disaster, minimise the impact of disasters, save lives, alleviate human suffering, and re-establish the activities of society, the present thesis aims to answer the following research question: *What strategic and operational insights from HO complex dynamics can SD models provide?*

1.1 Research topics and objectives

We aim to model the complex dynamics of HO using SD as a tool to help decision-makers. For that, the start point of our research is to understand the state of the art regarding the intersection of the two research streams (HO and SD), through the development of Paper 1. Thus, our specific objective in this paper is to outline current literature trends and research opportunities. To do so, we aim to answer two research questions: (i) Which topics in HOM drive SD simulation modelling research? (ii) What are the existing gaps and opportunities in SD

application in HO extant literature? This paper delivers a taxonomy, a framework, and a research agenda.

Two additional papers are developed to analyse different high-relevant HO deeply. Paper 2 encompasses an HO focused on donations to vulnerable communities during the COVID-19 pandemic. The intended research question is: What are the potential impacts of donations of food and cleaning supplies on the COVID-19 contagion rate in the Bottom of the Pyramid (BoP) population? In Paper 2, we perform SD simulations, developed through a survey, delivering analyses on how donations can reduce the number of people infected and deaths and how donations can secure food affordability.

Paper 3, in turn, encompasses a migrant-receiving country HO. The intended research question is: How HO scale capacity to meet the migrants needs? In Paper 3, through our SD simulation developed through a case study, we deliver analysis concerning scalability bottlenecks and interactions among the three pillars of the Brazilian operation (e.g., border ordering, sheltering, and internalisation).

Through a paper-based thesis – a research based on a set of academic papers developed during the doctoral period (Kubota et al., 2021) – the research questions and objectives motivated the three papers in this thesis. Paper 1 is submitted to the Journal of Humanitarian Logistics and Supply Chain Management (JHLSCM) (Cunha et al., 2022b). Paper 2 is already published at the Annals of Operations Research (ANOR) (Cunha et al., 2022a). Paper 3 will be submitted after the exam members considerations (Cunha et al., 2022c). Figure 1 illustrates the thesis structure, considering the primary and secondary objectives, research questions, and methodology adopted in each paper.

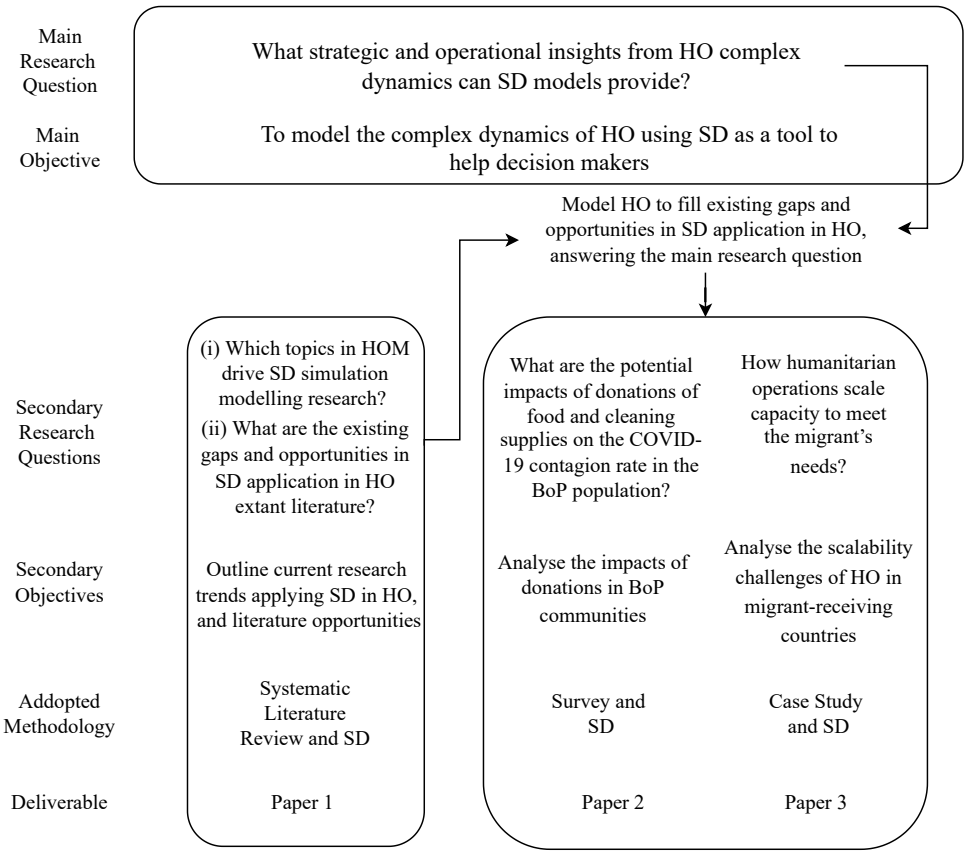


Figure 1 - Thesis Structure

1.2 Contribution originality, relevance, non-triviality, and limitations

The primary research relevance relies on SD models being built to solve fundamental and relevant real-world problems (Sterman, 2000). Thus, the first problem addressed consider vulnerable populations and their needs during the COVID-19 pandemic, whereas the second problem considers the migratory movement from Venezuelans to Brazil.

The current COVID-19 pandemic resulted in a health and socioeconomic crisis, leading to the infection of millions of people, and causing the death of hundreds of thousands worldwide. To slow the spread of the disease, isolations measures have been highlighted as the most effective policies. However, the BoP population of low-and middle-income countries, who depend on their daily outside-home jobs for income, may not follow these measures; they must either work under risky conditions or refrain from working and suffer from severe income cuts. In this context, the first studied operation aims to support Rio de Janeiro (Brazil) BoP

populations living in favelas during the pandemic through the distribution of donations, evaluating the potential impacts of two policies to improve well-being in vulnerable communities: (i) donations of food to increase affordability and (ii) donations of cleaning and hygiene supplies to enhance sanitation procedures and practices.

The second study encompasses the Brazilian federal government operation to welcome, shelter, and internalise Venezuelans across Brazil. Data estimate that 3.6% of the world population, approximately 281 million, are migrants (IOM, 2022). This displacement of millions occurs for several reasons: armed conflicts, extreme violence, natural disasters, and severe economic and political instability. The social, economic, and political crisis in Venezuela has caused a part of the population to struggle with hunger, disease, and risk of death. It has led to the infringement of fundamental rights such as access to nourishment, health, security, and an acceptable living standard (Mazuera-Arias et al., 2020). Therefore, a massive outflow of people from Venezuela has been recorded since 2015 that has intensified over time. In this context, we studied the Operation Welcome to improve Brazil's assistance to the vulnerable Venezuelan population and analyse scalability bottlenecks of this and other migrant-receiving country HO.

The research relevance can also be discussed from academics' and practitioners' views. For academia, the relevance focuses on results that consolidate the HO literature and Humanitarian OM research based on empirical data. For practitioners, the discussions raised based on the simulations and their results serve as a basis for improving decision-making (e.g., decision regarding the type of donation to be addressed in a BoP community, the type of distribution of the donation, the border control policy to be adopted in a migrant perspective or the outcome of an increase in shelters capacity).

The thesis originality is observed through the contribution to theory elaboration. There are many ways theories can be elaborated: introducing new concepts, conducting an in-depth investigation of the relationships among concepts, or examining boundary conditions (Ketokivi and Choi, 2014). Thus, we work on an in-depth qualitative analysis of the SD variables involved in HO through the SLR, delivering taxonomies tables. Also, we summarise the concepts in a framework. The representation of the framework through a causal loop diagram (CLD) - a SD tool - makes it more comprehensive for academics and practitioners looking to

understand and improve their operations. With the empirical data collected, simulations are performed, covering literature gaps, quantitatively investigating the relationships among concepts, and examining the boundary conditions. The originality of these simulations is due to the uniqueness of the operations and how they are represented mathematically. For practice, the models contribute to decision-making and public policy formulation considering the dynamic complexity of HO. For this, dashboards are developed through the Forio platform, available at https://forio.com/app/labhands/migrant-receiving-humanitarian-operations and forio.com/app/labhands/anor, making the experience of decision-makers straightforward.

The thesis's non-triviality is highlighted the through the existing literature synthesis complexity considering the interface between SD and HO, the adoption of multiple research methods (Systematic Literature Review (SLR), Survey, Case Study, and SD), and the need to collect empirical data. Altay and Green (2006) endorse the difficulty in collecting real data. Besiou and Van Wassenhove (2021) demonstrate that researchers end up not developing simulation models due to a lack of quantitative data (for example, Anjomshoae et al., 2017; Obaze, 2019; Harpring et al., 2021). Data collection is a challenge itself, and, considering the pandemic, this empirical evidence represented even more obstacles.

Regarding the research limitations, the theoretical CLD developed in the SLR is based on papers retrieved from Scopus and Web of Science databases. In this sense, it is worth noting that not considering grey literature (such as books, reports, theses, and dissertations) implies a publication bias regarding initiatives in the early stages of development or alternative publishing channels. Furthermore, the development of models presents pitfalls since models are real-world representations, and everyone experiences the world through filters. Our real-world knowledge is also limited by the dynamic complexity and restricted information (Sterman, 2000). Besides, models can continually be improved, therefore, being those improvements limitations of our simulation.

1.3 Thesis structure

This thesis is structured in 7 chapters. The first chapter provides a background on the research topic, research questions, objectives, originality,

relevance, and research non-triviality. Chapter 2 comprises the research methodology. The following chapters exhibit the published or in the process of publishing papers that compose this thesis. Therefore, Chapter 3 presents the SLR paper, Chapter 4 brings the survey paper (Paper 2), and Chapter 5 discusses the case study paper (Paper 3). Chapter 6 provides the discussion and main thesis contributions, followed by a chapter with final considerations and suggestions for future works.

2
Research methods

This chapter presents the multi-methodological procedures used in the research. Multi-methodological operations management involves at least two distinct OM research methods – analytical modelling, quantitative empirical, case studies – to meet the research goals (Choi et al., 2016). To achieve the objectives and answer the research questions, we used systematic literature review, system dynamics (analytical modelling), survey (quantitative empirical), and case study methods.

The SLR is applied to identify state of the art regarding SD models in HO. As shown in Figure 2, the first step of the thesis is the previous knowledge understanding regarding the main thesis topic. The theoretical outputs of this step are the proposition of taxonomies tables, a framework summarising the existing literature, and the research agenda. Besides the SLR, literature understanding of specific issues is also addressed in Papers 2 and 3. The survey method and the case study are developed to study two distinct HO through SD models.

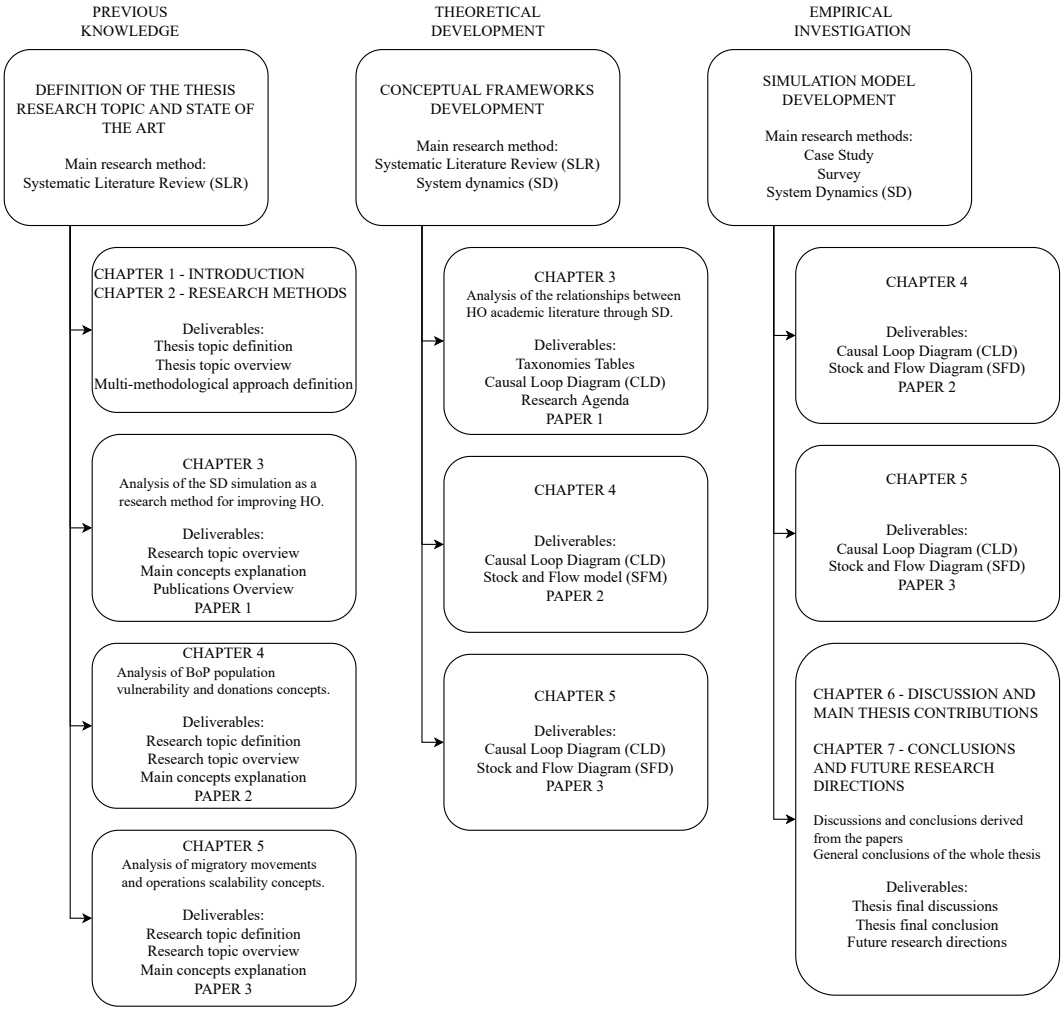


Figure 2 – Chapters and Methodologies structure

Source: adapted from Kubota (2017)

2.1 Systematic literature review

SLR is a research method that aims to review, update, critique, and improve knowledge about a specific topic (Torraco, 2016). SLR is a method that can be structured in eight steps, according to Thomé et al. (2016), namely: formulation of the research problem, literature search, data collection, quality assessment, data analysis and synthesis, interpretation, presentation of results, and review update.

Considering the thesis scope, the SLR method's application is carried out to meet the first secondary objectives. Thus, it aims to outline the current research trends applying SD in HO, the bottlenecks, and literature gaps.

The literature search considers two databases: Scopus and Web of Science (WoS). The use of both databases is due to the capacity for complementarity

between journals indexed in the two databases (Thomé et al., 2016; Mongeon and Paul-Hus, 2016). The summary of the literature search step, demonstrating the papers found in each database and papers selected after scope delimitation, is shown in Figure 3.

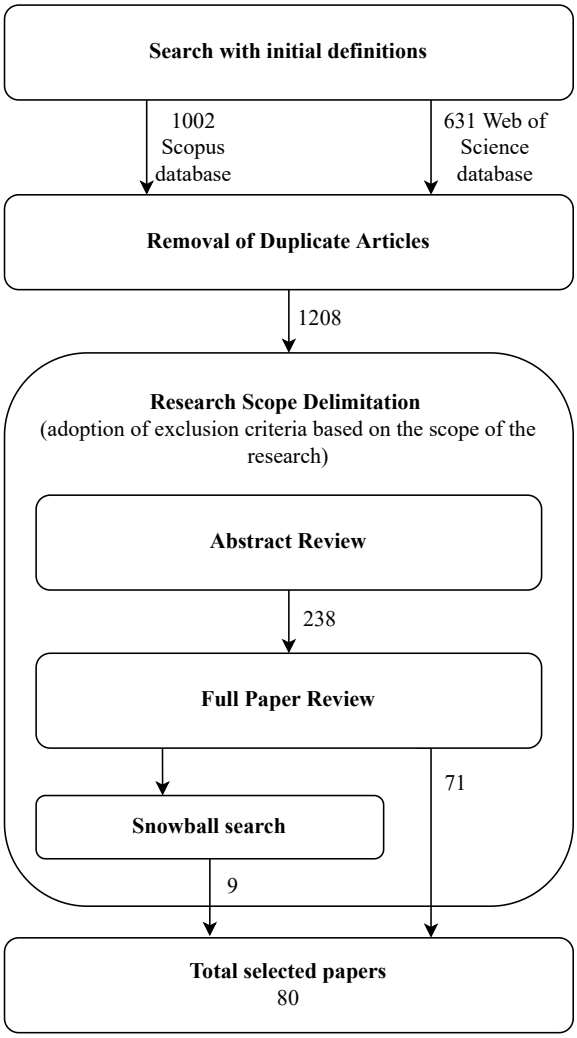


Figure 3 - Summary of literature search

The data collection step is performed by identifying and compiling the elements sought in the works in auxiliary tables. The components extracted from the selected documents are general information - title, authors, year of publication, publication channels, keywords, type of document and abstract - and specific to publications - disaster life cycle, humanitarian kind of operation, main variables. The creation of a standard data collection procedure allows full traceability of content related to each search step, and, therefore, reproducibility.

The data analysis consists of a bibliometric study to set basic statistics: annual scientific production, most cited documents, most relevant authors and their production over time, and most relevant sources. The data analysis was carried out through the bibliometrix library tool: An R-tool for comprehensive science mapping analysis.

Data synthesis and interpretation are based on the development of taxonomies tables, with a list of variables related to HO, a framework (CLD), and a research agenda. To translate the theory presented in the literature review into a CLD, we point out the most relevant feedback loops in the system. Further details of the adopted method and results can be found in Paper 1: "Looking Back and Beyond the Complex Dynamics of Humanitarian Operations".

2.2 System dynamics

The SD method consists of decomposing a complex problem into a set of variables, diagramming the feedback structure among the variables from a cause to an effect through causal loop diagrams (CLD), and assigning mathematical rules to determine the interactions between the variables through the stock and flow diagrams (SFD) (Sterman, 2000; Diedrichs et al., 2016).

Sterman (2000) proposes that an SD model be developed based on five steps: problem articulation, formulation of the dynamic hypothesis, formulation of a simulation model, testing, and policy design and evaluation. Figure 4 demonstrates the thesis problem articulation, portrays the steps of articulating the problem and formulation of the dynamic's hypothesis for the two studied operations (the management and distribution of donations to BoP population from Rio de Janeiro favelas and the Welcome Operation).

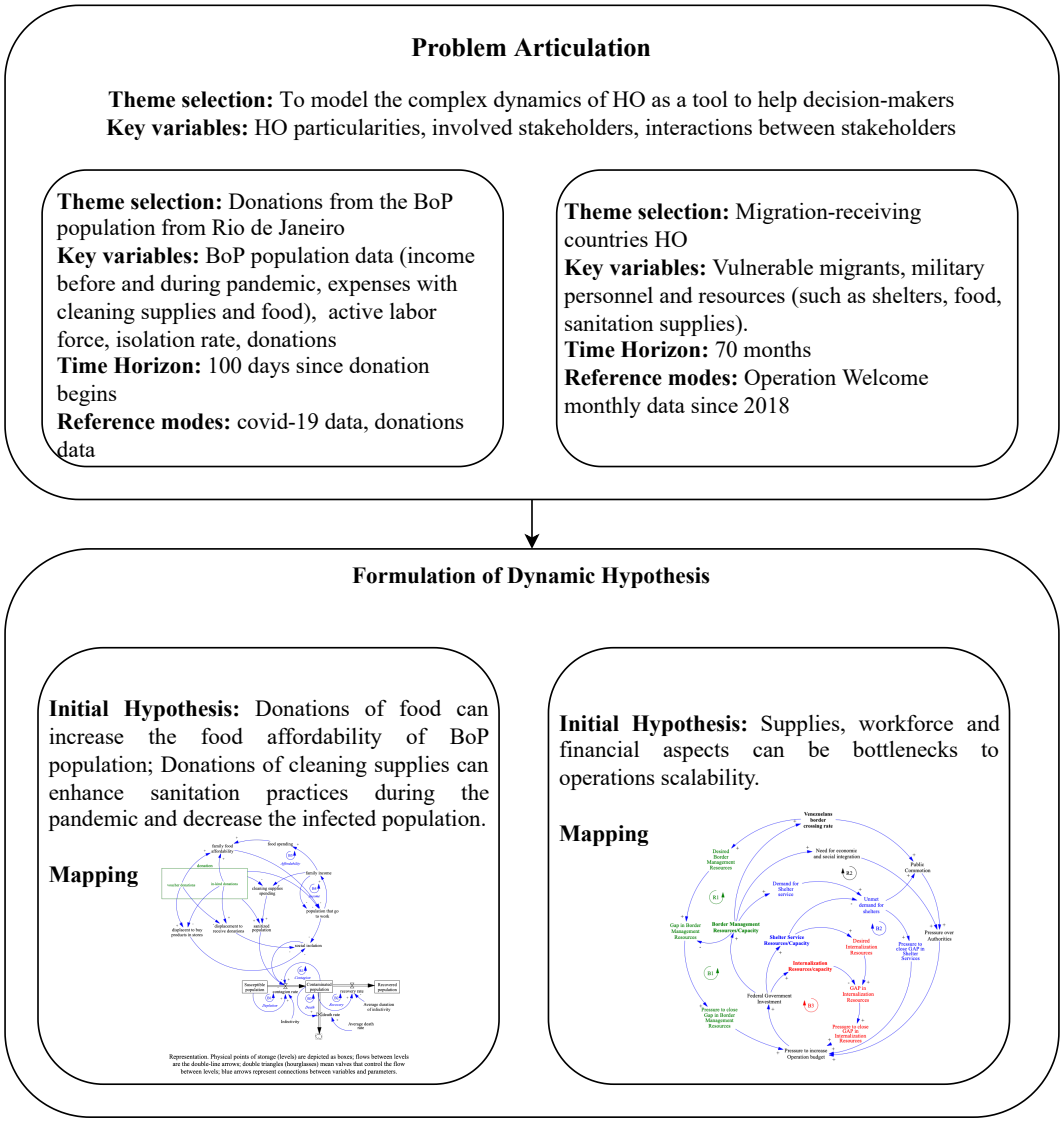


Figure 4 - Steps for SD development

The remaining steps, further details of the adopted method and results can be found in Papers 2 and 3.

2.3 Survey

Survey research aims to contribute to knowledge in a particular area of interest, collecting data and information about individuals, narrowing the distance between theory and practice (Cauchick et al., 2012). Considering the scope of this thesis, this method's application is carried out to meet the second secondary objective. Thus, it aims to assist in the modelling process of a complex HO.

The survey method determines information about large populations with a known level of accuracy (Forza, 2002). Therefore, to collect data from the Bottom of the Pyramid (BoP) population from Rio de Janeiro, the present thesis adopted the survey method based on Forza (2002) steps, presented in Figure 5.

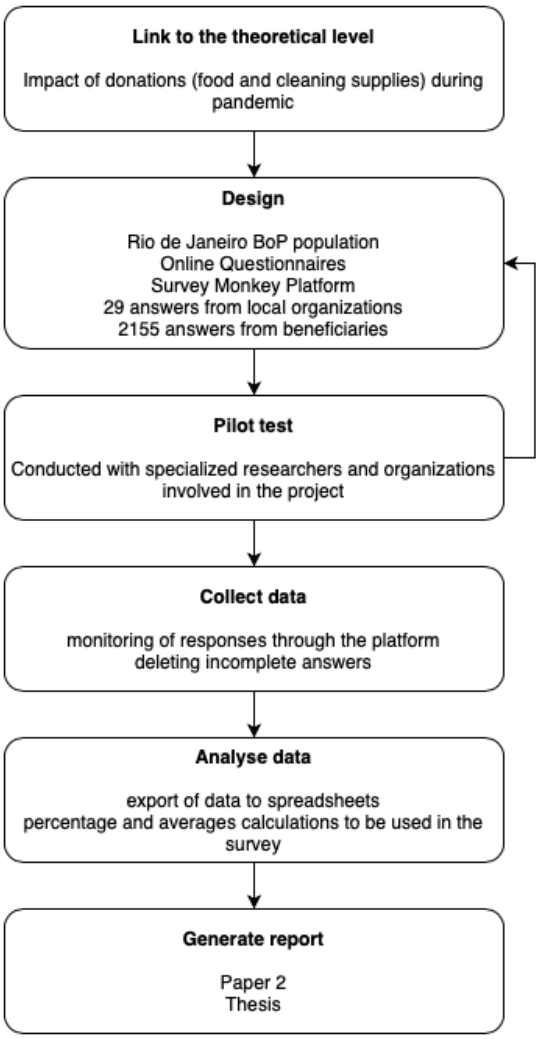


Figure 5 - Steps for Survey development

The unit of analysis linked to the theoretical level is the humanitarian project led by three large non-governmental organisations (NGOs) to distribute food and hygiene products to 143 favelas in Rio de Janeiro. Two structured questionnaires were designed to collect data. The first questionnaire surveyed the organisations behind the humanitarian project, and the second questionnaire focused on favelas residents served by the humanitarian project. The questions submitted to the organisations embrace a pandemic behaviour in the communities, and the

operations performed to deliver the donations. The questions submitted to the population also encompass an overview of the number of infected and deaths in their households, type of donation priority, and their financial situation. Pilot testing is also carried out to check the questionnaire understanding and necessary changes.

The questionnaires were sent via email, and at the end of the first week, we sent a reminder to the respondents. Thus, from 2020 May 29th to June 14th, we received 29 answers from local organisations and 2155 responses from beneficiaries.

Data collection took place virtually through the Survey Monkey platform. Answers are extracted and exported to Microsoft Office Excel, where data processing is performed, where non-responses and incomplete answers are excluded from the analysis. In the analysis stage, basic descriptive statistics were calculated, such as percentages and means.

Further details of the adopted method and results can be found in Paper 2: "Measuring the Impact of Donations at the Bottom of the Pyramid (BoP) amid the COVID-19 Pandemic".

2.4 Case study

The case study method investigates a contemporary phenomenon within its real-life context (Yin, 2013). We adopt a six-step case study methodology proposed by Yin (2013): plan, project, preparation, data collection, analysis, and sharing.

Figure 6 illustrates the steps taken to develop the case study. The operation studied, research question, and propositions have already been discussed previously. However, we must emphasise that the focus is on a specific operation due to the need for a deeper understanding of the theme. Thus, the case study of this work is a unique case. Cauchick and Souza (2012) explain that the case study can be a single case - where it is expected that there is greater depth in the investigation and less generalisation capacity - or multiple cases - where there is a possibility of greater generalisation, but with less depth in the assessment of each case. We opt to study Operation Welcome as we were able to carry out field visit, have access to different stakeholders and data, and because it is an operation recognized by the United Nations as a successful model of humanitarian management (Brazil Report, 2022).

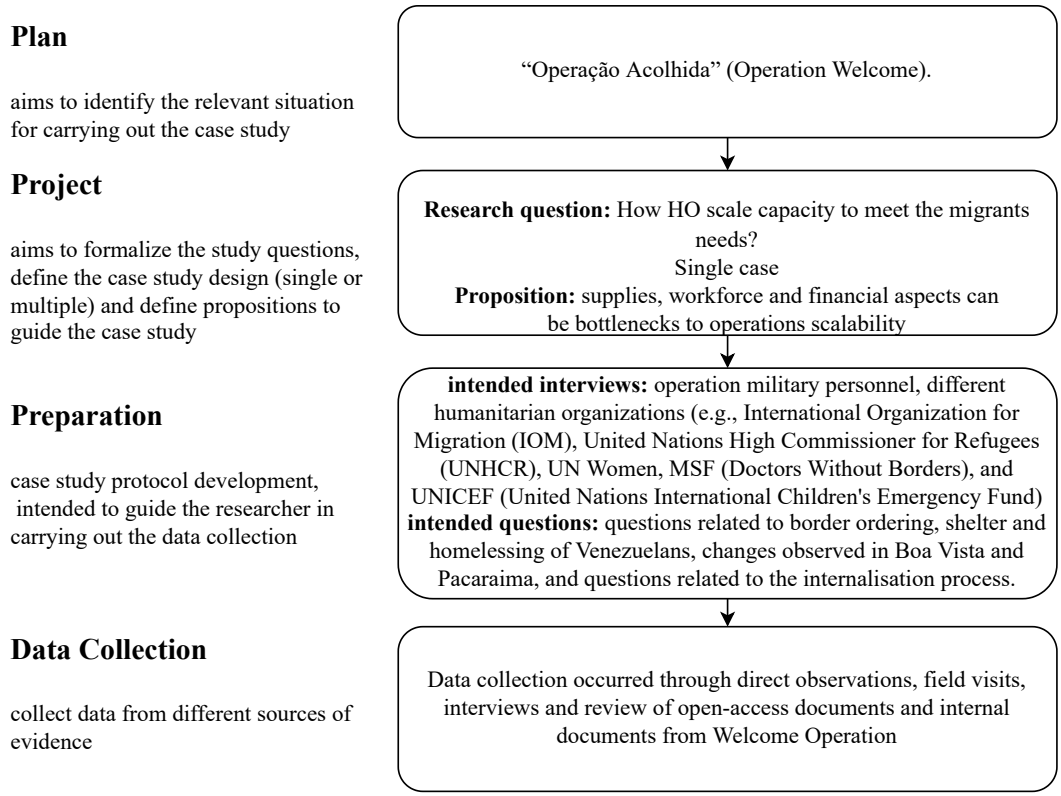


Figure 6 - Steps for Case Study development

In January 2020, field visits were carried out, including shelters located in Pacaraima city (close to the border) and Boa Vista city (capital of Roraima state), and military installations of Welcome Operation - e.g., interagency base, Reception and Support Desk (PRA), identification post (PRI), and internalisation and triage post (PI Trg)). Thus, direct observations gathered during interviews, and review of open-access documents and internal documents from Operation Welcome are the sources used to model the operation and getter data. Data triangulation is guaranteed through multiple means of data collection (Voss et al., 2002), increasing the robustness and validity of the case study.

Further details of the adopted method and data analysis and results can be found in Paper 3: "Challenges to scale migration-related Humanitarian Operations".

3
Looking back and beyond the complex dynamics of humanitarian operations

This chapter presents the Paper 1 (Cunha et al., 2022b), which was submitted to the Journal of Humanitarian Logistics and Supply Chain Management (JHLSCM). Emerald copyrights show that the first authors can use the paper in their thesis (Appendix 1).

3.1 Introduction

Disasters have increased yearly worldwide, causing human life losses, environmental damage, infrastructure disruption, and economic losses (Altay and Green, 2006; Behl and Dutta, 2019). Among the major disasters of the 21st century are the 2004 Indonesia tsunami, the 2005 Hurricane Katrina on the southern coast of the United States, the 2010 Haiti earthquake, and the ongoing COVID-19 pandemic. The September 11, 2001, terrorist attack on the United States migratory movement of Syrians, Venezuelans, and Afghans to other countries due to economic, social, and political crises are other examples of disasters of significant magnitudes.

The experiences with recent disasters have highlighted the need for additional guidance, structure, and support to improve the response to disaster-imposed challenges (Kim *et al.*, 2018). The support activities that help to minimise disaster impact, delivering required relief supplies to the affected area to the right people in the shortest possible time, propitiating people to get back to their everyday life, are known as Humanitarian Operations (HO) (Leiras *et al.*, 2014; Mishra *et al.*, 2019). Managing those activities performed before and after a disaster to prevent loss of human life and diminish its impact is known as Humanitarian Operations Management (HOM) (Altay and Green, 2006).

Therefore, the increasing number of people affected by disasters and the impact worldwide led to the development of an expansive aid industry (Fontainha *et al.*, 2022). In addition to drawing the attention of practitioners, HOM has turned

into an emergent area of interest for academics (Mishra *et al.*, 2019). The intriguing operations management (OM) context in which HO is inserted has attracted increased research in the past decade (Besiou and Van Wassenhove, 2021). HO involve multiple stakeholders with different objectives, interacting and exchanging information and resources, making the problem constantly dynamic. Besides, the location and timing of the next disaster are unknown, causing HO to have a high degree of uncertainty once stakeholders need to operate under scarce financial and time resources, making these operations dynamic and complex to manage (Besiou and Van Wassenhove, 2021).

Research in the HOM relies upon studying analytical tools, including simulation, optimisation, probability, and statistics, upon supporting decision-makers (Altay and Green, 2006; Behl and Dutta, 2019). One of the most recognised techniques in HOM is the simulation, by providing support for carrying out experiments in the real world, facilitating the understanding of physical processes, information flow, decision making, and helping to prepare humanitarian aid workers (Galindo and Batta, 2013; Mishra *et al.*, 2019).

The simulation of HO has evolved significantly over the past ten years (Mishra *et al.*, 2019). System Dynamics (SD) has been steadily used in modelling HO (Sopha and Asih, 2018; Besiou and Van Wassenhove, 2021), besides being the most predominant simulation technique in this context (Mishra *et al.*, 2019). The SD method represents problems through computer simulations, providing tools such as causal mapping and simulation modelling (Sterman, 2000). Several researchers have emphasised the excellent fit of the SD method for the HOM field (Gonçalves, 2008; Kunz *et al.*, 2014; Guo and Kapucu, 2019; Besiou and Van Wassenhove, 2021) in different applications such as handling *material* convergence (Patil *et al.*, 2021), evacuation planning (Ahmad and Simonovic, 2001; Simonovic and Ahmad, 2005; Favereau *et al.*, 2020), early warning systems (da Silva *et al.,* 2020), capacity building (Gonçalves, 2011), human resource allocation (Gonçalves, 2011; Sopha and Asih, 2018), the performance of humanitarian organisations (Anjomshoae *et al.*, 2017), relief supply allocation (Peng *et al.*, 2014a; Peng *et al.*, 2014b; Rao and Xie, 2014; Xu *et al.*, 2016), facility restoration (Hwang *et al.*, 2015; 2016), vehicle fleet management (Besiou *et al.*, 2011; Besiou *et al.*, 2014), and inventory pre-positioning (Kunz *et al.*, 2014).

Thus, considering the progress of using SD simulation modelling in the HO context, the present paper aims to analyse the SD simulation as a research method for improving HOM by answering two research questions: (i) Which topics in HOM drive SD simulation modelling research? (ii) What are the existing gaps and opportunities in SD application in HO extant literature? Therefore, we adopt the systematic literature review (SLR) methodology to answer these questions.

The SLR provides a rigorous and well-defined approach to review the available literature on HO and HOM fields. Critical analysis and synthesis provide structured foundations to understand and generate discussions about the subject. We deliver three SLR possible outcomes proposed by Torraco (2005) - a taxonomy, a framework, and a research agenda. The taxonomy classifies the extant literature according to subjects/topics from pre-and post-disaster stages. The conceptual framework, illustrated through a CLD, synthesises the literature based on critical assessment. CLDs consist of variables connected by arrows denoting the causal influences among the variables (Sterman, 2000). The research agenda builds upon the clusters highlighted by Behl and Dutta (2019) to pose new research propositions (Torraco, 2005). Therefore, this paper contribution relies on the systematic representation of the relations involved in the complex context of HOM.

After this introductory section, Section 2 presents the research methodology. Section 3 describes the academic literature analysis and findings through a subsection of publications overview (looking back into the publications) and a subsection connecting the issues mapped through a CLD. Section 4 presents a research agenda (looking beyond the publications). Finally, Section 5 highlights the conclusions.

3.2 Methodology

We use the SLR methodology to select and analyse the extant literature that adopts SD in HOM field studies, map the topics studied (taxonomy), summarise the research in a CLD, and develop a research agenda according to Behl and Dutta (2019) classification of Disaster and Humanitarian related papers. A literature review is crucial for mapping and analysing the literature and identifying potential research gaps to expand further the knowledge base (Tranfield *et al.*, 2003). Therefore, the research adopts the eight-step proposed by Thomé *et al.* (2016) to

conduct the SLR: (i) research problem formulation; (ii) literature search; (iii) data collection; (iv) quality assessment; (v) data analysis and synthesis; (vi) interpretation; (vii) presentation of results; and (viii) updating of the review.

The Scopus and Web of Science databases were selected in the literature search due to the more significant number of indexed journals, according to Mongeon and Paul-Hus (2016). The research considered three groups of keywords defined broadly enough to avoid artificial limitations on the desired documents but still capable of excluding undesirable results (Petticrew and Roberts, 2008):

- The first group of keywords addresses the method of “system dynamics”.
- The second group of keywords encompasses HOM terminologies such as "operations", "logistics", "management", and "supply chain".
- The third group includes keywords such as “disaster*”, “relief”, and “humanitar*” from previous papers such as Leiras *et al.* (2014) and Fontainha *et al.* (2017) and specific disasters listed by the International Federation of Red Cross and Red Crescent Societies (IFRC) and Emergency Events Database (EM-DAT).

We searched for titles, abstracts, and keywords in Scopus and topics in Web of Science databases in May 2022, resulting in 1002 documents from the Scopus database and 631 documents from the Web of Science database, without initial exclusions. We developed a conceptual matrix in an Excel spreadsheet with data from the 1633 documents. Then, manually we removed 425 documents duplicated in the Web of Science and Scopus databases.

We adopted inclusion and exclusion criteria for abstracts and full paper reading. The inclusions criteria are: (i) research on major disasters; (ii) research on the HO field; and (iii) adoption of SD modelling. The first inclusion criteria consider the analysis of papers encompassing disasters. There is a marked space between what is termed “routine emergencies” or “everyday emergencies” – as building construction disasters, cities power consumption, and urban conservation emergencies - and more severe emergencies, disasters, and catastrophes (Altay and Green, 2006). In this paper, we consider only disasters, discarding research on urban problems or routine issues of a specific region, for example. The second inclusion criteria consider studies about a particular disaster and humanitarian aid, operations management, logistics, or supply chains involved in the subject. The third inclusion

criteria consider only papers that adopt SD or SD coupled with other techniques for a full reading and analysis of the articles. Therefore, papers that mention SD and encourage the use of the method, but that SD is not the central methodology were not selected. As exclusion criteria, we consider (i) research on routine problems; (ii) ecosystem (fauna and flora) disruptions; (iii) documents not available; (iv) proceedings and books.

The full reading of the previously selected abstracts resulted in a selection of 80 papers. After the document selection through databases search, we also conducted a snowball search. The method is characterised by the reference analysis of the selected articles, aiming to increase the coverage of documents to be analysed. Figure 7 summarises the steps in this section using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) diagram, as proposed by Moher *et al.* (2009).

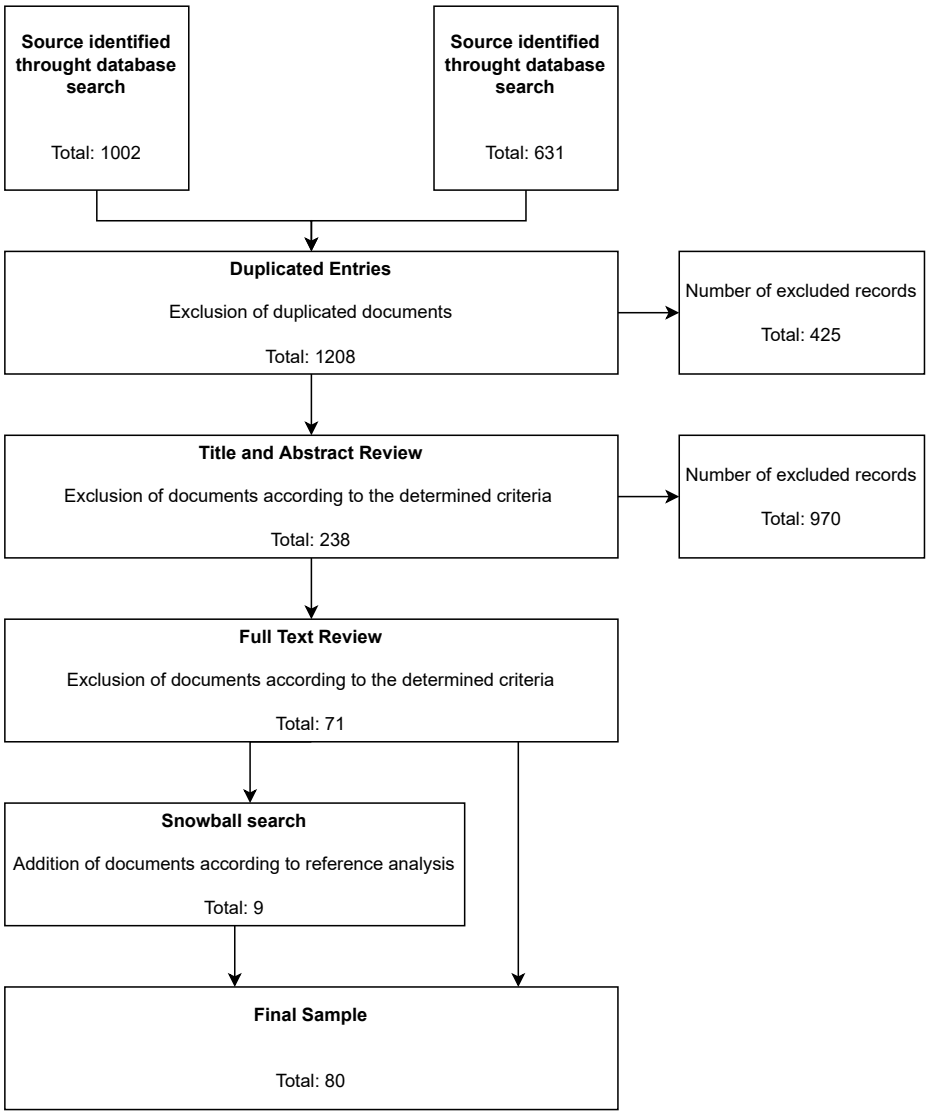


Figure 7 - Flow of information through systematic review phases

For data collection of the 80 papers, we also developed a conceptual matrix in Excel spreadsheet (Vom Brocke *et al.*, 2009) containing the documents in the lines and the columns the title, abstract, publication year, keywords, and references as well as a space for categorising the works according to the application to the research to be developed. Creating a standard data collection procedure allows full traceability and replicability of content related to each search step. The data analysis consists of a bibliometric study to set basic statistics and was carried out through the *bibliometrix* library: an R-tool for comprehensive science mapping analysis. Sections 3 and 4 present the data analysis, synthesis, and interpretation, providing a taxonomy table, a framework (CLD), and a research agenda. The CLD is carried

out through the Vensim software, a simulation software to improve real systems' performance and provide causal tracing of structure and behaviour. The discussion of the results provides the interpretation of the results.

3.3 Results

This section encompasses the SLR results.

3.3.1 Publications' overview

When analysing the sample of papers, we noticed some trends. The first paper appeared in 2001, with research publications spikes in 2008, 2015, 2018, and 2020, reflecting the continuous publication trend of papers adopting SD in HO.

The papers are published in different journals and conferences. The most relevant publication channels are the Journal of Humanitarian Logistics and Supply Chain Management (JHLSCM), Production and Operations Management, International Journal of Disaster Risk Reduction (IJDRR), Annals of Operations Research (ANOR), and Natural Hazards with 7, 5, 4, 3, and 3 publications each, respectively. Journals in different areas also cover the topic, such as the Journal of Construction Engineering and Management, Behavioral Science, and Production Economics, characterising the theme as multidisciplinary.

We can highlight Luk Van Wassenhove and Maria Besiou being the authors with more publications related to the theme, as first authors or co-authors. The three most cited papers encompass completely different HO topics. Simonovic and Ahmad (2005) research brings light to an SD model for capturing human behaviour – acceptance of evacuation orders by the area's residents under threat – during flood disaster evacuation. In turn, Kunz *et al.* (2014) research the trade-off between investing in disaster management capabilities – such as training staff, pre-negotiating customs agreements with countries prone to disasters, or harmonising import procedures with local customs clearance procedures and pre-positioning inventory. Besiou *et al.* (2011) illustrate the appropriateness of SD methodology as a tool for humanitarian decision-makers to understand the effect of their decisions on HO.

Table 1 summarises how SD has been used based on the previous analysis of Besiou and Van Wassenhove (2021). Most papers (61%) present conceptual models

or frameworks to explain the research problem or summarise the findings. 70% present CLD, while 76% present SFD or simulations results. Regarding the data type used, from the papers that adopt an SFD, two papers do not present data and perform simulations (indicating as a future study), 64% use real data, considering focus group discussions, cases studies, and semi-structured interviews, whereas 33% consider hypothetical data.

Table 1 - SD usage in publications

References	Conceptual model	CLD	SFD or simulation result	Real data	Hypothetical data
Ager *et al.* (2015)		X			
Ahmad and Simonovic (2001)	X		X	X	
Allahi *et al.* (2018)		X	X		
Allahi *et al.* (2020)		X	X	X	
Allahi *et al.* (2021)	X	X	X	X	
Anagnostou *et al.* (2016)		X	X	X	
Anjomshoae *et al.* (2017)	X	X			
Arboleda *et al.* (2007)		X	X	X	
Armenia et al. (2018)		X	X		X
Babaei and Shahanaghi (2018)	X				
Berariu *et al.* (2016a)		X	X	X	
Berariu *et al.* (2016b)		X	X	X	
Besiou and Van Wassenhove (2021)	X				
Besiou *et al.* (2011)	X	X	X	X	
Besiou *et al.* (2014)		X	X	X	
Cohen *et al.* (2013)	X		X		X
Cruz-Cantillo (2014)	X	X	X	X	
Cunha *et al.* (2021)		X			
Cunha *et al.* (2022)	X	X	X	X	
da Silva *et al.* (2020)	X	X			
Diaz *et al.* (2015)			X		X
Diaz *et al.* (2019)			X	X	
Diedrichs *et al.* (2016)	X		X		X
Favereau *et al.* (2020)	X	X	X	X	
Feofilovs *et al.* (2020)	X	X			
Gillespie *et al.* (2004)		X	X		
Gonçalves (2008)		X	X		X
Gonçalves (2011)		X	X		X
Gonçalves *et al.* (2022)	X		X	X	
Gotangco *et al.* (2014)			X		X
Guo and Kapucu (2019)	X	X	X		X
Guzmán Cortés *et al.* (2019)	X	X	X		X
Han *et al.* (2008)	X	X	X		X
Harpring *et al.* (2021)	X	X			
Heaslip *et al.* (2012)	X	X			
Hernantes *et al.* (2013)	X	X	X	X	
Hiltz *et al.* (2013)	X	X			
Hwang *et al.* (2015)	X	X	X	X	
Hwang *et al.* (2016)	X	X	X	X	
Khanmohammadi *et al.* (2018)		X	X		X
Kim *et al.* (2018)	X		X	X	X

Kosmas *et al.* (2022)	X	X	X	X	
Kumar *et al.* (2015)			X		X
Kunz *et al.* (2014)	X		X	X	
Kwesi-Buor *et al.* (2019)	X	X	X	X	
Lawrence *et al.* (2022)	X		X		
Li *et al.* (2019)		X	X	X	
Min and Hong (2011)		X	X		X
Mishra and Sharma (2020)		X	X	X	
Mishra *et al.* (2019)					
Ni *et al.* (2015)	X	X	X		X
Obaze (2019)	X	X			
Patil *et al.* (2021)	X	X	X	X	
Peng *et al.* (2014a)	X	X	X		X
Peng *et al.* (2014b)	X	X	X	X	
Perrone *et al.* (2020)	X	X			
Powell *et al.* (2016)	X	X			
Powell *et al.* (2018)	X	X			
Pujadi (2017)	X				
Qiu *et al.* (2021)	X	X	X		X
Ramezankhani and Najafiyazdi (2008)		X	X	X	
Rao and Xie (2014)	X		X	X	
Santella *et al.* (2009)			X		X
Shi *et al.* (2021)			X		X
Simonovic and Ahmad (2005)	X	X	X	X	
Song *et al.* (2018)	X	X	X	X	
Sopha and Asih (2018)		X	X	X	
Stewart and Ivanov (2019)	X		X	X	
Su and Jin (2008)		X	X	X	
Suarez (2015)	X				
Uddin *et al.* (2018)	X				
Van Oorschot *et al.* (2022)			X	X	
Van Wassenhove and Besiou (2013)	X				
Voyer *et al.* (2015)		X	X	X	
Voyer *et al.* (2016)		X	X		X
Wang *et al.* (2012)	X	X	X	X	
Wu *et al.* (2015)			X	X	
Xu *et al.* (2015)	X	X	X	X	
Xu *et al.* (2016)	X	X	X	X	
Zhong (2018)	X	X	X	X	

3.3.2 Mapped relations

For developing a framework (CLD), we considered the perspective of a disaster life cycle composed of pre-event (mitigation and preparedness) and post-event stages (response and recovery) (Altay and Green, 2006; Hernantes *et al.*, 2013), as summarised in the figures of this section.

3.3.2.1 Pre-disaster stage

Table 2 summarises the variables selected according to specific topics covered in the pre-disaster literature: population behaviour, Early Warning Systems (EWS), evacuation planning, and preparedness.

Table 2 - Subjects, references, and variables addressed at the pre-disaster stage

Subjects/topics covered in the literature	**Reference**	**CLD variables**
Evacuation planning and process	Ahmad and Simonovic (2001); Simonovic and Ahmad (2005); Cruz-Cantillo (2014); Pujadi (2017); Da Silva *et al.* (2020); Favereau *et al.* (2020); Shi *et al.* (2021); Kosmas *et al.* (2022)	Evacuation process; acceptance (evacuation decision); evacuation resistance; true alerts; false alerts; system performance; alerts effectiveness; emission of more moderate alerts
Population behaviour	Ahmad and Simonovic (2001); Gillespie *et al.* (2004); Simonovic and Ahmad (2005); Powell *et al.* (2016); Pujadi (2017); Favereau *et al.* (2020)	Concern rate; awareness/ knowledge; danger recognition; perceived need to be prepared; acceptance (evacuation decision); evacuation resistance knowledge of population routes/places.
Preparedness	Gillespie *et al.* (2004); Gotangco *et al.* (2014); Kunz *et al.* (2014); Anagnostou *et al.* (2016); Berariu *et al.* (2016a); Powell *et al.* (2016); Kwesi-Buor *et al.* (2019); Kosmas *et al.* (2022)	training and education; preparedness

The main topics presented in Table 2 serve as the basis for the development of Figure 8.

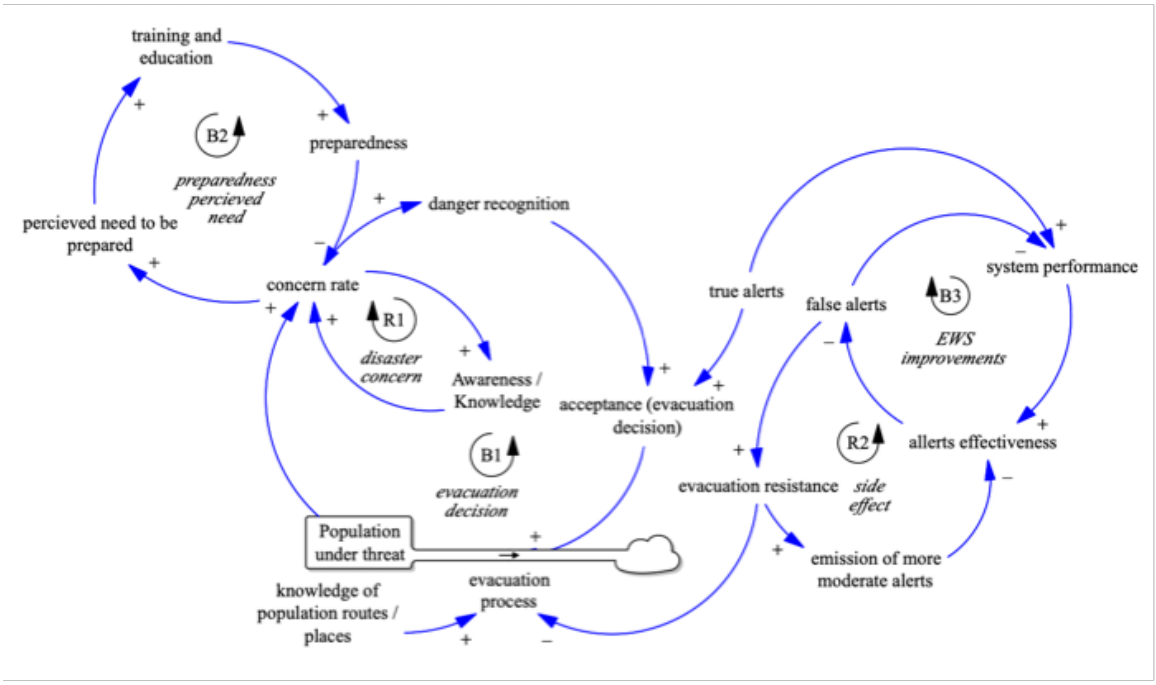


Figure 8 - Pre-Disaster population behaviour

Once a population is under threat of a disaster, the concern rate and danger recognition regarding the consequences of the possible disaster cause the people to accept the decision to evacuate if a disaster strikes. This population movement is represented through the Balancing loop B1 (evacuation decision). The Reinforcing loop R1 (disaster concern) shows that the more the population knows about a particular disaster and its consequences, the greater its concern rate. The Balancing loop B2 (preparedness perceived need) demonstrates that the population needs to prepare for a possible disaster once the population is concerned. For this, training and education are essential. Figure 8 shows that the decision to evacuate a region under threat is based on alerts (EWS). The reinforcing loop R2 (side effect) demonstrates that the decision to evacuate would suffer resistance if false alarms occur. Academics and practitioners discuss the effect of false alerts being the "Cry Wolf Syndrome", one effect which people tend to become less likely to evacuate after the frequent occurrence of false alerts (da Silva *et al.*, 2020). Finally, the Balancing loop B3 (EWS improvements) shows the system's performance to prevent false alarms and affect the decision to evacuate the population.

3.3.2.2 Post-disaster stage

After identifying pre-disaster relationships, Table 3 indicates topics addressed at the post-disaster stage.

Table 3 - Subjects, references, and variables addressed at the post-disaster stage

Subjects/topics covered in the literature	Reference	CLD variables
Capacity building	Gonçalves (2008); Gonçalves (2011); Besiou *et al.* (2011); Sopha and Asih (2018); Harpring *et al.* (2021)	Hum.Organisations Capacity; effort for capacity building; capacity erosion; capacity building allocated resources; pressure to build capacity; GAP in people receiving relief/recovery; knowledge gained/lessons learned
Relief and recovery operation	Ramezankhani and Najafiyazdi (2008); Gonçalves (2008); Gonçalves (2011); Besiou *et al.* (2011); Voyer *et al.* (2015); Obaze (2019); Harpring *et al.* (2021);	GAP in people receiving relief/recovery; pressure to provide relief/recovery; relief/recovery allocated resources; relief/recovery operations; required resources and services for relief/recovery operations
Productivity (performance management)	Sopha and Asih (2018); Anjomshoae *et al.* (2017); Obaze (2019); Stewart and Ivanov (2019)	Productivity; desired productivity;
Media coverage	Besiou *et al.* (2011); Cruz-Cantillo (2014); Gontangco *et al.* (2014); Anjomshoae *et al.* (2017); Perrone *et al.* (2020); Kosmas *et al.* (2022)	Media coverage
Funding	Besiou *et al.* (2011); Cruz-Cantillo (2014); Gontangco *et al.* (2014); Ni *et al.* (2015); Voyer *et al.* (2015); Anjomshoae *et al.* (2017); Allahi *et al.* (2018); Guzmán Cortés *et al.* (2019); Obaze (2019); Allahi *et al.* (2020); Patil *et al.* (2021); Cunha *et al.* (2022); Lawrence *et al.* (2022)	External funding; local/regional funding; donations; unsolicited donations
Collaboration and Coordination	Heaslip *et al.* (2012); Anjomshoae *et al.* (2017); Obaze (2019)	hum. organisations reputation; collaboration and coordination with partners

Infrastructure damage	Ramezankhani and Najafiyazdi (2008); Harpring *et al.* (2011); Peng *et al.* (2014a); Peng *et al.* (2014b); Ni *et al.* (2015); Voyer *et al.* (2015); Song *et al.* (2018); Guo and Kapuco (2019); Guzmán Cortés *et al.* (2019); Feofilovs *et al.* (2020); Perrone *et al.* (2020); Lawrence *et al.* (2022)	disaster magnitude; damage to infrastructure
Services Demand	Diaz *et al.* (2015), Diaz *et al.* (2019), and Kumar *et al.* (2015), Kim *et al.* (2018); Hernantes *et al.* (2013), Powell *et al.* (2016), and Armenia *et al.* (2018); Suarez (2015), Hiltz *et al.* (2013), Diedrichs *et al.* (2016), Han *et al.* (2008), and Zhong (2018); Ager *et al.* (2015), Arboleda *et al.* (2007), Babaei and Shahanaghi (2018), Su and Jin (2008), Khanmohammadi *et al.* (2018), Powell *et al.* (2018), Li *et al.* (2019), Xu *et al.* (2015), and Voyer *et al.* (2016). Hwang *et al.* (2015) and Hwang *et al.* (2016); Lawrence *et al.* (2022)	demand for services
Logistics capacity	Rao and Xie (2014); Peng *et al.* (2014a); Peng *et al.* (2014b); Xu *et al.* (2016); Guo and Kapucu (2019); Lawrence *et al.* (2022)	logistics capacity
Fleet management	Besiou *et al.* (2011); Rao and Xie (2014); Besiou *et al.* (2014); Peng *et al.* (2014); Peng *et al.* (2014b); Wu *et al.* (2015); Voyer *et al.* (2015); Xu *et al.* (2016); Berariu *et al.* (2016b); Guo and Kapucu (2019); Lawrence *et al.* (2022)	vehicle/truck availability; ship availability; transport time; drivers availability
Resource allocation/distribution	Besiou *et al.* (2011); Min and Hong (2011); Peng *et al.* (2014a); Peng *et al.* (2014b); Kunz *et al.*	need for resource replenishment; resource shipments; resource in transit

	(2014); Rao and Xie (2014); Ni *et al.* (2015); Xu *et al.* (2016); Guo and Kapucu (2019); Berariu *et al.* (2016b)	

The subjects presented in Table 3 serve as the basis for the development of Figure 9, which visually exhibits the interactions of the main variables identified in each topic.

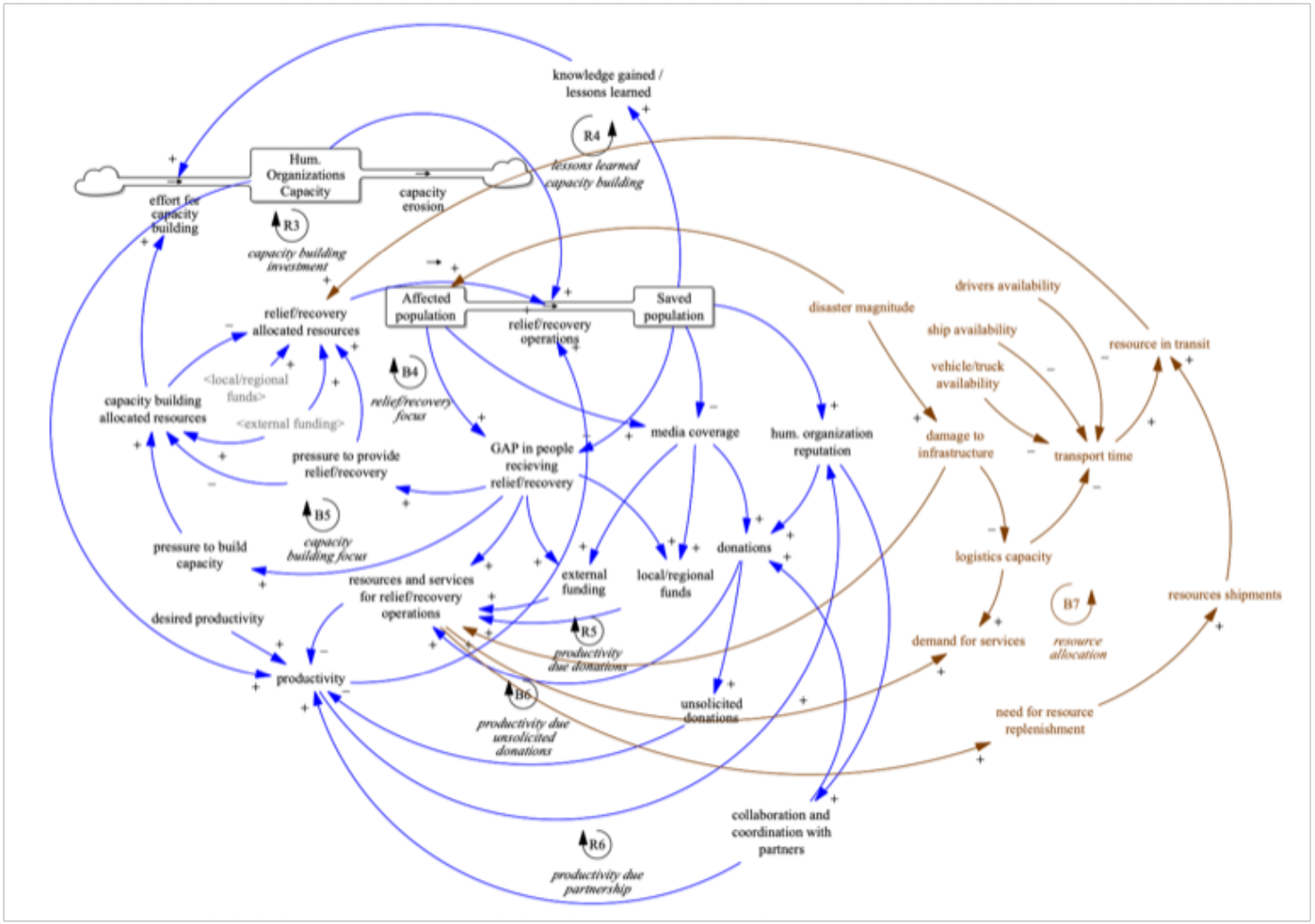


Figure 9 - Post-disaster relief and recovery needs

What we previously called the under-threat population is now the affected population once the disaster strike. Balancing loop B4 (relief/recovery focus) demonstrates that the greater the number of people in need of help (GAP in people receiving relief/recovery), the greater the pressure to provide aid by allocating resources for relief/recovery. Local and external investments are needed for relief/recovery operations. Thus, the balancing loop B5 (capacity building focus) demonstrates that the greater the number of people needing help, the greater the pressure to support humanitarian organisations in relief and recovery operations.

Figure 9 also represents humanitarian organisations through their capacity building (e.g., hiring and training people, capturing lessons learned, structuring organisational processes), as defined by the Reinforcing loop R3 (capacity building investment) and Reinforcing loop R4 (lessons learned capacity building).

Three other loops in Figure 9 are related to performance management: productivity of the relief and recovery operation after a disaster. Therefore, we present the reinforcing loop R5, referring to productivity due to donations, and the balancing loop B6, referring to productivity once unsolicited donations are received. Finally, the reinforcing loop R6 refers to productivity due to collaboration and coordination of tasks with partners.

Table 3 and Figure 9 also present infrastructure repair topics found in the analysed papers. According to the damage caused by a disaster, there will be a need for repairs in terms of infrastructure and services. Therefore, the Balancing loop B7 (resource allocation) adds the resource distribution chain for relief and recovery operations to the diagram.

Demand for services variable, including water, energy, housing, mobility, education, and health services. Several articles deal with this variable, enabling a deeper study of the topic. Diaz *et al.* (2015; 2019), Kumar *et al.* (2015), and Lawrence *et al.* (2022), for example, address housing recovery. Kim *et al.* (2018) and Ramezankhani and Najafiyazdi (2008) research about debris management. Hernantes *et al.* (2013), Powell *et al.* (2016), and Armenia *et al.* (2018) deal with power company/energy services. Suarez (2015), Hiltz *et al.* (2013), Diedrichs *et al.* (2016), Han *et al.* (2008), and Zhong (2018) use the SD method to study information and communication services. Various studies also encompass the health care services, e.g., Ager *et al.* (2015), Arboleda *et al.* (2007), Babaei and Shahanaghi (2018), Su and Jin (2008), Khanmohammadi *et al.* (2018), Powell *et al.* (2018), Li *et al.* (2019), Xu *et al.* (2015), and Voyer *et al.* (2016). Hwang *et al.* (2015, 2016) cover the shortages of facility services, in general, including residential, commercial, and

industrial facilities. Also, some authors deal with the interactions between more than one service sector (e.g., information and communication services, power company/energy services, health care services), e.g., Santella *et al.* (2009), Hernantes *et al.* (2013), and Song *et al.* (2018).

Min and Hong (2011) bring the transport delay and delay between placing the order and receiving the order to the discussion. Peng *et al.* (2014a; 2014b), in turn, focus on information delay about the arrival of resources in the storage of the affected city.

Figure 9 also highlights a recurrent issue among the papers: the fleet management used in relief operations. Berariu *et al.* (2016b), Besiou *et al.* (2011), and Besiou *et al.* (2014) approach the theme bringing relations such as the desired number of vehicles to respond to a disaster according to the capacity of transport of these vehicles and the delays expected due to road conditions; use of financial donations for rental vehicles to be used during operations of disaster response; the stock of vehicles in response to a disaster also being formed by the use of vehicles from neighbouring countries to the country affected by the disaster. Similarly, considering another means of transport, Cohen *et al.* (2013), Anagnostou *et al.* (2016), Kwesi-Buor *et al.* (2019), and Lawrence *et al.* (2022) focus on the logistics required in the port environment and marine logistics in the event of disasters and the delivery of humanitarian aid through maritime support.

3.3.2.3 Pre- and post-disaster stage

Finally, the relationship between the pre-and post-disaster stages variables occurs through the need to allocate resources for disaster prevention and preparedness, encompassing resources for education and training of the population, development, and improvement of EWS (Figure 10).

The preparedness for the occurrence of a disaster encompasses the activities that can be performed by the population, the government, and humanitarian organisations before a disaster, aiming to decrease its adverse effects (Van Wassenhove, 2006; Kunz *et al.*, 2014). Preparing for a disruption propitiates the humanitarian community to react faster, changing the supply chain design at a moment's notice to avoid bottlenecks, closed conflict borders, or lack of donor funds (Stewart and Ivanov, 2019).

Part of the resources collected by a humanitarian organisation, for example, can be destined for the preparedness of a community. However, donors usually finance response efforts once a disaster strikes, not considering the importance of preparing for the event of a disaster (Kunz *et al.*, 2014; Ni *et al.*, 2015). In this sense, Gotangco *et al.* (2014) allege that local government should spend their funds on initiatives that help decrease the local

vulnerability before the occurrence of a disaster. Feofilovs *et al.* (2020) also corroborate by adding the "investment disaster risk reduction" variable in the CLD.

The need for improved EWS is highlighted by da Silva *et al.* (2020) as an essential tool to reduce the risk associated with disasters and save lives. Ahmad and Simonovic (2001) corroborate this finding by stating that the evacuation is more likely to occur if the potential victim is ordered to do so, the proper authority directly contacts the potential victim, and if past warnings proved accurate. Therefore, if the public views the warnings as ineffective, there is likely little incentive for political and budgetary support for the EWS. Thus, da Silva *et al.* (2020) evidence the budgetary need for effective EWS and population clarifications.

Kunz *et al.* (2014) and Ni *et al.* (2015) discuss inventory pre-positioning aiming to reduce the transport time of resources to the affected area – pre-positioning of relief supplies is the most well-known form of disaster preparation policy suggested in the literature, requiring high investment, and holding cost.

In addition to the evacuation process as a pre-disaster measure, as shown in Figure 10, papers discuss the topic of evacuation after the disaster occurrence (Berariu *et al.*, 2016a; Uddin *et al.*, 2018; Allahi *et al.*, 2021). Cruz-Cantillo (2014) shows that the decision to evacuate the area can occur before, during or after a disaster. Powell *et al.* (2016) mention the location of shelters as preparedness for an evacuation activity during disasters. The need for temporary shelters for the reception of the evacuated population and the migration process resulting from the loss of homes, jobs, and wages are also covered (Uddin *et al.*, 2018).

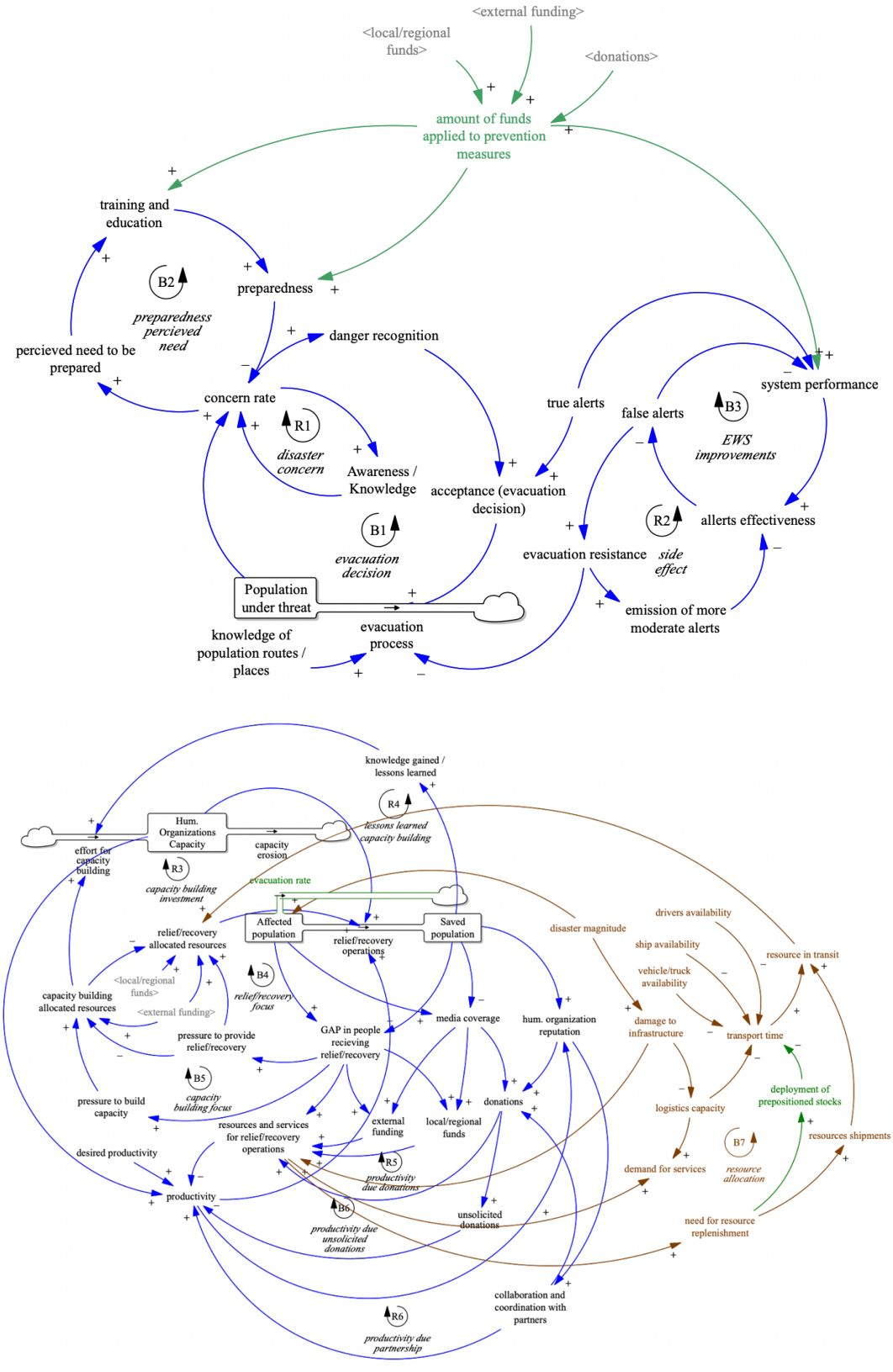


Figure 10 - Pre- and Post-Disaster humanitarian operations CLD

3.4 Discussion and research agenda

This section discusses the topics raised in the review and suggests future research on the complex dynamics of HO and HOM. From the sample of 80 papers, 12 research presents CLD and explains major relationships. Such papers typically suggest developing an SFD model for future research. Other 44 papers present both CLD and SFD models but mention limitations and suggest model improvements for future research. In those cases, researchers commonly suggest applying the models to other cases to enhance generalizability and result comparability.

Delays and their representations are a key concern in model development. Kumar *et al.* (2015) mention the importance of the awareness of delays and the flexibility in the work schedule in the policy design. Berariu *et al.* (2016b) and Besiou *et al.* (2011, 2014) focus on the delays expected due to infrastructure damages at the post-disaster stage. Gonçalves (2011) mentions human resource hiring and personnel training delays as a challenge for humanitarian organisations to scale up their operations. The need to study the scalability of operations is also a gap in the literature. Powell (2016) observe that their risk identification and assessment flood preparedness example was compact and limited, but the methods are scalable to more extensive systems (e.g., large-scale floods).

To deepen our analysis, we consider Behl and Dutta (2019) clustering of Disaster and Humanitarian related papers to identify gaps in the use of SD: (i) HSC-based review papers; (ii) Studies related to theoretical approach and case study in HSCM; (iii) Classification of HSC with respect to phases of disaster; (iv) Studies related to Humanitarian Logistics; (v) Performance Evaluation of HSCM; (vi) Resilience based HSCM studies; (vii) IT-related HSCM studies; (viii) Big Data Analytics in HSCM.

Of note, the topics addressed for the development of the CLD are related to HO (central research theme) and the concepts inserted in these operations used in the SLR search (operations, logistics, management, and supply chain). Therefore, the topics raised in this research are found within Behl and Dutta (2019) cluster (iv) Studies related to Humanitarian Logistics.

Two other groups proposed by Behl and Dutta (2019) do not fit our discussion: (ix) Transcendental shift from Disaster and Relief Management to

HSCM; (x) Discussion of Mathematical Models. Since our focus is not on the shift to HSCM over time, we consider all papers encompassing disaster-related topics in our research, regardless of the terminology used. Besides, once we study papers in SD, the mathematical modelling they present is in developing their models.

Three of the articles in our sample are review papers, Mishra *et al.* (2019), Cunha *et al.* (2021), and Besiou and Van Wassenhove (2021), fitting into the cluster "HSC-based review papers". Cunha *et al.* (2021) literature review analyses the influence of disasters on migratory movements. Besiou and Van Wassenhove (2021) review the extant literature of the JHLSCM journal using SD in HO. Mishra *et al.* (2019) review the application of simulation techniques (e.g., Monte Carlo simulation, discrete-event simulation, agent-based simulation, and system dynamics) in disaster management literature. Those reviews provide policy lessons, and implications learned from past recovery cases that can inform policy design in future disasters. Despite such insights, the reviews fail to distil the characteristics that render specific policies adequate during different disasters. Therefore, research that synthesises the best policies in different contexts remains an opportunity.

Other articles develop case studies, fitting into the cluster “studies related to theoretical approach and case study in HSCM”. Table 1 distinguishes case study papers regarding the type of data (e.g., real or hypothetical) utilised. Despite the number of case study papers, only a few develop multi-case research. Multi-case studies engaging in cross-case analyses lead to more generalisable insights and are essential for developing and adjusting CLD and SFD. The loops presented in those CLDs and SFD should be used by decision-makers considering sudden-onset, slow-onset, climate-related, or man-made disasters. For example, in the case of floods, evacuation decisions (Figure 10, loop B1) and EWS (Figure 10, loop B3) for the population to evacuate from risk areas are extremely important for lives to be saved. While considering a migratory movement due to a political crisis, the evacuation decision can come from different factors. Still, it starts from a concerning rate and arrives at the evacuation decision (Figure 10, loop B1). EWS, in this example, is not applicable since there will be no warning, but the need to migrate will come from the population.

The distinction between disaster phases is evident among the papers, directing us to develop a CLD with pre-and post-disaster distinction, fitting into the cluster “Classification of HSC with respect to phases of disaster”. Berariu *et al.* (2016a,

2016b) research, for example, considers flood response. Diaz *et al.* (2015; 2019) consider housing recovery after a catastrophe. Hwang *et al.* (2015) research facility restoration after a disaster. In contrast to these articles, da Silva *et al.* (2020) research EWS, Ahmad and Simonovic (2001) and Simonovic and Ahmad (2005) discuss human behaviour and evacuation planning before a disaster occurrence. Therefore, a summary of different disasters and their phases, considerations, consequences, policies, and implications for a general CLD is an opportunity for future research. Besides, although the distinction between pre-and post-disaster is evident in the sample, little is said about the intersection between pre-and post-disaster stages. Therefore, for future research, we propose the deepening of subjects that permeate disaster preparedness.

According to Behl and Dutta (2019), humanitarian logistics studies have most importantly discussed inventory management, procurement, transportation, warehousing, distribution, agility, sustainability-related studies, stakeholder, and coordination-related studies. Despite the range of topics this cluster covers, plenty of research opportunities remain. Lawrence *et al.* (2022) raise the research opportunity to address the logistical challenges at the nodes legs of the supply chain connections and the need to be synchronised to ensure an efficient, agile and continuous flow of materials in and out of the disaster zone. Santella *et al.* (2009), Uddin *et al.* (2018), and Allahi *et al.* (2021) bring to light the research opportunities related to disaster-affected population migration and the management of shelters used by the displaced population in catastrophic events. Allahi *et al.* (2021) show that the lack of support from HO in refugee crises can seriously impact migrants' health and education. Uddin *et al.* (2018) believe their research can be used as the base for designing future research to understand shelter dynamics and their effective contribution to disaster emergency response. Kosmas *et al.* (2022) is the first paper to apply SD in Search and Rescue (SAR) operations linked to Migration by Sea (MBS). SAR literature has primarily focused on asset allocation and positioning. Existing studies have examined different types of assets deployed for SAR activities or stations' locations for efficient operations. However, in our study, little was found on the subject. Considering MBS, there is plenty of opportunity for researchers: the arrival and disembarkation process at ports, the onward migration journeys, the return migrants' journey to their country of embarkation, humanitarian organisations (at sea and on land) role in short-and long-term actions.

Besides, the work of humanitarian organisations frequently involves the simultaneous implementation of development and disaster response programs (Van Wassenhove and Besiou, 2013). However, the great immensity of works is related to sudden-onset disasters (e.g., earthquakes, floods, hurricanes), presenting few papers referring to slow-onset disasters (e.g., famine, poverty, refugee crises) and, consequently, development programs, corroborating with Besiou *et al.* (2021) statement that development-aid supply chains literature is scarce. Still, in this context, another opportunity for future studies is the dependency generated once humanitarian organisations offer aid. Gonçalves (2011) points out that disaster relief may unintendedly lead to dependency. For example, Sodhi and Knuckles (2021) conducted a field study concluding that funding, although crucial for reducing deprivation in the short term, may increase the dependence on humanitarian aid rather than reduce it. The dependency theme is also closely related to the sustainability of operations, as long-term development programs require cost-efficient procurement, which may make sustainable interventions difficult (Besiou *et al.*, 2021). Some research investigating the impact of material convergence (i.e., unsolicited donations) also touches upon the issue of sustainability in HO. Nevertheless, still, there is ample opportunity for further research focusing on sustainability, such as the close relationship between HO and the United Nations Sustainable Development Goals (SDG) (Besiou *et al.*, 2021), reverse logistics of unused medical resources, fleet, generators, containers, and equipment necessary for the relief/recovery operation.

Regarding the cluster "Resilience-based HSCM studies", the community's resilience and the authorities' efforts in managing disasters before and after a disaster strike will dictate the severity of the damages (Diaz *et al.*, 2015). Anagnostou *et al.* (2016) employ SD modelling to analyse the behaviour of the interactions between Disaster Preparedness, Environment Instability, and Resilience in a logistics/supply chain network. Relationships such as "the more prepared, the more resilient" and "increased disaster awareness and preparedness, increased resilience" are demonstrated. Ager *et al.* (2015) cover the resilience of health systems, while Feofilovs *et al.* (2020) focus on community resilience against floods. Gotangco *et al.* (2014) integrate physical, social, economic, and organisational sectors into a system resilience model that can serve as government decision support tools. Harpring *et al.* (2021) advocate that supply chain resilience

is directly affected by the quality of infrastructure prior to a disaster. Therefore, the resilience theme appears in the sample of articles.

Several papers investigate the productivity and performance of HO, as well as performance evaluation topics, fitting into the cluster “Performance Evaluation of HSCM”. Once SD simulation relies on performance guiding policies and can be used for evaluating the performance of various systems (Mishra *et al.*, 2019), we can highlight research examples - such as Peng *et al.* (2014b) that compared the system performance of eight scenarios based on different assumptions (e.g., delay, demand forecasting, information sharing, inventory planning strategies, and transport), and Heaslip *et al.* (2012) that focus in procedures to increase the performance of the cooperation between stakeholders. Still, studies indicate disaster management performance and measurement as a research gap (da Silva *et al.*, 2020). Without measuring the performance in terms of effectiveness, it is difficult to understand current practices and promote improvement (Lettieri *et al.*, 2009; da Silva *et al.*, 2020). Targeting the productivity and performance of humanitarian organisations, Kosmas *et al.* (2022) suggest further research looking at humanitarian organisations resource use (e.g., in terms of area coverage and dollars per life saved) by employing historical data.

Technological innovations (e.g., drones, big data, and artificial intelligence) have been introduced, aiming to improve the efficiency and effectiveness of HO. These clear trends are only expected to grow faster, requiring humanitarians to adapt their operations and skill sets (Besiou and Van Wassenhove, 2019). Recent research discussing information, technology, and communication systems in the context of disasters - fitting into the cluster "IT-related HSCM studies" - also shed light on existing gaps for research development (Hiltz *et al.*, 2013). According to Diedrichs *et al.* (2016), the effects of communication in emergency disaster logistics are difficult to quantify and usually underestimated. Diedrichs *et al.* (2016) state that although the role of communication between actors in an emergency disaster response operation has been studied qualitatively (with theoretical advances), they provide a first attempt to quantify their impact on the number of lives saved and dollars spent. Diedrichs *et al.* (2016) also analyse the need for practical implementation by IT specialists to create a user-friendly mobile interface that allows response managers to easily input estimated disaster conditions and obtain instant decision support, including comprehensive feedback on the

ramifications of any course of action under consideration. Lawrence *et al.* (2022) highlighted the necessity to track and trace relief items aiming to accelerate the supply delivery. One way to track and trace is through Quick Response (QR) code, which can be used offline in disaster situations.

Still, in the context of technology, articles bring up games to approach the subject. Suarez (2015) presents an analytical framework and states that playable system dynamic models can immerse participants in an intensely interactive learning and dialogue experience that accelerates results. Shi *et al.* (2021) show that disaster research using game theory involved disaster phases such as mitigation, preparedness, and response have been studied but still lacks the understanding of the interactions and game relationships between (and within) government and beneficiaries. Significant advancements could be made by delving into residents' and local government's behavioural interactions from a dynamic perspective.

In addition to these technology-related opportunities, big data appears as a recent theme adopted and applied in HSCM (Behl and Dutta, 2019), fitting into the cluster “Big Data Analytics in HSCM”. Big data analytics can summarise disaster data, predict likely future trends, and evaluate different scenarios to prescribe possible outcomes (Lawrence *et al.*, 2022). The data used by academic research have been mainly through case studies. However, social media data, GIS-based data and Google analytics are gaining space. Lawrence *et al.* (2022) discuss the possibility of using digital platforms for crowdsourcing. Han *et al.* (2008) discuss the importance of real-time scene information to disaster relief commanders. The timely and accurate transmission of information and the objective reporting of truth through media vigorously enhance the entire people's relief (Han *et al.*, 2008). Suarez (2015) states that their study represents a first step in pursuing an innovation that can help disaster managers further understand and use geoinformation to support humanitarian decisions.

Still, it is essential to mention the difficulty in collecting data regarding the models' development and improvement. Once the frequency of disasters increases every year, emergency agencies have already recognised disaster-related data's crucial role in mitigating the disaster's impacts (Kim *et al.*, 2018). Favereau *et al.* (2020), for example, talk about the need for the availability of information — parameter adjustment, variables, and events — to generate new scenarios in evacuation decisions under disaster events context. Gotangco *et al.* (2014) suggest

that future work on their model should be concerned primarily with replacing the dummy variables with actual values based on historical data from the sources. Guo and Kapucu (2019) also show that data was limited, and the contingency plans of their model did not cover all stakeholders (e.g., volunteer organisations) in potential disaster response. Similarly, Diaz *et al.* (2015) suggest that further research should use actual data for the model's experiments and serve as a solid background for future predictions in the context of a housing recovery. Therefore, the same finding on the difficulty of obtaining data appears in different contexts (Hernantes *et al.*, 2013; Hiltz *et al.*, 2013; Kumar *et al.*, 2015).

Suggestions for future studies are summarised in Table 4.

Table 4 - Opportunities for future research

Behl and Dutta (2019) cluster	**Research Agenda**
Review of HSC based review papers	- Review of policies (policy implications and lessons learned) adopted in each of the HO areas (e.g., trade-offs between cost and time prioritization policies to deliver supplies to an affected area, policies for short- or long-term relief and recovery operations).
Studies related to theoretical approach and case study in HSCM	- Development of multi-case studies for cross-case analyses - Development of case studies with interaction among different stakeholders (lack of communication between different humanitarian organisations leading to information delays)
Classification of HSC with respect to phases of disaster	- Summary of HO regarding different disasters and their phases, considerations, consequences, policies, and implications for a general CLD - Deepening of subjects that permeate the intersection between pre- and post- disaster stages (e.g., allocation of funds for disaster preparedness and response)
Studies related to Humanitarian Logistics	- Sustainability in HO (e.g., reverse logistics impact on sustainability, cost-effectiveness of reverse logistics, trade-off between cost and time requirements of sustainable solutions) - Link between HO and SDG - Disaster-affected population migration (e.g., management of shelters used by the displaced population, analysis of available routes to leave the affected place) - SAR operations (e.g., resources and assets logistics, role of volunteering to provide necessary support to experts, management of mixed fleets that can be employed) - MBS (e.g., arrival and disembarkation process at ports, onward migration journeys, return to

	their country of embarkation migrants journey, humanitarian organizations role in short-and long-term actions, cooperation between stakeholders at land and sea) - Logistical challenges at the nodes legs of the supply chain connections (associated logistics in the conveyance of supplies between means of transport, associated logistics in the last mile distribution). - Humanitarian Organizations development programs - Humanitarian Organizations dependency (disaster relief operations leading to dependency of the affected area, necessity to ascribe long-term development goals to reduce relief operations impacts)
Performance Evaluation of HSCM	- Understanding of current practices in HO and the performance management and measurement - Map of policies simulated in different cases (disaster type and operation type) according to productivity and performance - Use of historical data to look at humanitarian organizations resource use (e.g., monetary value per life saved, and area coverage)
IT related HSCM studies	- Quantification of the effects of information, technology, and communication systems in HO - Creation of user-friendly mobile interfaces systems/platforms (e.g., platforms to teach and explain about disaster risks, platforms to ask for help, platforms to receive alerts) - Development of games for interactive learning (evacuation planning games, humanitarian organization management in the face of development programs games, allocating donations games)
Big Data Analytics in HSCM	- Data collection - Adoption of social media data, GIS based data and Google analytics (e.g., people beliefs, most mentioned and discussed topics)

3.5 Conclusion

This study reviews the HOM literature review and identifies 80 papers published from 2001 to May 2022. By analysing the selected papers, we map the topics studied in the extant literature, define a list of literature subjects (taxonomy), and connect the main variables identified in a CLD.

Tables 2 and 3 provide a taxonomy of subjects and variables focusing on pre- and post-disaster with the associated references. The comprehensive CLD, presented in Figure 10, maps the interrelationships among the variables identified

in our SLR. Together, the taxonomy and the comprehensive CLD shed light on HOM topics using SD modelling, answering the first research question.

Such as other diagrams and models, academic researchers could use the proposed CLD to provide:

i. pre-disaster descriptive case studies: migratory movements around the globe, evacuation decision, knowledge of population routes, and evacuation process.
ii. post-disaster descriptive case studies: the impact of donations and last-mile distribution in populations most affected in a pandemic scenario.
iii. analysis of hypothesised causal influences (that can evolve into theory building) and relationships using mental models that communicate detailed disaster and humanitarian crises.

Future studies can address the causal feedback identified by using systems thinking and SD, specifically investigating each variable to see and confirm their cause-and-effect relationships in the model. The qualitative SD approach provides an interactive tool to depict process feedback, highlight complicated causal relationships, and model key variables for future validation.

To investigate the gaps in the HO literature, we analysed the papers from our SLR according to the clusters proposed by Behl and Dutta (2019) and systematically considered opportunities for further research, which led to developing the discussion section and research agenda (Table 4), answering the second research question. The research agenda (Table 4) serves as a guide for advancing HOM studies through SD. We hope that the opportunities for research identified in our research agenda can boost research in this area and improve decision-making in the field, leading to improved policies and more effective humanitarian efforts.

3.6 Final considerations

The SLR brings a theoretical foundation for this thesis, since it addresses all the papers found in the academic literature at the intersection of the use of SD in HO. Besides, the research agenda poses opportunities for future research that that we cover in our case studies.

Therefore, the present thesis research two distinct HO. The first operation consists of collecting and distributing donations in favelas in Rio de Janeiro, where an SFD is developed and simulated through empirical data obtained through a survey with the population of the favelas and directly with the involved organisations. Paper 2 encompass research opportunities highlighted in Paper 1 as: “development of case studies with interaction among different stakeholders”, “use of historical data to look at humanitarian organizations resource use”, “logistical challenges at the nodes legs of the supply chain connections”. The second studied operation considers the research gap “disaster-affected population migration”. The Brazilian federal government Operation to welcome, shelter, and internalise Venezuelans in Brazil is studied. An SFD is developed and simulated through empirical data obtained directly with the operation.

4
Measuring the impact of donations at the bottom of the pyramid (BoP) amid the COVID-19 pandemic

This chapter presents the Paper 2. The Version of Record of this article is published in Annals of Operations Research and is available online at https://link.springer.com/article/ 10.1007/s10479-021-04378-5. Reproduced with permission from Springer Nature, according to Springer permission copyrights (Appendix 2).

4.1 Introduction

Over the past several decades, the previous experiences with disease outbreaks have consistently improved society's mechanisms to respond to health crises (Biggerstaff et al., 2014). More recently, the COVID-19 pandemic, caused by the novel coronavirus SARS-CoV-2, has been changing habits and increasing uncertainty about the future, highlighting the importance and urgent need for actions for vulnerable populations during a crisis response (de Camargo Fiorini et al., 2021). Although the global impacts of the pandemic throughout the world remain unclear, the ensued health and socioeconomic crisis has resulted in the infection of millions of people and caused the death of hundreds of thousands worldwide (WHO, 2020). Moreover, the COVID-19 pandemic will have significant impacts on the economy (Fernandes, 2020; McKibbin and Fernando, 2020), and it could cost the world approximately US$11.7 trillion (BusinessToday .In, 2020).

Isolation measures have been highlighted as among the most effective policies aimed at slowing the spread of the disease and, therefore, alleviating the burden on healthcare systems (Antunes et al., 2020; Burch and Bunt, 2020; Crokidakis, 2020; Giudice et al., 2020). However, these measures impose a dilemma on BoP communities of low- and middle-income countries. These communities are especially vulnerable once people live in impoverished areas, with a lack of basic sanitation, poor quality of life, weak legal mechanisms, low literacy,

and frequently have unreliable sources of income (Srivastava et al., 2020). Access to clean water can be a challenge since the private sector is often the last resort provider (Subrahmanyan and Gomez-Arias, 2008). Such environmental conditions increase the risk of COVID-19 infection, which rapidly spreads over large urban perimeters, making these populations even more vulnerable (Unger and Riley, 2007).

Global attention is shifting toward developing countries and their BoP, where many humanitarian crises strike (Oloruntoba et al., 2019). It is estimated that 4 billion people worldwide encompass the BoP population. This population is concentrated mainly in Asia, Africa, Eastern Europe, and Latin America, and their number is expected to increase by 50% until 2040 (Wimschneider et al., 2020). In 2008, Brazil had 25% of its population among the poorest 50% of the worldwide population (Dumalanede et al., 2020).

The BoP population depends on an informal economy that is inefficient and poorly distributed (Subrahmanyan and Gomez-Arias, 2008). This population becomes the worst affected, mainly due to unemployment and lack of structured financial aid. Also, household sustenance becomes a severe challenge, posing a disproportionate toll on children's physical and psychological health (Chakrapani et al., 2020). For example, in Brazilian favelas, it is estimated that 47% of the inhabitants have informal jobs (Instituto Data Favela, 2020). Besides, most of these jobs demand physical attendance, and thus home office is not feasible. Hence, they must either work under risky conditions or refrain from working and suffer from severe income cuts. The decrease in families' incomes reduces their affordability to access essential food items (Global Food Security Index, 2020), consequently reducing their food security.

Therefore, the impact of the pandemic on this segment of the population is considerably higher relative to other segments. A Brazilian study has shown that the black and brown races were independently associated with increased in-hospital COVID-19 mortality, even after adjusting for sex, age, level of education, region of residence, and comorbidities (Peres et al., 2021). Besides, the difference in the proportion of employed people between black/brown and white races rose from 2.4% to 5.3% due to the effects of the pandemic (Ipea, 2021). In Brazilian favelas, 66% of the residents are either black or brown (Zenker, 2008), even though only 56% of the overall population are self-declared as those races (IBGE, 2019). Thus,

people living in favelas have suffered from higher mortality during the pandemic and higher unemployment rates.

As pandemics result in an abrupt and considerable increase in mortality rates, as well as generate social, political, and economic disruptions (Madhav et al., 2017), they can be viewed as disasters, thus demanding the intervention from humanitarian organisations (HOs) (Anparasan and Lejeune, 2018, Besiou and Van Wassenhove, 2020). Policies to control COVID-19 – such as food assistance and the search for the achievement of the Sphere Humanitarian Standards for water, sanitation, and hygiene (Corburn et al., 2020) – are goals often underachieved by governments in the BoP population, making the humanitarian aid fundamental for the vulnerable communities. HOs – which include a wide range of organisations, from international to locally active non-governmental organisations – respond to disasters by implementing adequate response measures. These measures rely on special emergency funds for initial disaster response missions and donations to fund the relief operations (Turrini et al., 2020). HOs work to plan, implement, and control the humanitarian supply chains from raising resources (monetary funds, goods, and services) from donors to the last-mile delivery to meet the urgent needs.

In a complex context, the relevance of the urgent need for humanitarian aid targeted at vulnerable communities is indisputable (Lau et al., 2020; Poole et al., 2020). However, several challenges have surfaced during the pandemic, especially regarding the operationalisation of deliveries of food and cleaning supplies (Corburn et al., 2020; Haynes et al., 2020). At the BoP, the basics infrastructure - facilities and installations such as roads and shelves - that managers take for granted in industrialised and emerging economies are often missing (Fawcett and Waller, 2015). If not well planned and executed, the distribution of donations considering the outbreak context may cause agglomerations, further disseminating the virus (Leão et al., 2021). Besides, stakeholders might overlook the securement of private and public funds to the delivery of food and cleaning supplies to the BoP, as capturing and quantifying its impacts is not a straightforward process (Ahmen et al., 2020; De Oliveira Andrade, 2020; Rodriguez-Morales et al., 2020).

The financial stability of the disaster victims is fundamental to recovery. However, this aspect is often neglected in the disaster' academic literature (Behl and Dutta, 2020), and each disaster case has particular characteristics and circumstances regarding how to cope with the ensuing financial shock (Gallagher

and Hartley, 2017). Academic literature on how donations during the COVID-19 pandemic impact the BoP population is scarce. However, the grey literature highlights their positive impact on the most vulnerable population (Chakrapani et al., 2020; Unicef, 2020). In contrast, studies focusing on the context of the healthcare system are abundant. Although reports and booklets have addressed the impact of donations during the COVID-19 pandemic on the most vulnerable population (UNICEF, 2020; Vongkiatkajorn and Daily, 2020), there is a lack of academic papers in the area. In addition, to the best of our knowledge, there are no studies that quantify these effects. Furthermore, according to Khalid et al. (2020), the BoP literature has mainly focused on business-to-consumer (B2C) issues. Few works study the BoP in humanitarian situations.

In this context, this work seeks to fulfil the exposed research gap, evaluating the potential impacts of the following two policies to improve well-being in vulnerable communities (Corburn et al., 2020): (i) donations of food to increase affordability and (ii) donations of cleaning and hygiene supplies to enhance sanitation procedures and practices. We evaluate the impacts of such donations to provide more access to food supplies and measure the impacts of cleaning supplies on controlling the COVID-19 outbreak in vulnerable communities. Therefore, we aim to answer the following research question: *what are the potential impacts of donations of food and cleaning supplies on the COVID-19 contagion rate in the BoP population?*

To answer the research question, we surveyed 2,155 people living in 143 favelas in Rio de Janeiro (Brazil). Rio de Janeiro was chosen, once it is the Brazilian city with the largest population living in favelas (22% of the inhabitants), and the average per capita income is below US$100 per month (IBGE, 2010). It is important to highlight in this context that Brazil reached 584,000 deaths due to COVID-19 by September 2021, a mark only surpassed by the United States, and the economic vulnerability increases the degree of lethality of COVID-19 among the poor in Brazil (Baqui et al., 2020; Peres et al., 2021; Phillips, 2020). Besides, Rio de Janeiro is the Brazilian capital with the highest COVID-19 mortality, and it was responsible for 5% of the deaths in Brazil, while its population represents only 3% of the total.

We evaluated the impact of donations with a system dynamics (SD) modelling approach. The SD methodology is applied to understand the non-linear behaviour of feedback loops and highly interconnected systems over time and to

derive potential future behaviour (Đula and Größler, 2021). These scenarios support the development of targeted policies to address core issues in the complex systems (Carvalho and Mazzon, 2020). SD makes use of established causal mechanisms and mathematical relationships aimed at scenario building and policy formulation. Therefore, the SD approach uses known causality to computationally devise scenarios that will potentially support decision-making in various contexts (Sterman et al., 2015). Thus, SD is highly suited to evaluate the potential impacts of different policies on complex systems, where the patterns of behaviour over time are emphasised (Richardson, 2011, 2020). In this paper, we aim at evaluating the potential impacts of different donation mechanisms and policies on the contagion rate of COVID-19 in the BoP population during a pandemic, which is an intrinsically complex system displaying non-linear behaviour over time and high interconnectedness among social, economic, and epidemiological variables (Rahmandad et al., 2021). SD has been widely used to support public policy and healthcare decision-making at a global level (Ghaffarzadegan et al., 2011), as it applies computer simulation models to test these different scenarios and explore "what-if questions" (Álvarez et al., 2015). More particularly, the development of such simulation scenarios can quantify the potential impacts of policy-based interventions (Stummer et al., 2021). In addition, the SD approach can integrate different effects, which are conceptualised as feedback loops, accumulation dynamics, significant system delays, and nonlinear relationships among key variables (Darabi and Hosseinichimeh, 2020).

SD has been used to study various subjects, including the analysis of trade-offs between a provision of relief assistance and capacity building in humanitarian organisations (Gonçalves, 2011) and investments in disaster management capabilities and pre-positioning of inventory (Kunz et al., 2014). In addition, it is also used to model and simulate epidemics, such as Ebola, Middle East Respiratory Syndrome (MERS), Severe Acute Respiratory Syndrome (SARS), and Malaria (SDS, 2020). More recently, studies applying SD in the context of pandemics gained prominence due to the global context of the coronavirus (Rodrigues et al., 2020; Sahin et al., 2020; Vega, 2020). Thus, SD provided us with the possibility of modelling the dynamics of the coronavirus disease and analysing the different impacts of donations, depending on the type of donations received (gift-in-kind or monetary), distribution channel (gift-in-kind or voucher), donation intensity

(quantity and frequency), last-mile delivery mode (organised or disorganised), type of gift-in-kind donation (food or cleaning supplies), and local of purchase relief supplies with received voucher donation (local market x supermarket).

Our paper is structured as follows. Section 2 presents the theoretical foundation of our research, and Section 3 the problem statement. Section 4 offers the model development, including the causal loop diagram and the simulation model. Section 5 reports the simulation of the problem, presenting the data collection, model validation, and results. Section 6 consists of the discussion, with theoretical and practical implications. Finally, Section 7 summarises the concluding remarks, limitations, and future research avenues.

4.2 Theoretical foundation

Funding is crucial in the humanitarian operations (Burkart et al., 2016; Mejia et al., 2019). It not only determines the scope of humanitarian actions but also has a significant impact on speed, effectiveness, and efficiency (Burkart et al., 2016). In this sense, the donation is crucial for funding.

Donations can be classified as earmarked or unearmarked. Unearmarked donations go to a general fund, where the donor does not influence the fund allocation among the agency projects (Toyasaki and Wakolbinger, 2014). Earmarked donations are sent to specific emergency-cause funds (the donors choose the fund allocation) (Aflaki and Pedraza-Martinez, 2016; Toyasaki and Wakolbinger, 2014).

Different aspects can influence the donor's decision about the fund allocation, such as the cultural interest in the disaster region and the trust in the local government (Aruga and Bolt, 2020). If on the one hand, earmarked donations play a key role in humanitarian operations (Tortora and Steensen, 2014), as it attracts more donations (Aflaki and Pedraza-Martinez, 2016) and encourages short-term projects focused on tangible results that can be measurable (Baumann, 2021). On the other hand, when only unearmarked is allowed, the expected donation volume is smaller. Still, HOs will have the flexibility to allocate it between the different projects (disaster response or development programs), besides reaching better operational performance (Aflaki and Pedraza-Martinez, 2016).

A meaningful discussion about donation on literature involves their channels. The current emphasis is on donations through online channels. Online donations have increased over the years (Koksal et al., 2021), rising as an option for traditional monetary donation channels (Koksal et al., 2021). Online donation plays a vital role in vulnerable communities because it is helpful for HOs appeals for funds from many donors (Hou et al., 2021). This scenario highlights the need for online donation platforms once it helps HOs reduce cost as data supplied by the donor and receipts and communication can be done electronically (Koksal et al., 2021). Online crowdfunding, for example, has emerged as a tool for raising funds for emergency response, as proposed by Chakarapani et al. (2020) in the Indian pandemic context. More than 30 percent in crowdfunding platforms is expected to rise in terms of the global transaction value from 2018 to 2022 (Behl and Dutta, 2019). However, it is fundamental to understand the donor behaviour and factors that increase their engagement concerning online donation platforms. Different authors have contributed to this topic – see Behl and Dutta (2020), Hou et al. (2021), and Yilmaz and Blackburn (2020).

Different forms of donations are explored by academic literature. Johnson (2011) proposes using Corporate Social Responsibility (CSR) funds as an alternative form of financial capitation in the context of humanitarian operations. According to Behl and Dutta (2019), CSR positively affects donation-based crowdfunding to recover after a disaster. The authors highlight the role of CSR initiatives in encouraging crowdfunding activities for social demands by organising campaigns to reach donations with social activities.

The aid delivery to beneficiaries during a disaster response is due by HO (Fontainha et al., 2017). Government, private, and individual donors can provide gift-in-kind and monetary donations to HOs. However, a monetary donation has the flexibility advantage once the money can be allocated according to the project needs (Dais and Davis, 2020). In this sense, achieving a higher volume of monetary donation is the primary goal of HOs (Hsu et al., 2021).

Donations can reach the beneficiaries in different ways. A very common categorisation separates gift-in-kind, cash-based donations – cash or voucher. Gift-in-kind donations can be categorised into types of products, which have different effects on the population. The donations of cleaning supplies are especially relevant in the COVID-19 pandemic since they enable hygiene practices to reduce virus

transmission. On the other hand, the donations of food rise affordability since food comprises approximately 60% of a household's income in poor areas (von Braun, 2008). Gift-in-kind donations have the advantage of immediately providing beneficiaries with assess to the needed goods (Sabates-Wheeler and Devereux, 2010). However, they can negatively impact local market sales (Oliveira, 2020). Piotrowicz (2018) mentions the advantages and disadvantages of in-kind food donations, being the immediate access, and to favour women and the elderly some of the benefits, and the transport and storage costs, competition with local markets, and trade some disadvantages.

Therefore, gift-in-kind donations can reduce virus transmission by preventing people from leaving their houses to purchase goods. However, in the humanitarian context, beneficiaries themselves often perform the last-mile distribution, who collect the items at specific sites (Muggy and Stamm, 2020). Thus, depending on how pick-up procedures are organised, they may generate agglomeration points, spreading the virus. Therefore, last-mile distribution is crucial since delivering humanitarian aid to vulnerable populations may impact health, improve their food security, and indirectly impact the population's social behaviour and movement patterns, which can influence their morbidity and mortality (Aaby et al., 1999). As stressed by the Sphere Standards (Sphere Project, 2011), "distribution points should be established where they are safe and most convenient for the recipients, not based on logistic convenience for the distributing agency." The focus of the last-mile distribution in the relief network is the effective assistance to victims, impacting the "accessibility" in the relief network (Zhang et al., 2020). Accessibility can be related to the response time (Noyan and Kahvecioğlu, 2018). According to Noyan et al. (2016), network conditions and demographical characteristics affect access to relief supplies. In this sense, it is possible to correlate the social isolation restriction as a variable that influences accessibility.

In turn, the cash-based model reduces the length of traditional humanitarian supply chains by creating a more agile chain once it allows beneficiaries to buy what they need instead of giving them the items (Heaslip et al., 2018). This model speeds up delivery and reduces overall costs (Piotrowicz, 2018). Other advantages of cash-based donations include the cost-efficiency and the stimulus to production and market growth (Piotrowicz, 2018). However, the risk of theft, inappropriate

use, corruption, limited donor resources available, inflation, and the inability to reach the most vulnerable people are pointed as disadvantages of cash donations (Heaslip et al., 2018; Piotrowicz, 2018). Although the cash-based system promotes the empowerment of local markets, supporting the region regenerations (Aruga and Bolt, 2020), it requires continuous assessment of the local supply availability (Besiou and Van Wassenhove, 2020). Besides, neighbourhood stores (i.e., "nano stores") typically have poor quality products and high prices (Subrahmanyan and Gomez-Arias, 2008). However, the displacement to supermarkets usually encompasses crowded public transportation, thus raising the possibility of virus contamination during a pandemic.

Vouchers require distribution in paper or electronic format and have a cash value to be used for payment. However, vouchers have limitations once they are restricted for use with specific suppliers or services and require a network of organisations that accept vouchers as means of payment. Figure 11 summarises the assistance modes (cash, voucher, or in-kind donations) and the donor, donations channels, and allocation modes.

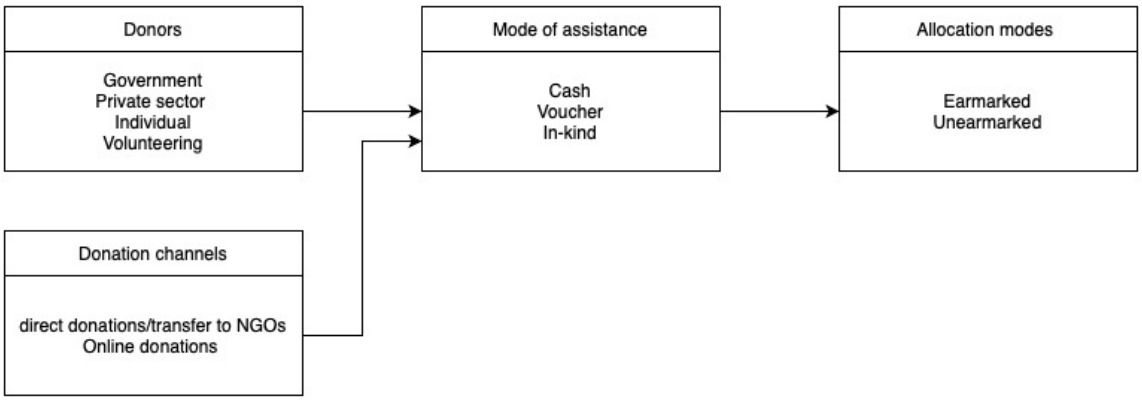


Figure 11 - Schematic representation of the assistance modes, donors, donations channels and allocation modes

4.3 Problem statement

The BoP population living in favelas faces more exposure to COVID-19 as favelas are overcrowded spaces. This population has low resilience to socioeconomic shocks, as people living in favelas usually have irregular incomes due to informal labour, a higher incidence of poverty, and a high dependence on

daily income (World Bank Report, 2020). In addition, social distancing and self-isolation might not be options, and access to reliable water supplies for handwashing may not be available. Therefore, favelas require specific responses, as the measures usually applied in other parts of the city may not effectively control the pandemic in these areas.

Amidst this troubling scenario, we model a humanitarian project led by three large non-governmental organisations. It aims to distribute food and hygiene products to 143 favelas in Rio de Janeiro. Figure 12 presents a schematic representation of the supply chain from monetary donations to the delivery of supplies to the communities.

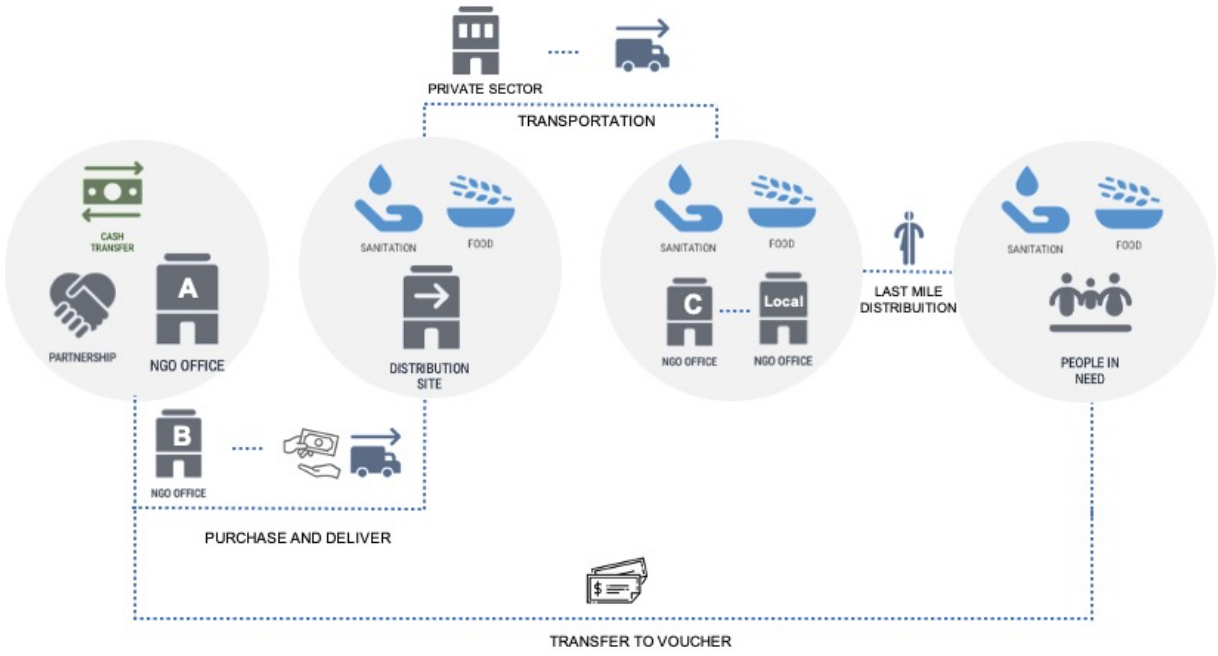


Figure 12 - Schematic representation of the donation chain in Rio de Janeiro communities

The humanitarian supply chain starts with Organisation A, which receives monetary donations from the private sector and individual donors through an online platform. Organisation A deals strictly with monetary donations for the following two main reasons: (i) reduction in donation movement and manipulation, following the sanitation measures recommended by the World Health Organization (WHO), and (ii) standardisation of donations to meet the demands of the BoP, avoiding the concentration of some types of items.

Organisation B, in turn, uses these donations to purchase the needed goods (food baskets and hygiene kits) or to transfer cash to vouchers. Organisation B is

also responsible for sanitising the products and delivering them to the carrier. The carrier, funded by the private sector, transports the items to the local organisations selected by Organisation C. These organisations are responsible for the last-mile distribution to the communities.

After the beneficiaries have received the deliveries, none of the organisations can adequately measure the donations' effects on the communities. Consequently, donors might be unmotivated to make further contributions. In addition, the organisations themselves lack information on these impacts, which becomes an obstacle to improving operations. As resources are scarce, quantifying gains and testing different scenarios become essential to better decision-making processes. For example, part of the donations is made in vouchers to the beneficiaries purchasing their food and cleaning supplies. Logistically, this is an easier and faster option for donors. In addition, it also avoids potential agglomeration when collecting gift-in-kind donations. However, the beneficiaries must leave their houses to buy food and cleaning supplies, which may raise their exposure to the virus. These factors cause a dilemma for organisations, as they cannot quantify the impact of each type of donation.

Other decisions that can influence the operation and impact the control of COVID-19 in these communities include determining the quantity and frequency of donations and defining allocations, i.e., between food and cleaning supplies and between gift-in-kind and voucher donations. More specifically, understanding the counterfactuals becomes imperative; what would be the number of infected and dead people in these communities had the donations not been made? We test the following scenarios in the simulation model: a scenario in which no donations have been made, a scenario in which only gift-in-kind donations are made, a scenario in which only voucher donations are made, and scenarios in which both in-kind and voucher donations occur.

4.4 Model development

SD is a method that qualitatively and quantitatively studies problems within systems displaying dynamic complexity. With the aid of computers, the SD method is geared towards representing high-order multivariate nonlinear systems with multiple feedbacks (Zhong et al., 2018). Thus, once the problem at hand is complex

due to the feedback processes – explained in subsection 4.1 – and nonlinearities – displayed in section 4.2 – contained in its variables, SD fits as the simulation method to be used. Besides, SD decomposes a complex problem into a set of variables and parameters, assigning mathematical rules to determine their interactions (Diedrichs et al., 2016), a valuable method for problems with many branches. In our case, examples of branches include distribution channel, quantity, and frequency of donations, type of product, delivery mode, and place of purchase, which will be further explained in the following sections.

The SD approach provides decision-makers with a set of tools that allow them to evaluate the potential results of their decisions, such as causal mapping – represented in subsection 4.1- and simulation modelling – detailed in subsection 4.2. Causal mapping enables the identification of essential variables and their interrelationships, therefore depicting the fundamental structure of the system whose behaviour we want to explore (Sterman, 2000a). The resulting simulation model, in turn, allows decision-makers to envision the behaviour of these variables and their interaction to identify the potential short- and long-term effects of the system (Sterman, 2000a). The high complexity of humanitarian operations makes SD a powerful tool to analyse nonlinear relationships, delays, accumulations, and feedback processes to adjust actions (Gonçalves, 2011).

4.4.1 Causal loop diagram

Causal Loop Diagrams (CLD) represent variables and their relationships, emphasising the structure of feedback loops. All systems consist of positive and negative feedback, and dynamics arise from these loops' interaction (Sterman, 2000a). Positive loops are self-reinforcing, while negative loops are self-correcting, denoting balancing loops. The CLD may also represent key variables in the form of stocks (accumulations) and flows (rates of change) to depict the structure underpinning a particular behaviour over time, commonly referred to as dynamic behaviour (Richardson, 2011; Sterman, 2000a).

Figure 13 shows the CLD combined with a standard stock-and-flow representation that uses the SIR epidemiological model (i.e., **S**usceptible, **I**nfected, and **R**ecuperated population) as an underlying representation of the COVID-19 spread. The standard SIR model is represented in the compartmentalised model

displayed at the bottom of Figure 13. The model shows each stage – Susceptible, Infected, and Recuperated – as a *stock* (boxes) with *flows* connecting each stage of the disease (double-line arrows with hourglasses in the middle). The feedback loops are marked with "R" for the *reinforcing* loops and "B" for *balancing* loops. Initially proposed by Kermack and McKendrick's (1927), the standard SIR formulation has been widely and consistently used and enhanced in epidemiology over the years. In the SIR model, the contagion process that diffuses the epidemic is represented by the ***reinforcing loop R1 (contagion)***. As the disease progresses, it infects healthy individuals closing the ***balancing loop B1 (depletion)***. Once infected, they either recover ***(balancing loop B2 – recover)*** and develop immunity or die ***(balancing loop B3 - death)***. That is, we do not consider reinfection by the virus. The SIR model has been intensively used in local and global efforts to model the ongoing COVID-19 pandemic and simulate its potential effects on health, education, and the economy to inform public policy using a SD approach (Ghaffarzadegan and Rahmandad, 2020; Rahmandad et al., 2021). In this paper, we use the standard formulation of the SIR epidemiological model as prescribed by the specialised literature (see, e.g., Karanfil et al., 2020; Michael Barton et al., 2020; Sterman, 2000b; Struben, 2020).

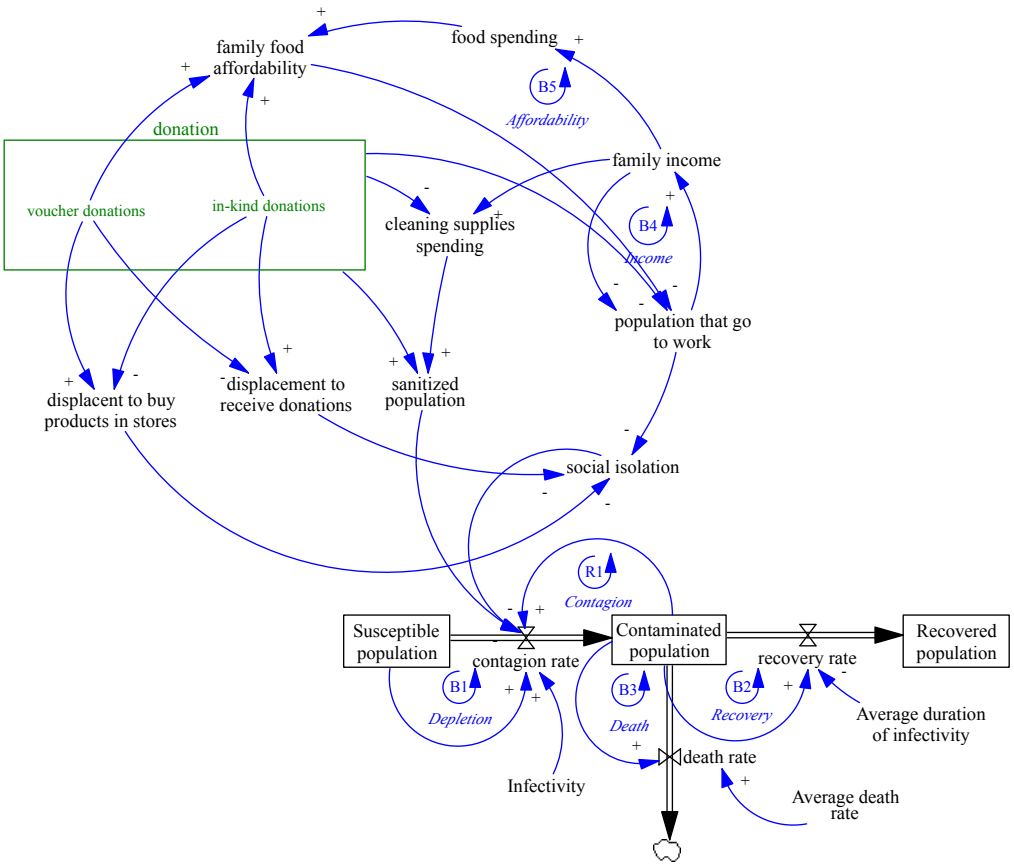
The constructs displayed in Figure 13 are based on literature and accumulated knowledge of the COVID-19 dynamic behaviour. These constructs are further detailed in the following paragraphs. On top of the SIR model, Figure 13 also shows the usual behaviour of a community, where the families buy food and hygiene products, in addition to other assets not studied in this research, using part (or all) of their monthly income (De Carvalho et al., 2021). Hygiene products are needed to keep the house and its residents clean, which decreases the rate of contagion by viruses (Ribeiro et al., 2021). ***Balancing loop B4 (income)*** demonstrates that the lower the family income, the greater the population will work, as they need income to survive. The larger the number of people going to work, the greater the family income and the lesser the social isolation. The higher the family's income, the more it can buy food, therefore presenting higher food affordability and, consequently, the less the population needs to go to work (***balancing loop B5 - affordability***).

With the rapid spread of the COVID-19, the Brazilian government enacted social isolation measures at the local levels in the municipalities to contain the quick

dissemination of the virus (Bezerra et al., 2020; Crokidakis, 2020). The CLD in Figure 13 shows the main changes and effects emerging from the enactment of those measures. When isolation begins, many vulnerable low-income families lose all or part of their income, which is caused either by the isolation itself or the economic crisis it generates (The Lancet, 2020). The income losses are also related to the rigid restrictions on how society operates, as some of these people have informal jobs that rely on the normal functioning of businesses and households - e.g., unregistered domestic workers, informal street workers, or deliverymen (Monteiro de Oliveira et al., 2020; Tavares and Betti, 2021). The income cuts leave family members with no choice but to return to work, even with enacted social isolation measures. Therefore, the portion of the population that needs to continue working reduces the rate of social isolation and influences contagion dynamics.

At this point, donations become crucial to maintain families' livelihoods since they support people in complying with social distancing and help keep the most vulnerable population nourished and in sanitary conditions (Bento and Couto, 2021; Rodrigues et al., 2021). The volume of food and cleaning supplies consumed in a community is based on two main aspects: (i) the population's income and (ii) the number of donations obtained. Cleaning supplies are especially useful in the context of a pandemic, in which a highly infectious disease is rapidly spreading. A high level of hygiene reduces transmission and, therefore, the number of infected people. Food supplies are essential to reduce the effects of income cuts on the food security (Nathan and Benon, 2020). In addition, food supply donations help keep the population at home since the need to leave home to go to work is reduced (Nathan and Benon, 2020).

How donations are made also influences the outcomes (Leddy et al., 2020). On the one hand, in-kind donations demand that the beneficiaries leave their houses to obtain donations from a distribution centre; however, there is no need to go shopping for supplies. On the other hand, *voucher donations* may avoid agglomerations in distribution centres (depending on how they are distributed and recharged) but require travel to the stores (Pereira and Oliveira, 2020; White et al., 2020). Figure 13 shows how the different types of donations affect the contagion rate.



Representation. Physical points of storage (levels) are depicted as boxes; flows between levels are the double-line arrows; double triangles (hourglasses) mean valves that control the flow between levels; blue arrows represent connections between variables and parameters.

Figure 13 - Causal loop diagram depicting the SIR epidemiological model and the typical community purchasing behaviour

4.4.2 Simulation model

Considering the presented causal diagram, we developed a simulation model using Vensim Pro (Ventana System), as depicted in Figure 14. Table 5 summarises the parameters used, including the variable names, brief descriptions, and their units.

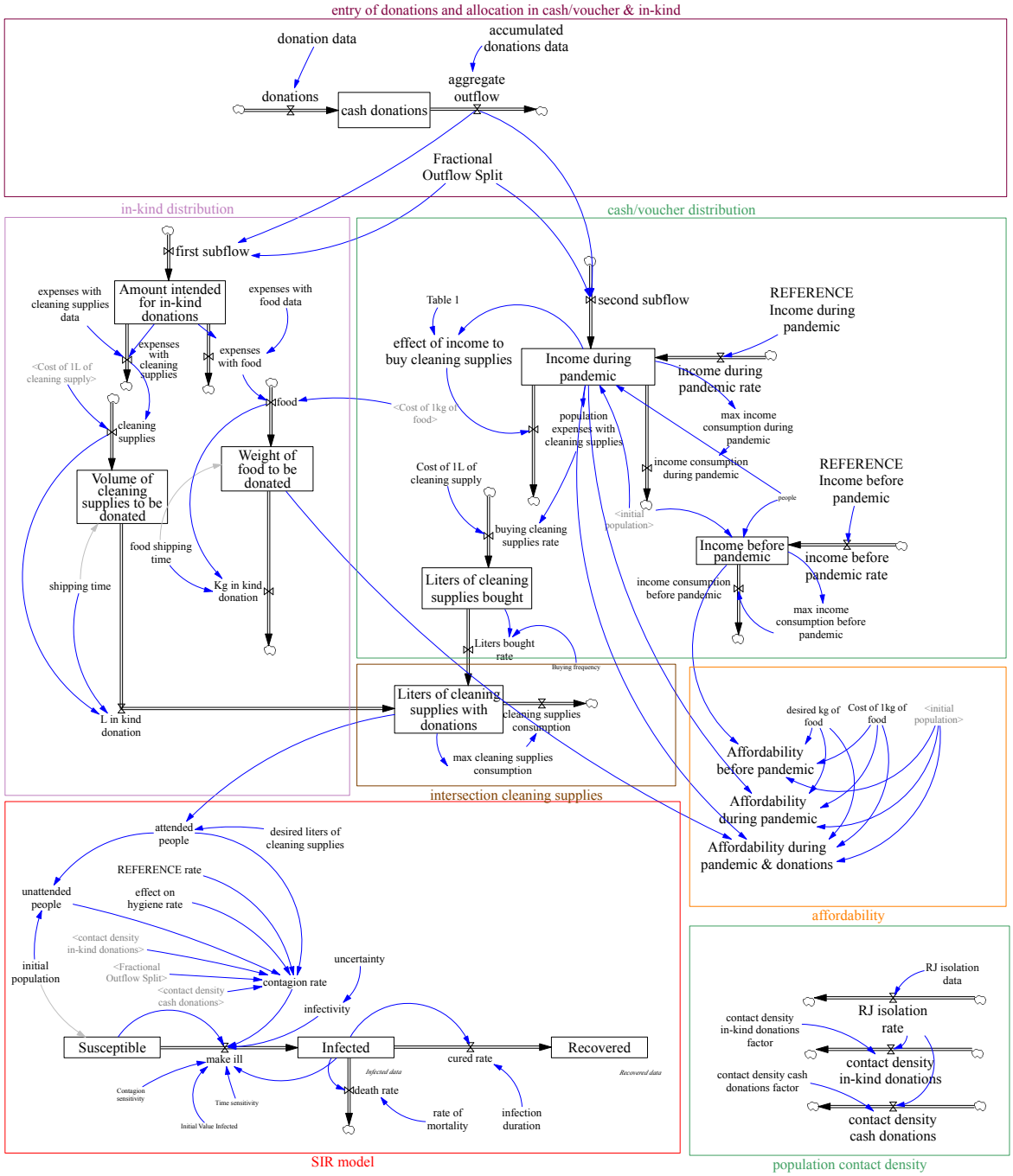


Figure 14 - Complete Simulation Model

Table 5 - Variable descriptions

Variable	Description	Units
Affordability before pandemic	BoP population's ability to purchase food before the pandemic	1/people
Affordability during pandemic	Ability to buy food by the BoP population during the pandemic	1/people
Affordability during pandemic + donations	Ability to purchase food by the BoP population during the pandemic and with the help of donations	1/people
Amount intended for in-kind donations	Financial amount for in-kind donations	real
Attended people	BoP population served by donations	people
Cleaning supplies consumption	Consumption of hygiene products by the BoP population	litre/day
Contact density cash donations	Contagion density due to contact of the population that received cash donations	Dmnl
Contact density in-kind donations	Contagion density due to contact of the population that received in-kind donations	Dmnl
Contagion rate	Rate of infection by the virus	people
Cost of 1 kg of food	Cost of 1 kg of food	real/kilo
Desired kg of food	Kilograms of food desired to keep the BoP population fed	kilo
Effect on hygiene rate	Effect that hygiene has on the contagion of the population by the virus	Dmnl
Expenses with cleaning supplies	HO spending on hygiene products to be donated	real/day
Expenses with food	HO spending on food to be donated	real/day
First subflow (aggregate outflow*Fractional Outflow Split)	Flow of financial input into the stock destined to purchase in-kind donations	real/day
Income before pandemic	Income before the pandemic	real
Income consumption during pandemic	Population spending during the pandemic	real/day
Income during pandemic	Income of the BoP population during the pandemic	real
Income during pandemic rate	Inflow of money into the population's income stock	real/day
Initial population	Initial population	people
Liters in kind donation	Litres of in-kind donations of hygiene products	litre/day
Litres bought rate	Litres of hygiene products purchased and donated to the BoP population	litre/day
Litres of cleaning supplies with donations	Litres of hygiene products purchased and donated to the BoP population	liter
population expenses with cleaning supplies	Population spending on hygiene products during the pandemic	real/day
Second subflow (aggregate outflow* (1-Fractional Outflow Split))	Financial inflow through donations to the stock of the BoP population's income	real/day
Unattended people	BoP population not served by donations	people
Weight of food to be donated	Kilograms of food to be donated to the BoP population	kilo

The model starts with the cash collection and distribution of donations. The distribution occurs on the following two fronts: (i) distribution of in-kind products;

(ii) distribution of vouchers to the population. The number of donations to each front is defined in the model by the variable “Fractional Outflow Split”. Therefore, the “Fractional Outflow Split” variable allows the model to capture the amount of money intended for the purchase of food and hygiene products (equation 1) to be physically (in-kind) donated to the beneficiaries and to capture the movement of the cash donations, which will increase the monthly family income (equation 2).

$$\begin{aligned} &Amount\ intended\ for\ inkind\ donations \\ &\quad = \int [\,(aggregate\ outflow * Fractional\ Outflow\ Split) \\ &\quad - expenses\ with\ cleaning\ supplies - expenses\ with\ food] \end{aligned} \tag{1}$$

$$\begin{aligned} &Income\ during\ pandemic \\ &\quad = \int [income\ during\ pandemic\ rate \\ &\quad + \left(aggrefate\ outflow * (1 - Fractional\ Outflow\ Split)\right) \\ &\quad - population\ expenses\ with\ cleaning\ supplies \\ &\quad - income\ consumption\ during\ pandemic\ ] \end{aligned} \tag{2}$$

Since part of the monetary donations is destined to purchase hygiene products and food baskets to be distributed (in-kind), the model accounts for the litres of hygiene products and kilograms of food bought and donated. The model uses litres of hygiene products and kilos of food in each basket and does not consider price fluctuations resulting from the pandemic. This occurs since the organisations may change the products in the basic basket, if necessary, to maintain the same final price and the number of products throughout the period.

When a portion of the donations is designed for voucher distribution and, therefore, influences the population's income, the model calculates the population's spending on hygiene products, the litres of hygiene products purchased by the people, and the population’s affordability concerning food with and without donations. As the amount of food and the number of vouchers donated increase the population’s income, they also influence food affordability. Thus, we estimated the level of affordability before the pandemic (Equation 3), during the pandemic without the aid of donations (Equation 4), and during the pandemic with the assistance of donations (Equation 5).

$$\begin{aligned} &Affordability\ before\ the\ pandemic \\ &= \frac{Income\ before\ the\ pandemic}{Cost\ of\ 1kg\ of\ food * desired\ kg\ of\ food * initial\ population} \end{aligned} \tag{3}$$

$$Affordability\ during\ the\ pandemic = \frac{REFERENCE\ Income\ during\ pandemic}{Cost\ of\ 1\ kg\ of\ food\ *\ desired\ kg\ of\ food\ *\ initial\ population} \quad (4)$$

$$Affordability\ during\ the\ pandemic\&\ donations = \frac{Income\ during\ the\ pandemic + (Weight\ of\ food\ to\ be\ donated * Cost\ of\ 1\ kg\ of\ food)}{Cost\ of\ 1\ kg\ of\ food\ *\ desired\ kg\ of\ food\ *\ initial\ population} \quad (5)$$

The volume (in litres) of hygiene products donated and distributed and the litres of hygiene products purchased by the population are computed in the variable "Litres of cleaning supplies with donations" (Equation 6).

$$Liters\ of\ cleaning\ supplies\ with\ donations = \int (L\ in\ kind\ donation + Liters\ bought\ rate - cleaning\ supplies\ consumption) \quad (6)$$

The calculated number of litres of cleaning supplies and the population's isolation rate are used to calculate the contagion rate (Equation 7). Thus, donations of hygiene products are represented in the model as a variable influencing the contagion rate.

$$contagio\ rate = contact\ density\ inkind\ donations * Fractional\ Outflow\ Split + contact\ density\ cash\ donations * (1- Fractional\ Outflow\ Split) * attended\ people * REFERENCE\ rate * (1-effect\ on\ hygiene\ rate))+(unattended\ people * REFERENCE\ rate))/ attended\ people + unattended\ people \quad (7)$$

4.5 Problem simulation

This section describes the primary data sources, the model validation, and the simulation model results.

4.5.1 Data collection

We used the following three main data sources as inputs: (i) data on the number of cases, deaths, and recovered people were retrieved from a data panel that collects information from the communities and the government (Voz das comunidades, 2020); (ii) data on food and hygiene products donated per day were

obtained from the project's organisations; and (iii) data on community behaviour were obtained through surveys (Forza, 2002) with the beneficiaries and local organisations that perform the deliveries. The survey was developed according to the six steps defined by Forza (2002): connection with the theoretical constructs, survey design, pilot test, data collection, data analysis, and report.

The questionnaires were sent via email; 29 responses were received from local organisations, and 2,155 were received from beneficiaries from May 29th to June 14th, 2020. The percentage of answered questions was 85%. The questions submitted to the organisations encompassed an overview of COVID-19 numbers in the communities and the operations performed to deliver the donations. Most organisations (75%) have a system for beneficiaries to collect donations on-site, exposing them to the disease. However, 81% of these organisations stated that there were no agglomerations during collections. In addition, 64% of the organisations preferred to distribute in-kind donations rather than vouchers.

Similarly, the beneficiaries were asked about their preferred type of donation (66% prefer in-kind), the number of infected people and deaths in their households, and their financial situation (their income during and after the isolation measures, their usual expenses for food and cleaning supplies, and how those expenses would change if their income doubled).

Therefore, the desired expenses on food and cleaning supplies were estimated using the answers from the survey regarding how much the beneficiaries would spend if their income doubled, which resulted in a monthly average of U$ 144.38 on food and U$ 39.48 on cleaning supplies per family. Table 6 lists the other parameters of the base scenario.

Table 6 - Standard parameters

Parameters	**Value**
Time Interval	Days
Time Step	0.125 days
Infection Duration	15.73 days
Initial Population	320,000 beneficiaries
First Infected	March 22nd, 2020
REFERENCE contagion rate	2.91
Effect on hygiene rate	0.2

We ran the model over 210 days since we have data regarding donations during this period. The time interval was 1 day because of the disease dynamics. The model time step is 0.125, following the rule to set a time step between one-fourth and one-tenth the size of the shortest time constant in the model (Sterman, 2000a).

As for the infection duration, we used COVID-19 hospitalisation data provided by the Brazilian Ministry of Health (Ministério da Saúde, 2020). We then used the average hospital length of stay to proxy the infection duration (15.73 days). Additionally, considering the Brazilian Ministry of Health data, the first COVID-19 case reported in a vulnerable community in Rio was on March 22nd, which is also used in the model for the first infected person. We defined the initial population as 320,000 inhabitants, corresponding to the estimated number of people living in the favelas assisted by the project in the city of Rio de Janeiro (Cavallieri and Vial, 2012) based on the last census conducted by the Brazilian Institute of Geography and Statistics (IBGE).

Based on the literature, we estimated the effect that the use of cleaning supplies could have on reducing the contagion rate. Aiello et al. (2008) highlighted that using soap and hand sanitisers combined with hand-hygiene education prevented 21% of respiratory-related illnesses. Aiello and Larson (2002) reviewed 54 papers that associated hygiene measures with infectious diseases and reported that most of them showed a reduction greater than 20% in infections after implementing these policies. One of these reviewed papers found a 49.7% reduction in respiratory-related illnesses when students in a specific school were provided with hand sanitisers (Dyer et al., 2000). Therefore, to avoid overestimating the potential of the hygiene supplies donated, we used the lowest of these numbers. We considered that a person has a 20% lower chance of being infected if the hygiene standards are met.

4.5.2 Model validation

Model validation is crucial to ensure the findings' validity (Barlas, 1996; Sterman, 2000b). We validated our model structure by using the authors' knowledge, the results from our survey, and validity tests, following the protocols

put forth by (Schwaninger and Grösser, 2016), who categorise tests on model-related contexts, model structures, and model behaviours.

Model-related context tests can help avoid ill-conceived models and the use of inappropriate modelling methods (Schwaninger and Grösser, 2016). In this sense, we performed the model framing test by clearly describing the goal(s) of the model, the involved stakeholders, and the insights gained from using the model. We also performed a test to ensure the adequacy of the methodology, as we explained the use of the SD methodology in the present research. We make the need to use it even more evident when presenting the model due to the dynamic complexity, the feedback mechanisms, and the nonlinear interdependency of structural elements, which is materialised by the mathematical relations of the computational model.

The model structure tests assess whether the model logic is attuned to the real world structure (Schwaninger and Grösser, 2016). We performed a dimensional consistency test and sensitivity tests using Vensim standard features. The former checks the consistency of the dimensional units to establish the internal validity of the model. The latter assesses changes in the model outcome behaviour given a systematic variation in input parameters, revealing those parameters to which the model behaviour is highly sensitive.

The model behaviour tests are empirical and compare simulation outcomes with actual data. We performed a behaviour anomaly test. In constructing and analysing an SD model, one strives to have it behave like the actual system under study. However, the analyst may detect anomalous features of the model's behaviour, which conflict with the real system's behaviour. Once the behavioural anomaly is traced to the components of the model structure responsible for the anomaly, one often finds flaws in the model assumptions (Schwaninger and Grösser, 2016). Therefore, we tested for behavioural anomalies throughout the modelling process. Finally, we applied the family member test since a model should generally represent the class of that system to which the case belongs (Schwaninger and Grösser, 2016). Thus, we analyse and use in the model two families that should be highlighted, i.e., the use of the SIR model, a classic model in the representation of infectious diseases (epidemiological family), and the use of structure elements called the SplitFlow molecule.

4.6 Results

This section first presents the results from the current practice scenario (base scenario), with 95% of the donations being in-kind donations. This scenario was calibrated according to the isolation rate in RJ. Only 3% of the in-kind donations were earmarked to purchase hygiene products in the base scenario, while 97% were allocated for food items. Figure 15 demonstrates how the affordability would have been different if 25%, 50%, or 75% of the in-kind donations were allocated to hygiene products. Therefore, the results show that affordability increases with the volume of food distributed.

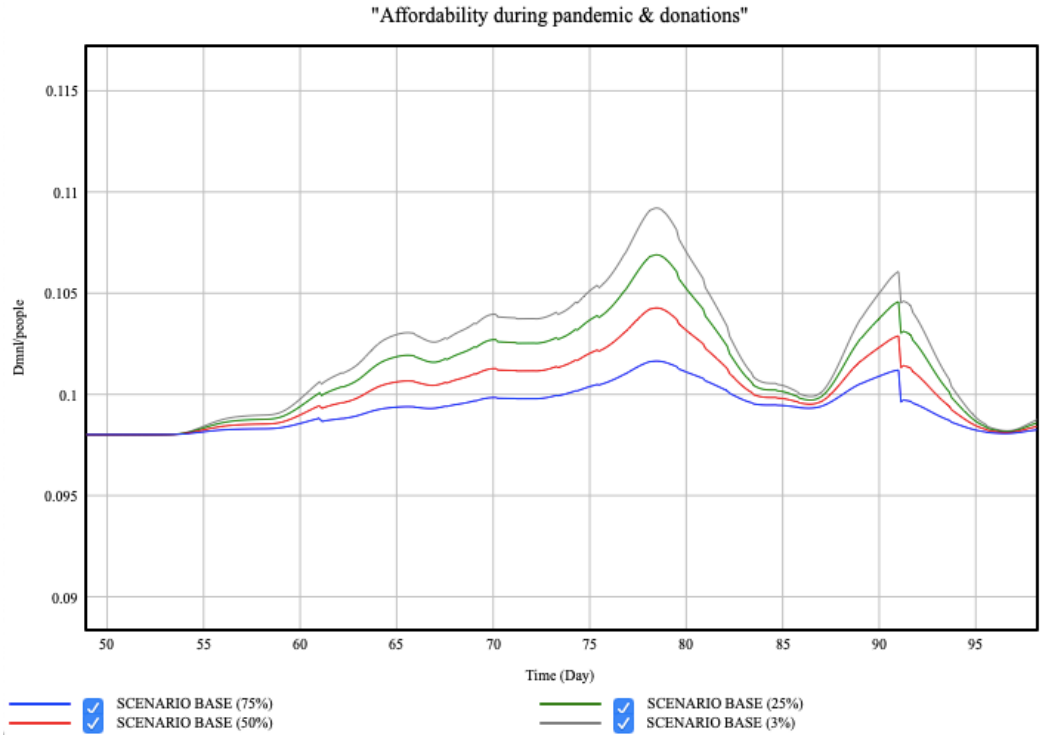


Figure 15 - Affordability with variations of the base scenario

Considering the levels of affordability introduced in Figure 15, we present the number of infections (Figure 16) for the base scenarios. In our model, the level of affordability does not interfere with the infection rates; thus, the analyses are independent.

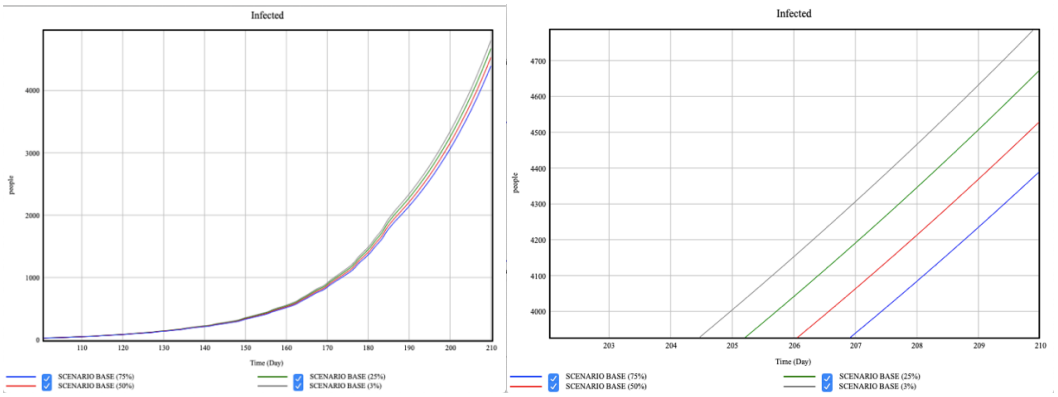


Figure 16 - Number of infected people in different base scenarios

In addition, Table 7 shows the number of infected people on day 210 in each base scenario. A 25% increase in donations of hygiene products would reduce the number of infections by approximately 3%.

Table 7 - Number of infected people on day 210 in the different base scenarios

Time (Day)	210
Infected : SCENARIO BASE (75%)	4391.93
Infected : SCENARIO BASE (50%)	4531.34
Infected : SCENARIO BASE (25%)	4674.96
Infected : SCENARIO BASE (3%)	4804.91

To proceed with the analyses, we consider as a premise the 50%/50% base scenario. We assume that half of the in-kind donations (95% of the total donations) are hygiene products and the other half are food items. Based on this premise, we can analyse the model's changes considering donations of hygiene products and food.

Table 8 defines the six scenarios we used to analyse the impact of donations on the BoP population. We varied the percentages between in-kind and voucher donations, and in each scenario, we varied the contact density factor. Therefore, the lines (numbers) in Table 8 represent the percentages of donations, while the columns (letters) represent the differences in the contact density factor used.

Table 8 - Scenario analysis with varying levels of in-kind and cash/voucher donations

	IN-KIND DONATIONS			CASH/VOUCHER DONATIONS			
	distribution at home (0 contact density factor)	**organised distribution (0.1 contact density factor)**	**disorganised distribution (0.2 contact density factor)**	**organised distribution and purchase in local market (0.1+0.2 contact density factor)**	**organised distribution and purchase in supermarkets (0.1+0.3 contact density factor)**	**disorganised distribution and purchase in local market (0.2 + 0.2 contact density factor)**	**disorganised distribution and purchase in supermarkets (0.2 + 0.3 contact density factor)**
SCENARIO 1	**0%**			**0%**			
	SCENARIO 1						
SCENARIO 2	**100%**			**0%**			
	SCENARIO 2 (A)	SCENARIO 2 (B)	SCENARIO 2 (C)	-			
SCENARIO 3	**0%**			**100%**			
	-			SCENARIO 3 (D)	SCENARIO 3 (E)		SCENARIO 3 (F)
SCENARIO 4	**50%**			**50%**			
	SCENARIO 4 (A)	SCENARIO 4 (B)	SCENARIO 4 (C)	SCENARIO 4 (D)	SCENARIO 4 (E)		SCENARIO 4 (F)
SCENARIO 5	**70%**			**30%**			
	SCENARIO 5 (A)	SCENARIO (B)	SCENARIO (C)	SCENARIO (D)	SCENARIO (E)		SCENARIO (F)
CENARIO 6	**30%**			**70%**			
	SCENARIO 6 (A)	SCENARIO 6 (B)	SCENARIO 6 (C)	SCENARIO 6 (D)	SCENARIO 6 (E)		SCENARIO 6 (F)

Scenario 1 considers no donations, Scenario 2 considers only in-kind donations, and Scenario 3 consists of voucher donations only. Scenario 4 considers an equal distribution between in-kind and voucher donations, while Scenarios 5 and 6 prioritise one of the donation types. In each of the six scenarios presented, we performed six other simulations, changing the contact density factor to represent three aspects. First, we consider whether the distribution of supplies occurred directly in the homes of the populations. Second, whether the distribution occurred in an orderly or disorderly manner is considered. Third, as BoP markets in developing countries are characterised by informal and resource-scarce business environments (Brix-Asala and Seuring, 2020), we also considered contact density differences if the purchases occurred in local markets - considering that, in this case, the population moves less - or in distant commercial centres - assuming that the population movement is more significant in these cases.

The values used for the contact density factor variable are arbitrary since there is no research showing how much the displacement of the population to nearby or distant markets influences the global isolation rate of a city. However, the values vary from 0.1 to 0.5 to represent low and high contact densities, respectively.

In that case, when we have an organised distribution with the population buying goods at supermarkets, we have the same contact density (0.4) as a disorganised distribution but with the beneficiaries shopping at local markets. Therefore, we combined these two variations as one.

Figure 17 shows the results of the first three scenarios - without donations, with 100% in-kind donations, and with 100% voucher donations. Figure 17 shows that the affordability in Scenario 1 - without donations - is very low, meaning the population would have difficulty buying food. Scenario 2 has better accessibility than scenario 1, but it is still reduced. Even though Scenario 2 is best considering the number of infected people, Scenario 3 presents an enhanced result considering affordability since, in this scenario, vouchers are given to the population, who decides the allocation of food and hygiene products.

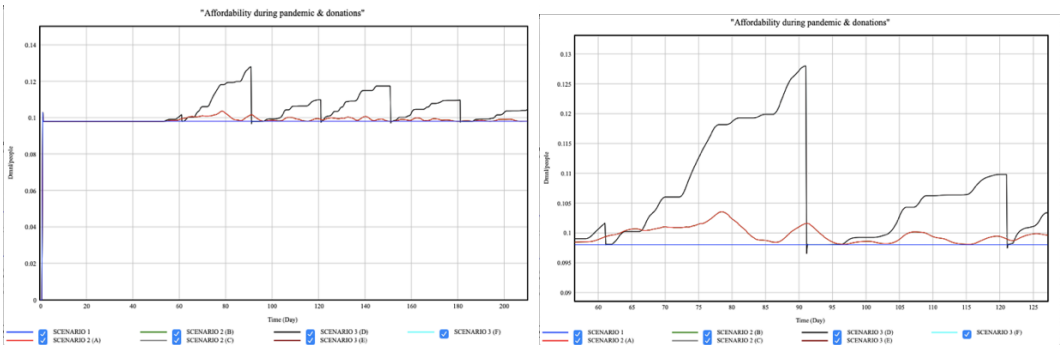


Figure 17 - Affordability results for Scenarios 1, 2 and 3

Schematic representation. Scenario 1 is represented by the blue line; Scenario 2 (all letters) is represented by the red line, as the contact density factor does not influence the affordability results; thus, all lines in scenario 2 overlap; Scenario 3 (all letters) is represented by the black line.

It should be noted that the different contact density factors do not interfere with the affordability results, as the affordability only encompasses the ability to buy food and is not related to the number of infected people. As in the infection results, scenarios 4, 5, and 6 fall between scenarios 2 and 3 (Figure 18), as they are combinations of these two extreme scenarios.

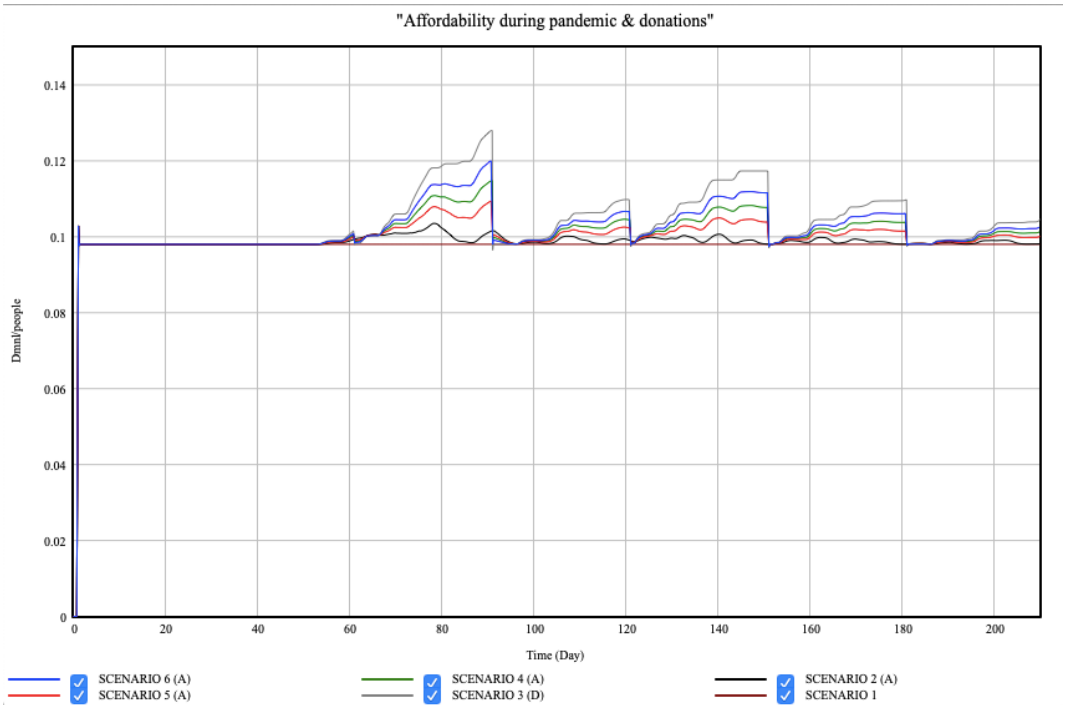


Figure 18 - Affordability results for scenarios 1, 2, 3, 4, 5 and 6

Schematic representation. As the contact density factor does not influence the affordability results, all possibilities of letters (which represent the contact density) in a specific scenario have the same result, which is why we can analyse scenario 3 (D) with the other scenarios in (A).

Table 9 shows the affordability results of all scenarios on day 91, the day that presented the highest affordability value. The affordability increases 20% when all donations are performed in vouchers (Scenario 3) compared to in-kind donations (Scenario 2).

Table 9 - Affordability results on day 91

Time (Day)	91
"Affordability during pandemic & donations" : SCENARIO 6 (A)	0.120061
"Affordability during pandemic & donations" : SCENARIO 5 (A)	0.109493
"Affordability during pandemic & donations" : SCENARIO 4 (A)	0.114777
"Affordability during pandemic & donations" : SCENARIO 3 (D)	0.127986
"Affordability during pandemic & donations" : SCENARIO 2 (A)	0.101567
"Affordability during pandemic & donations" : SCENARIO 1	0.0980136

For the number of infections, Scenario 1 has the steepest infection curve; it fails to reach the *plateau* of the curve not to overload the healthcare system. This scenario (without donations) presents results like those with a contact density factor of 0.5. Therefore, we can state that voucher donations with a disorganised

distribution of vouchers and purchases in supermarkets far from the beneficiaries' homes (having to take public transport) could result in infection numbers like the scenario where no donations were made.

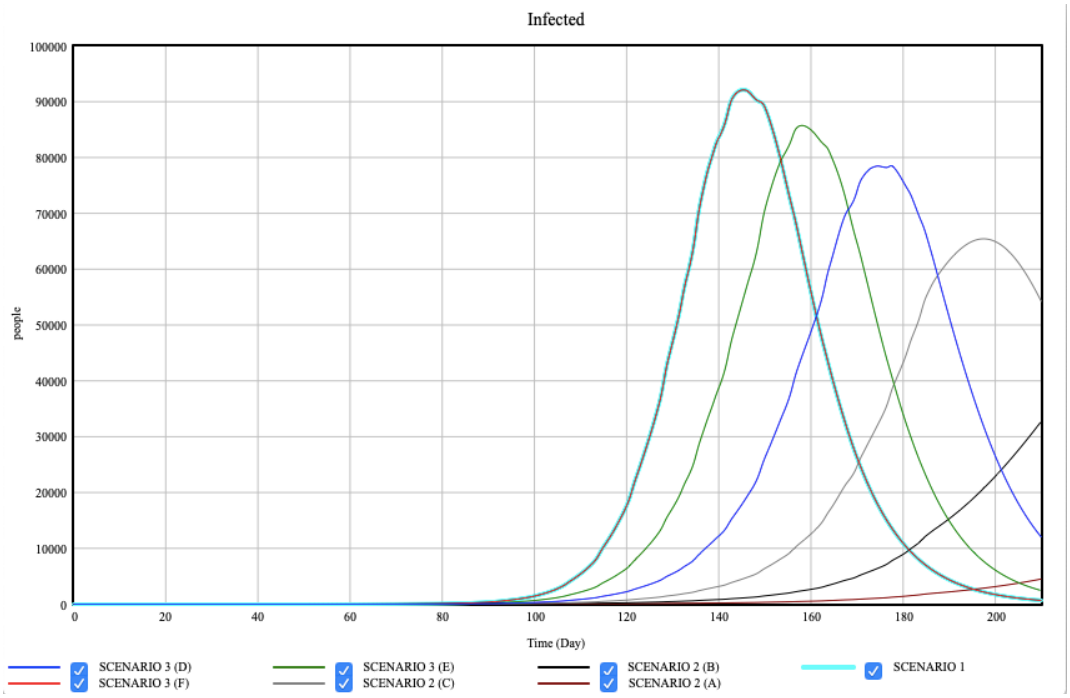


Figure 19 - Number of infected people in Scenarios 1, 2 and 3

Figure 19 demonstrates that the infected curve flattens according to the different contact density factors. Scenario 2 (A) has the lowest infection curve since this scenario has a home distribution (with no level of contact). The next curve is that of Scenario 2 (B), followed by Scenario 2 (C), Scenario 3 (D), Scenario 3 (E), and Scenario 3 (F).

The peak of cases when the contact density factor is 0.5 - scenario 3 (F) - is on day 145, with 92,072 people infected. Considering the contact density as 0 - scenario 2 (A) - the highest point of the infection curve is on day 210, with 4517 infected (Table 10).

Table 10 - Infected data results

Time (Day)	145	Time (Day)	210
Infected : SCENARIO 2 (A)	266.966	Infected : SCENARIO 2 (A)	4517.58
Infected : SCENARIO 2 (B)	1103.3	Infected : SCENARIO 2 (B)	32774.6
Infected : SCENARIO 2 (C)	4470.25	Infected : SCENARIO 2 (C)	54177.1
Infected : SCENARIO 3 (D)	17849.7	Infected : SCENARIO 3 (D)	11990.7
Infected : SCENARIO 3 (E)	53798.8	Infected : SCENARIO 3 (E)	2441.01
Infected : SCENARIO 3 (F)	92072.1	Infected : SCENARIO 3 (F)	680.479
Infected : SCENARIO 1	92117.6	Infected : SCENARIO 1	678.041

Scenarios 4, 5, and 6 show the same infection curve behaviour and are always between the curves of scenarios 2 and 3, as shown in Figure 20 and 21.

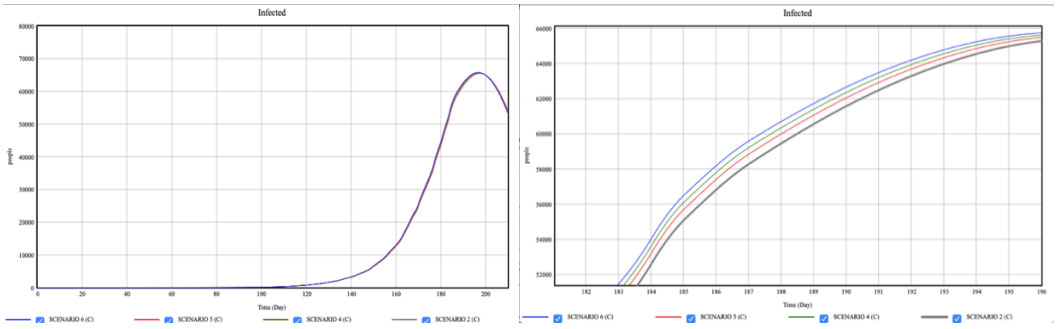


Figure 20 - Schematic representation showing that scenarios 4, 5, and 6 remain above scenario 2

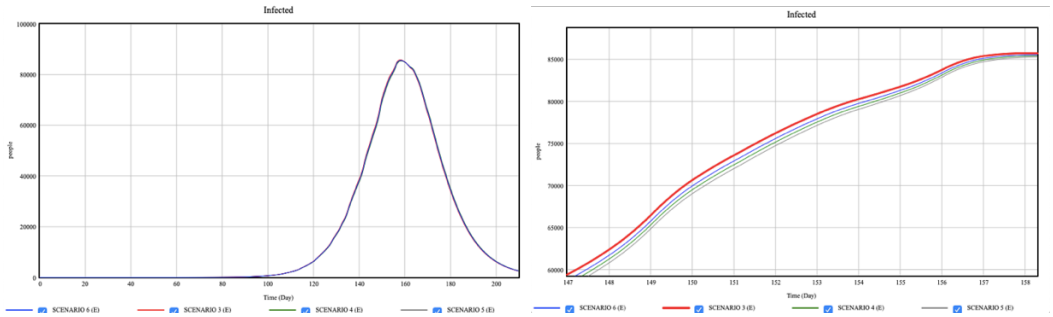


Figure 21 - Schematic representation showing that scenarios 4, 5, and 6 remain below scenario 3

Considering the infection curves presented, scenario 2 demonstrates better behaviour. Thus, scenario 2 presents a lower number of infected people. However, these results also vary according to the policy adopted when distributing the donations and how the beneficiaries to shop (local vs. supermarkets).

4.7 Discussion

We investigated the impacts of donating food and cleaning supplies to the vulnerable population in the BoP. We focused on two main aspects, i.e., affordability (food donations) and epidemic control (cleaning supply donations). We built an SD model based on empirical data collected from RJ communities and HOs. This section presents the practical discussion (Section 4.1.6.1) concerning our main results and the theoretical discussion (Section 4.1.6.2) considering the research subject and other relevant literature.

4.7.1 Practical discussion

Our research marks the first attempt of assessing the impact that donations have on the BoP populations, contributing to fulfil an academic research gap. We also show the importance of humanitarian aid in a pandemic context, given that the government has failed to appropriately support community inhabitants, especially during the COVID-19 outbreak (Andrade, 2020).

Our research findings emphasise that donations can improve the RJ BoP population's food affordability and reduce the number of infected people during a pandemic. This was only possible because of the effective participation of different stakeholders. The relevance of donations appears when governments are unable to meet the needs of inhabitants in such a short time frame. Therefore, we advocate in favour of stakeholder coordination so that a more significant portion of the population can receive aid.

Efficiency can be significantly affected depending on the type of donation made. Our modelling demonstrated that voucher donation has better results for food affordability. Reports on this topic showed that the direct distribution of food to the BoP caused an undesired side effect of food trading among residents in these vulnerable communities, affecting local sales, which were already severely affected by the ensued economic and sanitary crisis (Oliveira, 2020). Injecting money into the local economy through vouchers supports the maintenance of the financial system. In addition, last-mile deliveries represent a particular obstacle to distributing in-kind donations, as agglomerations contribute to the spread of the disease.

Our findings also demonstrated that in-kind donations present better results regarding the number of infected people. However, that is mainly because it prevents people from shopping and, therefore, becoming infected. Thus, how organisations deliver goods is also relevant. Agglomerations at donation pick-ups could significantly change the results of donation efforts. Therefore, actions such as delivering goods to beneficiaries' houses or organising pick-ups are also necessary when planning donations.

We emphasise that the results performed here do not encompass all possible scenarios. For instance, when we increase the percentage of donations spent on cleaning supplies, the donation of food decreases. If the beneficiaries do not have the necessary amount of food, they will need to leave their houses, which could cause an increase in the number of infections. Therefore, our results should be interpreted with caution. Even though our model shows that an increase in the percentage of cleaning supplies donated generates a decrease in the number of infections, it also reduces the population's affordability, eventually leading to more infections.

However, the importance of donations to support the BoP during crises, such as the pandemic, is indisputable. The type of donation, i.e., in-kind or voucher, depends on the primary needs of the beneficiaries and the project's objectives. Thus, if the focus is on an epidemiological issue focused on reducing cases, our model suggests prioritising in-kind donations and hygiene products. However, if the concern is about population food affordability, and local commerce, our results suggest voucher donations.

4.7.2 Theoretical discussion

Once a disaster strikes, financial aid is offered to the victims by different sources. However, most financial aid is temporary and short term (Behl et al., 2019; Behl and Dutta, 2019). The humanitarian project described and studied in this research, for example, is funded by individual, group contributions, and companies in the form of direct transfers to the HOs. However, it is not possible to determine how long this project will raise money. Other studies claim that the government is commonly the only stakeholder offering long-term support to the victims (Behl and Dutta, 2019).

Once the government understands/ is aware that the outbreak will cause economic impacts, containment measures (public policies) such as social support programs, food security plans and government financial assistance must be implemented. Cooperation and collaboration between the stakeholders are essential so that there is no rework during times of crisis. HOs and private companies can and should come together to help through donations. Alternatively, there are other sources of financial capitation, as crowdfunding and corporate social responsibility (CSR). Policies should be created regarding transportation and distribution plans, demand analysis plans, information-sharing tools, and even workforce adjustment once the HOs and companies can even use the BoP population to carry out the work.

Based on the data collected and the results achieved, we reinforce the need to engage other stakeholders beyond the government in donation campaigns. Supporting coordination efforts and collaboration between stakeholders (such as private and public donors, beneficiaries, HOs, and suppliers) is essential to fight the pandemic. In addition to corroborating the findings of Burkart et al. (2016), Fontainha et al. (2017), and Turrini et al. (2020), we believe that HOs should focus on aiding vulnerable populations during the pandemic (Vongkiatkajorn and Daily, 2020), ensuring that they receive supplies on time and in adequate quantities (Chakravarty, 2014). Our engagement with communities and HOs during data collection and the results we achieved emphasise that the effectiveness of donations is secured when incentives are aligned, communication among organisations is transparent, and stakeholders have clear roles. Furthermore, strategically designed donation programs must be deployed in operational practices, and activities should involve private-public arrangements, especially during a pandemic.

Our results are potentially applicable to other regions in the world, especially other low-and middle-income countries. In India, for example, as in Brazil, the BoP population has been severely affected by the pandemic. Chakrapani et al. (2020) argue that the lockdown scenario for BoP workers from India implied acute unemployment, lack of monetary resources, and an additional burden of supporting their families. The same phenomenon was experienced in the RJ population of BoP workers. Most of them, who are daily wagers, have lost their jobs, facing problems meeting their basic daily needs. Considering the similarity between the scenarios, we firmly believe that the types of donations investigated in this study would also reduce the number of infected people, deaths, and food

security of this portion of the population. However, according to Wimschneider et al. (2020), a typical characteristic of the Asian BoP is rural living circumstances, contrasting with the predominantly urban BoP in Latin America and Caribean, where 77% of these people are located in central city areas. Therefore, although donations can have positive results in countries with rural BoP populations, we believe that the results may differ slightly compared to regions with predominantly urban BoP populations.

4.8 Conclusions

This study aimed to comprehensively study the complexity of pandemics such as COVID-19 and the impacts of donations on reducing difficulties faced by the BoP population. The objective of our analyses was twofold: to determine how donations can reduce the number of people infected and deaths and how donations can secure food affordability. Regarding the number of infected people, our analysis (Table 10) demonstrates that the highest point of the infection curve could be reduced according to different scenarios, showing a difference of more than 57 thousand infected people between the scenario with the highest peak and that with the lowest peak. Concerning food affordability, we argue that affordability increases 20% when all donations are in the form of vouchers/cash (Scenario 3) compared to all in-kind donations (Scenario 2).

These numbers can serve as a basis for policymakers to aid vulnerable communities, especially during crises in which resources are scarce and must be efficiently explored. Thus, local governments can better plan and evaluate how their actions will impact people in need, including what and how to donate, besides federal government financial assistance. Furthermore, we hope that this work will encourage private for-profit organisations to participate in such actions, as it sheds light on the importance and impact of donations to these people.

Our study contributes to the literature by gathering evidence and providing insights into the role of donations to vulnerable communities in complex settings during periods of crisis. As little research concerning donations during the pandemic is found in the current literature, our paper is different from earlier studies on the particular topics of donations and pandemic responses as it: (i) focuses on the particular characteristics of donations (e.g., distribution channel, quantity,

frequency, type of product, delivery mode, and place of purchase goods with received voucher donation) and its effect on contagion rate in BoP population; (ii) unearths the dynamic patterns of behaviour emerging from the structured operations of donations and how they relate to the COVID-19 dynamics and (iii) explores the complex realities of the BoP population living in Brazilian favelas, which lack access to proper infrastructure and sanitation.

Additionally, our study corroborates results found in the grey literature, which emphasises that donations can limit the spread of the virus, protect key workers, and reduce the impact on some of the world's most vulnerable families (UNICEF, 2020). We highlight as our main contributions the development of an SD model that can capture, in addition to a classic SIR model, different aspects of social behaviour, including isolation, purchase of food and cleaning supplies, income, and donations. We also emphasise that the data were not empirically assumed but were estimated based on 2,155 survey responses from beneficiaries. Therefore, we hope that this research can justify the importance of donations and public-private-people relationships. We also expect to shed light on the experiences of BoP communities during times of emergency.

Our research has some limitations, which highlight possibilities for future studies. The first limitation is adopting a classic, however simple, epidemiological model (SIR model). As our research focus was not on epidemiological modelling, we opted for the classic SIR model. However, we suggest that future studies use more complex epidemiological models considering other factors, such as the number of hospitalisations and the number of beds available to the BoP population. The second concern is the isolation rates since we only consider changes of 1% and 2% according to the population movement. We also advocate the need for studies that describe ways in which donor motivation can be sustained since the lack of feedback might be discouraging. Also, concerning the model, we suggest that future studies consider variation in food prices during the pandemic, showing that the population's purchasing power was altered due to price fluctuations.

Finally, even though we have addressed the affordability topic, other pillars to examine food security are fundamental in future studies to define the direct relationship with the food security of the BoP population. The future scope of our work encompasses the triad composed of affordability (the ability of consumers to purchase food), availability (sufficiency of the national food supply and national

capacity to disseminate food), and quality (variety and nutritional quality of average diets), established dimensions necessary to examine food security (EIU, 2019).

5
Challenges to scale migration-related humanitarian operations

This chapter presents the Paper 3 (Cunha et al., 2022c). This paper will be submitted after the exam members considerations.

5.1 Introduction

Migration-related Humanitarian Operations (HO) have gained attention worldwide since data estimate that 3.6% of the world population are migrants (281 million) (IOM, 2022), a critical problem that can no longer be ignored (Oloruntoba and Banomyong, 2018). People around the world migrate due to climate-related disasters (e.g., the 2005 United States Katrina hurricane, the 2010 Haiti earthquake, and the 2017 floods and landslides that occurred in Sierra Leone's capital), conflicts and extreme violence (e.g., the current Ukrainian exodus, the Syrian migration since 2011 caused by the civil war, the Rohingya from Myanmar forced to seek safety in Bangladesh, and the Democratic Republic of the Congo) or economic, social, and political instability (e.g., faced by Venezuelans) (Missiriam and Schlenker, 2017; IOM, 2020; Cunha et al., 2021).

The scale and pace of international migration are notoriously challenging to predict as it is closely connected to acute events (e.g., severe instability, economic crisis, or conflict) and long-term trends (such as demographic change, economic development, and communications technology advances, and transportation access). Besides, international migration is not uniform globally but is shaped by economic, geographic, demographic, and other factors resulting in distinct migration patterns (IOM, 2022). These factors make planning a country's operation to receive immigrants complex and challenging. Thus, this paper analyses the scalability challenges of HO in migrant-receiving countries, aiming to understand how humanitarian operations scale capacity to meet the migrant's needs.

HO to host migrants are dynamically complex due to all the uncertainties involved in migratory movements (e.g., migration patterns, pace, and scale).

Besides involving multiple stakeholders, operating with extreme resource constraints (human and material) in environments with unreliable information and time-compressed schedules (Besiou and Van Wassenhove, 2021). Such dynamically complex environments are well aligned with System Dynamics (SD) approach to allow valuable insights (Gonçalves, 2008, Sopha and Asih, 2018; Besiou and Van Wassenhove, 2021). The SD method decomposes a real and complex problem into a set of variables, building models to understand and solve a particular problem from which insights might be generated into policies to improve system behaviour (Sterman, 2000; Abebe et al., 2021). Such models, both qualitative and quantitative modelling aspects of systems, are developed to investigate how complex systems evolve over time.

Evacuation planning and population routes/ places (usually focused on climate-related disasters, such as floods) are recurrent research themes in the interface of the academic literature on migratory movements and SD (Ahmad and Simonovic (2001); Simonovic and Ahmad (2005); Pujadi (2017); Da Silva et al. (2020); Favereau et al. (2020)). Transportation of relief supplies (Cruz-Cantillo, 2014), training of decision-makers in disaster response (Berariu et al., 2016), temporary shelter operations (Uddin et al., 2018), COVID-19 response to improve refugees' health and education (Allahi et al., 2021), and search and rescue migrants operations (Kosmas et al., 2022) are examples of research topics. However, to the best of our knowledge, there are no papers dealing with migrant-receiving HO through the development of SD models.

Our research has a strong social impact and contributes to the academic literature in four ways: (i) it provides discussion regarding the migration-related Humanitarian Operation Management (HOM) field; (ii) it provides a qualitative model exhibiting the interaction between the main pillars of migrant-related HO (i.e., border ordering, sheltering, and internalisation); (iii) it provides a general quantitative model, validated through a case study – Operation Welcome, the Brazilian federal government operation aimed at receiving, sheltering and internalising Venezuelans in Brazil – exploring the operation scalability – the need to increase or decrease its responsiveness according to a disaster magnitude - bottlenecks; and (iv) it unearths the dynamic patterns of behaviour emerging from the migration-related operation.

Our paper is structured as follows. Section 2 presents the theoretical foundation of our research, and Section 3 the problem statement. Section 4 offers the model development, including the causal loop diagram and the simulation model. Section 5 reports the model's applicability. Section 6 brings the discussion of theoretical and practical implications. Finally, Section 7 summarises the concluding remarks, limitations, and future research avenues.

5.2 Background

Scalability problems were first introduced in the manufacturing context since the rise of the assumption held by corporate leaders that the bigger is better, referring to the concept of "minimum efficient scale". This concept suggests that operations smaller than a specific size cannot be commercially viable. The logic of minimum efficient scale made managers strove to scale-up their companies' extent, aiming to deepen competitors and serve as a barrier to entry by potential newcomers (Pil and Holweg, 2003; Weiss, 1964).

In the manufacturing and industrial context, scalability is the ability to adjust the production capacity with minimal cost in minimal time (Putnik et al., 2013). It can be classified into physical – adding or removing material handling equipment, machines, and tools – and logical scalability attributes – including increasing or decreasing the number of workers or shifts by workers and outsourcing workers (Deif and ElMaraghy, 2007).

The capacity scalability problem is normally approached from a static view as the problem is the capacity expansion, aiming to meet increasing demand at a minimum cost (increased economic gains) (Deif and ElMaraghy, 2007; Nielsen and Lund, 2018). In a business context, for example, the primary understanding of scalability is related to its ability to exploit economies of scale (i.e., a rise in production capacity leads to a decrease in the unit costs of production) (Stampfl et al., 2013). However, in today's market, systems are typically faced with a rapidly changing and uncertain demand together with the continuous advancement of technology. Besides, businesses are concerned with managing people, processes, and other resources to produce their goods and services (Armistead and Machin, 1997); therefore, they are involved with their Operations Management (OM). Thus,

addressing the capacity scalability problem from a dynamic viewpoint has become more necessary (Deif and ElMaraghy, 2007).

Besides manufacturing, industrial, and business areas, scalability applications have grown over time, gaining notoriety in an ample range of application areas, such as Computer Science and Information Technology, Research and Development, Management, and Economics (Putnik et al., 2013; Stampfl et al., 2013; Lund and Nielsen, 2018; Hultberg and Pal, 2021).

In the HO context, the need to increase or decrease its responsiveness according to a disaster magnitude is also configured as a scalability problem (Tabaklar, 2017). Thus, in humanitarian settings, scalability refers to the scaling up and down of operations; from preparedness to the immediate response to a disaster, operations are scaled up, and from preparedness to reconstruction relief, operations are scaled down considering an anticipation strategy (Tabaklar, 2017).

Although the concept of scalability is defined in the humanitarian context, we found little research using the term scalability in our academic literature searches. Papers refer to the need to scale operations as the abrupt rise in demands causes shortages supplied through capacity building. Therefore, the HO literature discusses the importance of capacity building in effectively providing humanitarian relief (Gonçalves, 2011). Duran et al. (2011) mention that humanitarian organisations can enhance their emergency-response capacity by ensuring higher availability of relief supplies by pre-positioning inventory. Gonçalves (2011) discusses the trade-off between providing aid and building capacity (hiring and training people, capturing lessons learned, and structuring organisational processes) in humanitarian organisations. Besiou et al. (2014) research humanitarian fleet management and funding capacity in the aftermath of a disaster, as procurement capacity may be a problem in large-scale disasters. More recently, Gonçalves et al. (2022) approach the need to adjust hospital capacity (e.g., intensive care unit and ward beds, medical and nursing staff, and oxygen supply) during the COVID-19 pandemic to manage service capacity.

Despite these interesting contributions in the HO field considering scalability, these papers do not address the migration topic. Although there are some efforts to construct computable models of migration, the incorporation of associated policies has only been minimally explored (Nagurney et al., 2021). Besides, the academic literature permeating migratory movements and SD is restricted,

presenting research on topics such as: evacuation planning and population routes/ places, transportation of relief supplies, training of decision-makers in disaster response, temporary shelter, and search and rescue migrants operations example of literature. Disaster-affected migration appears as an opportunity for future research, with the scalability of migrant-receiving operations being the focus of our research.

5.3 Problem statement

Disasters are characterised as disruptions that physically affect a system as a whole and threatens its priorities and goals (Van Wassenhove, 2006). Different types of disasters are observed, such as sudden-onset or slow-onset disasters: (i) disasters caused by natural hazards (earthquake and hurricane are examples of sudden-onset disasters and famine, drought, poverty of slow on-set disasters); (ii) disasters caused by human actions (terrorist attack, and chemical spill are examples of sudden-onset disasters and political and refugee crisis of slow on-set disasters) (Van Wassenhove, 2006).

Considering the different disaster types, HO to face these disasters' present differences and similarities. For example, in all types of disasters, cooperation between stakeholders is a key factor in the efficiency of the operation. On the other hand, in sudden-onset disasters, the response focus will be on short-term operations, with an emphasis on saving lives and alleviating human suffering. In refugee crises, however, in addition to a short-term response (immediate response to assist migrants, providing food, water, and medical support, for example), long-term development operations (provision of necessary supplies, placement in shelters, socio-economic insertion) are needed.

Migratory movements happen year after year around the globe, and the response of migrant-receiving countries differs. Nation-states have classified migrants into specific categories (Garcia-Zamor, 2017). An international migrant is any person who has moved across an international border away from his/her habitual place of residence regardless of the cause, legal status, and length of the stay (Sweileh et al., 2018). A refugee, in turn, is a person fleeing conflict or persecution (deprivation of life, liberty, or physical being) defined and protected by international law. Unlike refugees, who cannot safely return home, migrants do

have the freedom to return home and continue to receive their government's protection (Sweileh et al., 2018). While a refugee is a forced migrant who seeks asylum abroad, an internally displaced person (IDP) is a forced migrant who relocates within the borders of her or his country of origin (Moore and Shellman, 2006).

However, regardless of where the migrant is coming from and the reason for their migration, when the migratory movement exceeds the absorption capacity of the receiving place, this is characterized as a disaster. The reception, welfare, and integration of migrants needing assistance are always nested in a complex background of dynamic multi-disciplinary issues (e.g., human rights, politics, healthcare, nutrition, gender, child protection), coordinated through HO (Oloruntoba and Banomyong, 2018). Therefore, finding a way to provide immediately (e.g., food, water, and healthcare) and longer-term aid (e.g., integration into host communities) is challenging. We can divide migrant-receiving HO into three main pillars, in which different attributions will compete: reception of migrants, shelter, and socio-economic insertion of these migrants in the receiving country. The scope of possible attributes is broad: search and rescue activities, triage, documentation, first aid, vaccine, feeding, sheltering, sanitation, providing cleaning supplies, and resettling beneficiaries to new locations, for example (Oloruntoba and Banomyong, 2018).

Researches state that the context of past experiences with displacement leads to political variations in refugee crisis response, addressing mainly security and economic concerns (Lischer, 2017). Therefore, good past migration experience tends to determine initial responses toward new people, while bad past experiences lead to restrictive policies for receiving new migrants (admission control policies). In many Middle Eastern countries, for example, the bad past experience with Palestinian refugees has shaped the response to Iraqi and Syrian refugees. Therefore, the influx of Iraqi to Jordan in 2006 led to restrictions that violated international refugee protection guidelines, with the government considering the Iraqis illegal rather than refugees. In 2008, Jordan introduced visa restrictions that required Iraqis to apply for a visa in Iraq rather than at the Jordanian border crossing (Lischer, 2017). The Turkish governments response to Syrian refugees has also created a precarious situation for Syrians on the border. Turkey does not grant Syrians refugee status or allow them to register for refugee; instead, they are given

"temporary protection." In 2013, Turkey adopted a policy that recognises Syrians as "guests" rather than as refugees and uses the term "guest camps" rather than refugee camps (Lischer, 2017).

The so-called Mediterranean migration crisis has also become a controversial issue in West European politics regarding admission control policies, with much debate about human rights and how to respond to the crisis. Italy adopted searches and rescue operations in 2013, often overshadowed by European Union (EU) member states' border – closure strategies supposedly adopted to guarantee border security (Panebianco, 2019). The Mediterranean migration crisis can also serve as an example of another recurrent migration policy: shelter capacity control (accommodations or refugee camps). Greek islands hosted, for example, a high number of migrants in irregular accommodations. Moria shelter, initially designed for hosting 3000 people, has expanded irregularly to host 12,000 people (Gökalp et al., 2022). To better manage the current and future flows, the Greek government has announced that it plans to replace the existing irregular structures with new accommodation centres with predefined capacities (Gökalp et al., 2022).

How governments deal with shelters or refugee camps differs from one country to another. Capacity control policies are recurrent so that governments may have some control over this vulnerable population. Some governments adopt practices that treat refugee camps as "incubators of social unrest, terrorism, and illicit markets" (Lischer, 2017). However, despite attempts to restrict refugees and regulate their living conditions, many businesses prosper in the Zaatari camp in Jordan, for example, services such as pizza delivery and wedding dress rentals (Lischer, 2017). In Kenya, the Dadaab camp is called a "closed camp", where refugees must obtain official permission to leave, and income generation is highly restricted (Lischer, 2017). The more restrictive the practices allowed in the shelters, the more difficult the process of socio-economic insertion of migrants into the community.

Besides the reception and shelter of vulnerable migrants, the socioeconomic insertion in the receiving country is essential for the community's well-being. For this insertion, the reduction of a floating population in the border region is of interest to the receiving country, as border cities do not usually have enough structure to socioeconomically absorb a large flow of migrants (Nargurey et al, 2020).. Therefore, through the implementation of incentives, the host country must

integrate these migrants into society, seeking greater socioeconomic well-being (Nargurey et al, 2020). The relocation mechanism decision of the EU – the distribution of persons in need of international protection among the Member States – to assist frontline states Greece and Italy in coping with many refugees travelling from the Mediterranean is an example of socioeconomic insertion (Šabić, 2017).

The scalability presents itself as an issue for the three pillars, not only a high number of migrants, but also a rupture in the migration pattern. Therefore, with a great influx of migrants or a change in the migration trend, the border management needs physical space to receive migrants needing assistance, immediate response supplies (food, medicine, and water), and greater documentation capacity, for example. The shelter management needs more physical structure, staff, and supplies (food, water, and hygiene products), while the socio-economical insertion management needs programs and policies that allow more migrants to be integrated into the community

5.4 Model development

This section describes a qualitative modelling of migrant-receiving countries (subsection 4.1) - considering the feedback structure diagramming among the variables from a cause to an effect through causal loop diagrams (CLD). Developing a CLD improves our conceptual system understanding and helps identify critical relationships among system variables (Abebe et al., 2021). Once the dynamic behaviour cannot reliably be inferred from qualitative models alone, then subsection 4.2 describes the quantitative stock and flow diagrams (SFD) and assign mathematical rules to determine the interactions between the variables (Sterman, 2000; Abebe et al., 2021).

In our research, we adopted the nomenclature migrants referring to international migrants, who may be refugees or temporary residence applicants. Our models do not consider internal displacement movements.

5.4.1 Causal loop diagram

We developed a CLD through an inductive modelling approach after understanding the literature and the main pillars of migrant-receiving HO. Therefore, from a sample of cases, dynamic hypotheses were raised to reach a

general framework (Cavana and Mares, 2004), presented through our CLD. The CLD begins with the representation of migrants crossing a migrant-receiving border. As more migrants needing assistance cross a border seeking for aid, the greater the resources required to manage the border. Considering the HO reception capacity (resources available to reception) and the desired reception capacity (total number of migrants at the border), a gap in border management resources appears. This gap creates pressure to increase investment to receive migrants needing assistance (Fig. 22, loop B1). Besides, the need for economic and social integration of those migrants also pressures authorities (Fig. 22, loop R1). The border ordering pillar directly influences the shelter of migrants needing assistance. The more unassisted migrants cross a migrant-receiving country border, the greater the number of migrants needing shelter. As the number of migrants requiring shelter increases against the installed capacity to receive migrants, the HO faces an increase in unmet demand for shelters. As the migrant-receiving country fails to serve all migrants in need, spontaneous occupations and illegal economies emerge. In turn, the unmet immigrant demand, the growth of spontaneous occupations, and illegal economies increase the pressure for further investment in the Shelter pillar (Fig. 22, loop B2). Finally, the main variables referring to the migrants internalisation to other places of the migrant-receiving country are captured. As the number of migrants sheltered increased, so do the need to internalise these migrants and open a vacancy to assist new unassisted people. Once again, if the internalisation rates are lower than the demand for internalisation, pressure on the government to make more investments in the Internalisation pillar of the HO are generated (Fig.22, loop B3).

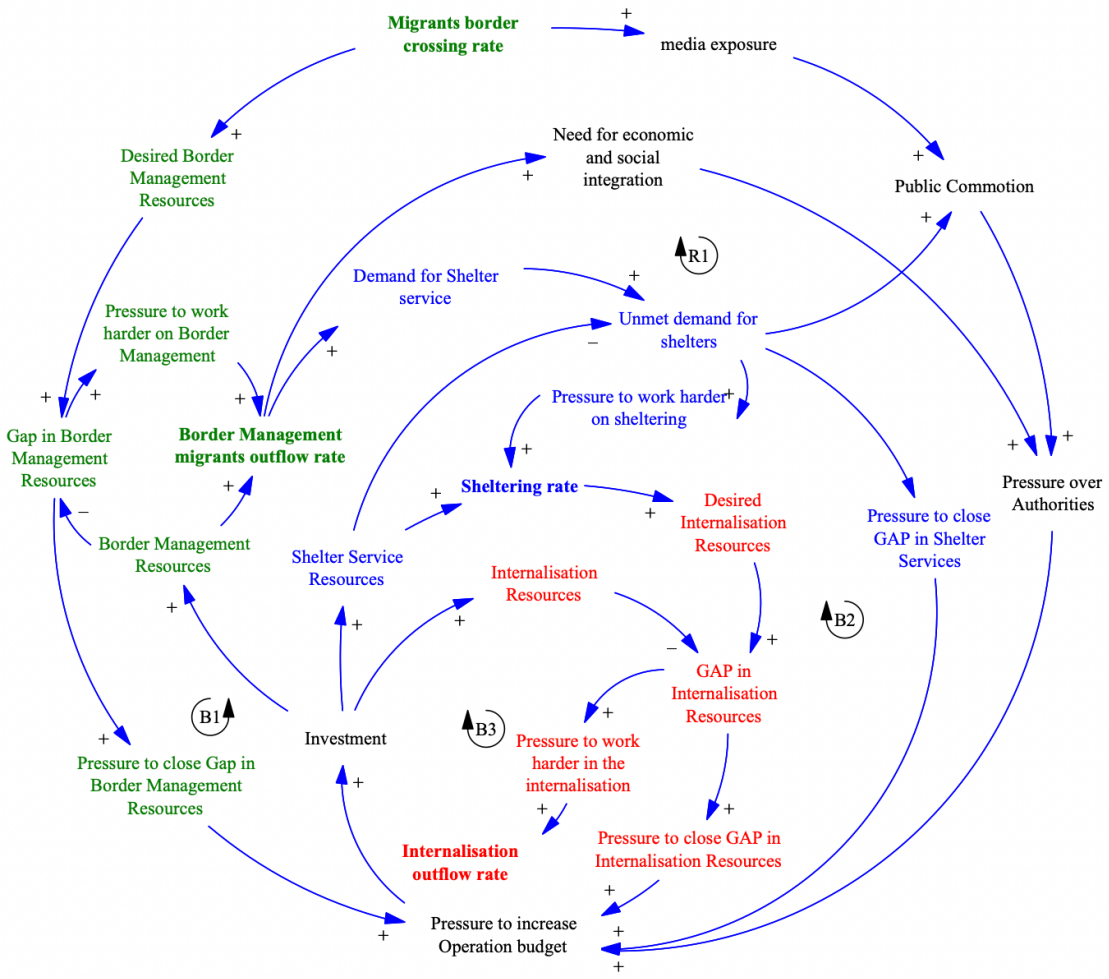


Figure 22 - Causal Loop Diagram representation

Schematic representation. Variables related to reception and border management are represented in green; variables related to shelter are represented in blue; internalisation process variables are represented in red; variables that permeate the operation are represented in black.

5.4.2 Simulation model

Once we translated the problem into a CLD, we moved on to developing an SFD (Figure 23 presents the developed model). We started by capturing the path taken by migrants once they cross the border of a migrant-receiving country. A migrant-receiving country receives not only migrants needing assistance but also migrants with financial conditions to maintain themselves. Therefore, in our model, we have the distinction between migrants needing assistance (named vulnerable in our model) and migrants non needing assistance (named non-vulnerable migrants). The migrants non needing assistance cross the border, pass through the regulatory agency of the receiving country to validate their documents, and follow their paths

without needing humanitarian assistance. The other migrants need assistance, shelter, and help for their socio-economic insertion in the receiving country (internalisation process). As the shelters have a maximum capacity, we consider that part of the migrants may not be allocated in shelters and, consequently, end up going to spontaneous occupations. Finally, we consider in our model that all migrants sheltered are candidates for internalisation, that is, to be transferred to other places in the country considering a socio-economic insertion. This insertion may be due to a job vacancy or due to meeting a family member with proven conditions to receive this vulnerable migrant, for example.

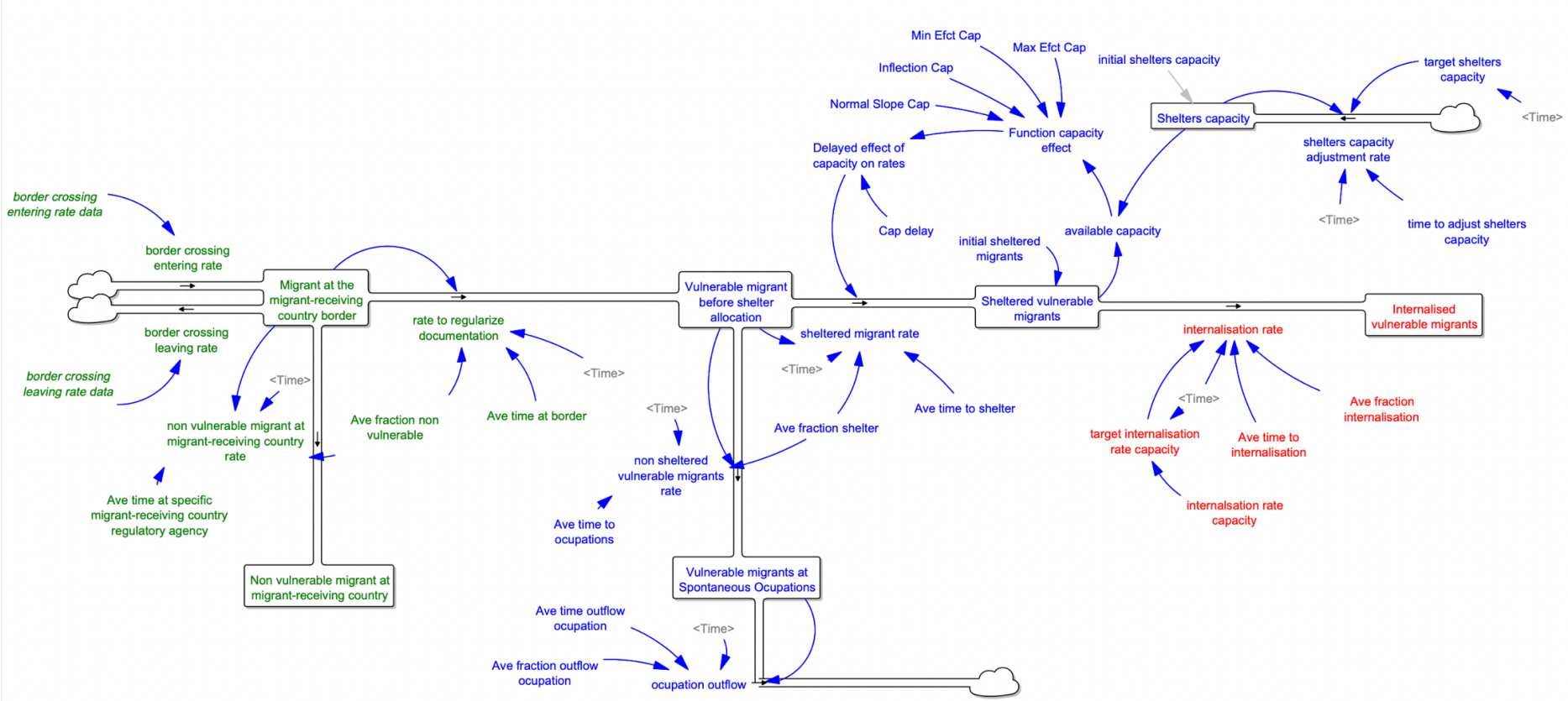


Figure 23 – System Dynamics simulation model

Schematic representation. Variables related to reception and border management are represented in green; variables related to shelter are represented in blue; internalisation process variables are represented in red.

The levels or stocks, represented in the model by boxes, are the physical points of storage. Thus, stocks accumulate or integrate their flows (represented by the double-line arrows). Equation 1 represents the mathematical formulation that capture the accumulation at each stage of the model, where Inflow(s) and Outflow(s) represent the value of inflow and outflow at any time *s* between the initial time *t0* and the current time *t*. Each flow, in turn, has a different mathematical formulation, (presented in Table 18 at Appendix 4).

$$Stock(t) = \int_{t0}^{t} [Inflow(s) - Outflow(s)]ds + Stock(t0) \quad (1)$$

As we expect to analyse the scalability of the operation, the model presents shelter and internalisation capacity constraints. As the operation has more available capacity, the greater the flow of people to be sheltered. However, as the available capacity is scared, the flow of people is small. We capture this non-linearity through an s-shaped logistic function, as shown in equation 2.

$$f(x) = (Max + Min) * \left(1 - \frac{\exp\big(slope * (x - inflection)\big)}{1 + \exp\big(slope * (x - inflection)\big)}\right) - Min \quad (2)$$

The lower bound (Min) and the upper bound (Max) capture the minimum and maximum effect of available capacity on the shelter's desired level. The inflection point determines the change in concavity. The slope reflects the operation sensitivity towards the migrants available shelter capacity. Full model calibration determines the values of the parameters in the logistic function.

The model also presents Internalisation capacity constraints. Thus, the internalisation rate is the minimum between the max internalisation capacity and the fraction of Venezuelans to be internalised by the time until internalisation.

5.5 Model applicability

This section presents the case study in which we applied and analysed our model. Therefore, subsection 5.1 presents the studied operation, subsection 5.2 presents the model adjustments based on the operation studied, subsection 5.3

presents the data collected and, finally, subsection 5.4 presents the policies defined to be simulated in this specific case.

5.5.1 Case study

Between the 60s and 80s, Venezuela was considered an immigrant host country because of the economic boom due to oil exploration. This situation changed after establishing a political and economic model that has deteriorated living conditions in Venezuela, turning it into a country of emigrants (Mazuera-Arias et al., 2020). Therefore, a massive outflow of people from Venezuela has been recorded since 2015 and has intensified over time since runaway inflation and shortages of essential goods, pushing people into poverty and increasing difficulty to access basic food products, health services, and public services. The social, economic, and political crisis in Venezuela has caused a part of the population to struggle with hunger, disease, and risk of death. It has led to the infringement of fundamental rights such as access to nourishment, health, security, and acceptable living standards (Mazuera-Arias et al., 2020; Aron Said and Castillo Jara, 2020).

An August 2022 report indicates approximately 6.81 million Venezuelan migrants, turning the Venezuelan migratory movement into Latin America (LA) largest external displacement crisis (Sweileh et al., 2018; Freier and Pérez, 2021; Mougenot et al., 2021). The Venezuelan migration is an unprecedented phenomenon in LA history regarding its social-economic and political impact and scale on the migrant-receiving countries (Mazuera-Arias et al., 2020), constituting a significant challenge for receiving countries across the region (Aron Said and Castillo Jara, 2020). Among the countries with the highest destination for Venezuelans are Colombia (2.48 million migrants), Peru (1.29 million migrants), Ecuador (502,200 migrants), Chile (448,100 migrants), and Brazil (358,400 migrants) (R4V, 2022).

Although Brazil is the fifth country to receive Venezuelans, Venezuelans enter Brazil in a border town named Pacaraima, in the state of Roraima. According to the Brazilian Institute of Geography and Statistics (IBGE), Pacaraima had an estimated population of 20 thousand people in 2021. The capital of the state of Roraima, Boa Vista city, in turn, had an estimated population of 436 thousand people in 2021 (IBGE, 2022). Thus, in this case, the migratory movement becomes

even more relevant since the border city and the state capital do not have the structure (physical and human resources) and conditions (supplies, financial resources) to support the entry and permanence of 358,000 migrants.

Therefore, we analyse the main challenges involved in the Operação Acolhida (Operation Welcome) scalability, the HO designed to receive Venezuelan immigrants in Brazil. In 2018, the Brazilian Federal Government created Operation Welcome. The Brazilian Provisional Measure number 820/2018, from February 2018, recognises the emergency humanitarian crisis, created the Federal Emergency Assistance Committee, and established emergency assistance measures for Venezuelan migrants and refugees. Ordinance number 629/2018 (March 2018) guaranteed the transfer of 1.9 million reais for shelter and social assistance actions. Also, in March 2018, Provisional Measure number 823/2018 opened an extraordinary credit of 190 million reais to finance the operational plan. Other ordinances followed, such as ordinances 1384 and 1385, which guaranteed the transfer of more than 190 million to be applied to health actions and services.

The Brazilian Operation' actions took place according to the immediate needs of the migrants. Therefore, the military personnel created a physical structure at Pacaraima city (border town with Venezuela) to receive the Venezuelans, followed by a space to shelter them at Boa Vista city (capital of Roraima state). These measures established the first two pillars of Operation Welcome: border ordering (e.g., documentation, vaccination, control, child protection, and other supports) and shelter (e.g., provision of shelter, food, sanitation supplies, and health care), as represented in Figure 22. Both pillars are coordinated by the military and by non-governmental organizations (e.g., International Organisation for Migration (IOM), and the UN Refugee Agency (UHHCR)). Over time, the Operation began efforts for the socio-economic insertion of vulnerable migrants in Brazil. For this, the third pillar of the Operation was created, the internalisation: the voluntary resettlement of Venezuelans from the border region to other Federation Units, with the objective of socio-economic inclusion (Operation Welcome, 2021). Therefore, the Operations goals include receiving, identifying, sorting, immunising, housing, and internalising migrants in vulnerable situations resulting from the migratory flow caused by the humanitarian crisis (Operation Welcome Compendium 001, 2019).

We consider the Brazilian government objectives and operational actions to host these migrants and the decisions to scale the Operation as migration flows

grew. Records show that the number of migrants has risen since 2015, reaching 800 people a day crossing the Brazilian border in 2019 (Silva et al., 2020). However, in mid-March 2020, Brazil's borders closed due to the COVID-19 pandemic (UNHCR Brazil, 2020). As a result, the contingents previously mobilised to act in the frontier or at the shelters were dismissed or relocated. With the opening of the borders after the pandemic, a suppressed flow of Venezuelans was expected. Nevertheless, the HO needed to scale down during the pandemic period, and there was a need for a fast HO scale up with the high flow of post-pandemic migrants.

Figure 24 illustrates the three pillars of Operation through OCHA Humanitarian Icons Guidelines and the complexities involved in the scalability of the operational assets. Thus, when it comes to scaling up or down an operation, different assets can be involved in these processes, such as time, staff management, needs assessment, financing community engagement, reporting, and information management.

Time is an essential asset as it takes time to scale an operation, time to plan, time to implement, and time for results. Staff management is necessary since a more significant number of military personnel is needed to increase an operation and, to decrease the operation, a smaller staff number. Similarly, a needs assessment is required as with more vulnerable migrants and more staff in operation, more supplies will be needed (e.g., food, medicine, hygiene products), and with fewer migrants and fewer staff, fewer supplies are required. The operation finances directly influence staff management and need assessment. Therefore, to scale an operation, the available budget must certainly be considered. Community engagement is a factor that pressures authorities to increase the funding available for operation; for example, with more vulnerable migrants on the streets, greater pressure on authorities to shelter them. Reporting and documenting all decisions and working with correct and concise information helps in making future decisions, making these valuable assets.

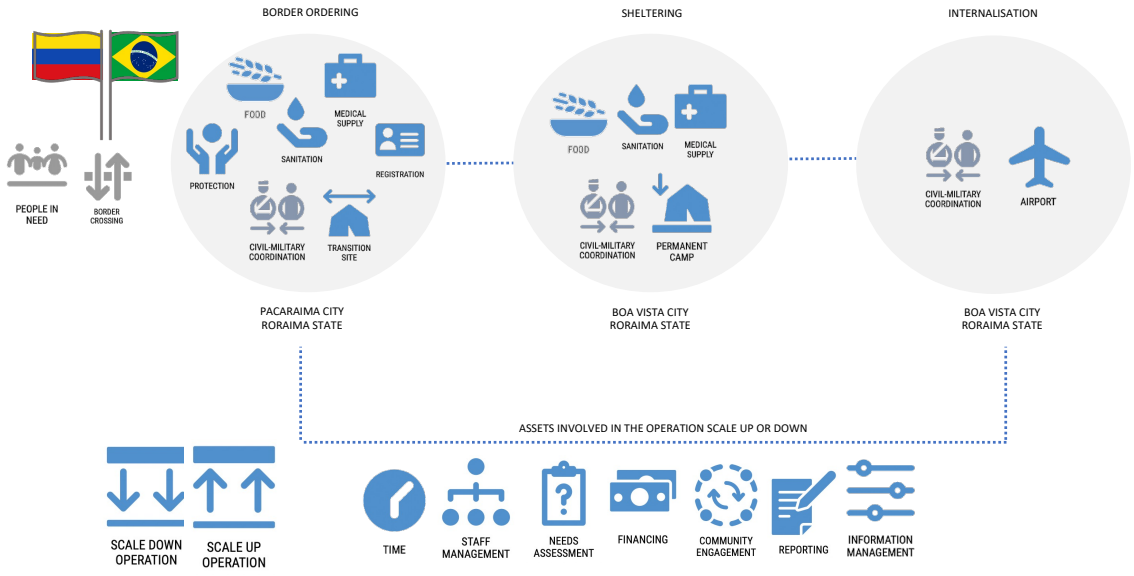


Figure 24 - Operation Welcome operational pillars

5.5.2 Model adjustment

We adjusted the model presented in Figure 23 to fit Operation Welcome. First, in addition to the shelters in Boa Vista, Operation Welcome offers temporary accommodation (lodge) in Pacaraima city. Therefore, when migrants cannot be allocated on the same day in shelters in Boa Vista, they can be accommodated in Pacaraima lodge (if the lodge is not at total capacity). In the model, it was necessary to add stock for the lodge, lodge accumulation stock inflow and outflow, and a capacity control mechanism as the mechanism of the shelters. Secondly, it was necessary to add to the model the flow of sheltered migrants who chose to return to their country of origin, in this case, Venezuela. Although it is recurrent that migrants still in vulnerable situations choose to return to their country of origin, what happens in the case of Venezuela to Brazil differs as migrants leave shelters. Some migrants take advantage of their stay in shelters (where it is not necessary to pay rent, food, or hygiene materials) to work and earn money. This practice does not represent a problem considering that the migrants are capitalizing themselves in search of their independence. However, with the COVID-19 pandemic, migrants who had saved money (as 1 Brazilian real corresponded, approximately, to 110 thousand Venezuelan bolivars in August 2022) chose to return to Venezuela to help their families. Third, our model considered three operation moments: before the COVID-

19 pandemic, during the COVID-19 pandemic and border closure, and after the border opening (we call the periods before, during, and after at the model). This operation moment differentiation represents a break in the migratory trend, as migrations were taking place before the COVID-19 pandemic, and it represented a rupture, closing of several borders worldwide. The border opening brought the migratory trend up again, causing repressed flows to reoccur. Therefore, we formulate the model rates considering the three moments.

5.5.3 Data collection

To collect empirical data regarding the operation pillars, we adopt the case study methodology proposed by Yin (2013) and guidelines offered by Voss et al. (2002) for a case study in OM. Therefore, a study protocol was developed to guide the researchers in collecting data.

Field visits were carried out in January 2020, before the pandemic be declared, in Roraima State (both in Pacaraima and Boa Vista cities). Field visits included visits to several shelters, two spontaneous occupations (e.g., unregulated immigrant occupations within the city) and Operations military installations (e.g., interagency base, Reception and Support Desk, identification post, and internalisation and triage post). Five semi-structured interviews were carried out formally, recorded, and transcribed, with an informed consent form, requesting authorization to use the information in academic reports and publications, with representatives from different humanitarian organisations (e.g., IOM, UNHCR, UN Women, Doctors Without Borders (MSF), and United Nations International Childrens Emergency Fund (UNICEF)). Other interviews were carried out in a more informal way, with military personnel during field visits (e.g., the Operations Coordinator, shelter managers, military installations coordinators, internalisation personnel, military officers that accompanied the field visits).

Besides the content and direct observations gathered during interviews and field visits, the case study involves a review of open-access documents and internal documents from the operation. Data triangulation is guaranteed through multiple means of data collection (Voss et al., 2002), increasing the robustness and validity of the case study.

Finally, in addition to the knowledge acquired and documents collected during the field visit, direct contact with the operation's managers was maintained throughout the development of the work. E-mail contact was maintained so that we constantly updated the spreadsheet with data needed for the model (presented in Table 11). Mobile app (WhatsApp) contact was maintained so that doubts and questions related to the operation could be answered more immediately. Table 11 presents the type of data used in the research, referring to the period March 2018 to February 2022 (48 months).

Table 11 - Empirical data collected

Empirical Data	Unit	Description
VNZ border crossing entering data	[people/month]	Number of Venezuelans crossing the border and entering Brazil
VNZ border crossing leaving data	[people/month]	Number of Venezuelans crossing the border and leaving Brazil
VNZ lodged data	[people]	Number of Venezuelans lodged at Pacaraima city
VNZ lodge capacity	[people]	Total capacity of Pacaraima lodges
Sheltered VNZ	[people]	Number of Venezuelans sheltered at Boa Vista city
Shelters capacity	[people]	Total capacity of the Boa Vista shelters
VNZ in Occupations	[people]	Number of Venezuelans not sheltered who are in spontaneous occupations
Return migration rate	[people/month]	Number of sheltered Venezuelans who choose to return to Venezuela
Internalised VNZ rate	[people/month]	Number of Venezuelans internalised by month
Internalised VNZ	[people]	Accumulated number of Venezuelans internalised

The monthly number of Venezuelans entering and leaving Brazil are inputs to the model. Since Venezuelans can cross the border, entering Pacaraima city for sightseeing, family visits, work, shopping, or other legal activities, the monthly flow of Venezuelans returning to Venezuela is high (up to 30% of the number of entries). Thus, we added to the model not only the number of entries but also the number of exits across the border since these migrants do not need the assistance of the operation.

Data referring to the number of Venezuelans lodged, sheltered, in spontaneous occupations, and internalised, as well as data on the capacity of lodges and shelters, are used to validate and calibrate the model.

5.5.4 Model calibration and validation

To develop a model credible for decision-makers (Freebairn et al., 2022), we adopted a participatory system modelling, engaging decision-makers in a collaborative learning process where they could contribute with their expertise in the model development. Therefore, considering the availability of the military involved in the operation, questions were asked throughout the modelling process to resolve possible doubts regarding the operation under analysis.

We subjected our model to a series of structural and behavioural validity tests, following a process suggested by Barlas (1996), Schwaninger and Grösser (2016) and Sterman (2000), to ensure the findings' validity. Structural and behavioural validity tests were performed incrementally; since the models beginning, we have verified the structural and behavioural relationships captured in our formulations. The first version of the model considered only the first pillar (border ordering). A revised version included the second pillar (sheltering), and a later version considered the integration of the three pillars of the operation.

Model structure tests assess whether model logic is consistent with real-world structure (Schwaninger & Grösser, 2016). We performed a dimensional consistency test to check the consistency of the dimensional units to establish the internal validity of the model. Model behaviour tests are empirical and compare simulation outcomes with actual data. We tested for behavioural anomalies throughout the modelling process, and we used model calibration to test the ability of the model to replicate observed behaviour, comparing the simulated behaviour of the model against available time-series data from real counterparts (Forrester, 1979; Homer, 2012). Figure 25 presents in red the empirical data collected, and in blue the simulation result, showing a very similar behaviour of five different variables: lodged VNZ, Sheltered VNZ, Internalised VNZ, BV Occupations, and VNZ return.

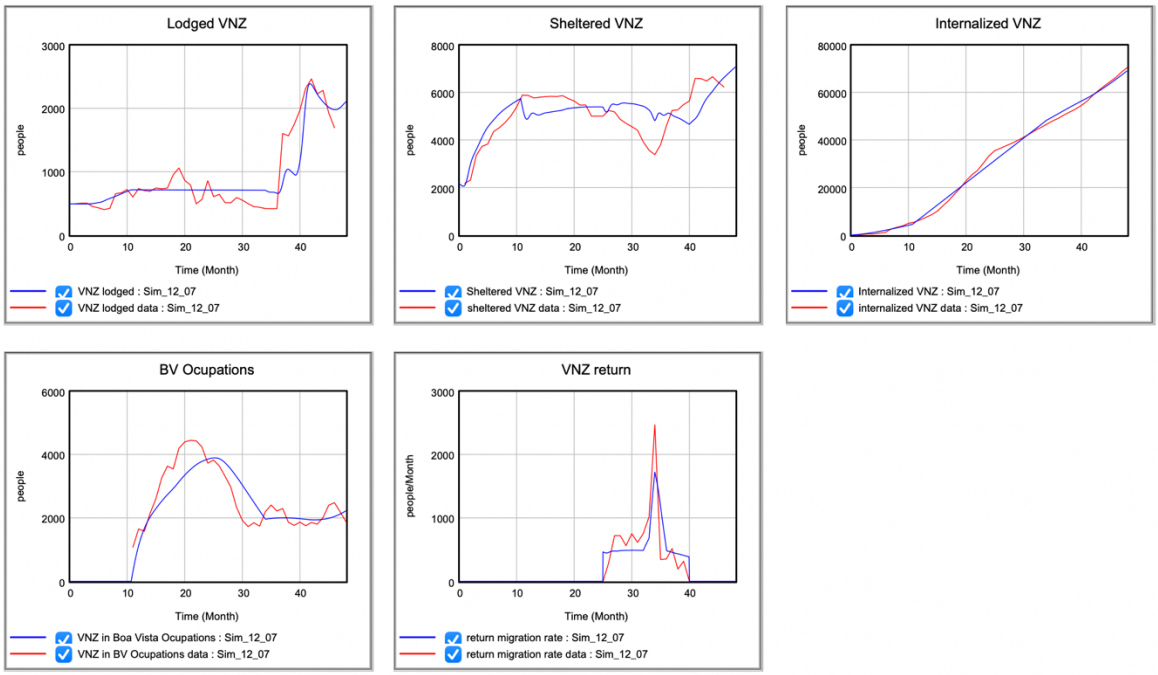


Figure 25- Empirical scenario simulation

To perform the calibration, we used the Vensim software optimization tool. The Payoff definition function determine whether optimization tool is used to calibrate the model to data or choose a best policy. Our calibration Payoff function considered the comparison between the variables simulated and the actual data variables (presented in Figure 25), according to the different weights for each pair of variables. The weights value in the calibration function are the data normalization (1 divided by the standard deviation of the data). In addition to the graphs, Theil Statistics were also analysed to reinforce the fit between the data. Table 12 shows the normalization as well as the result of R^2 and Thales statistics.

Table 12- Calibration statistics

Component	Normalization	R^2	U^M	U^S	U^C
VNZ lodged	0,00166252	0,805417	0,005505	0,154358	0,840136
Sheltered VNZ	0,000949069	0,480451	0,009228	0,173155	0,817618
VNZ in Occupations	0,00105222	0,649122	0,024046	0,046549	0,929406
return migration rate	0,00233753	0,774938	0,00152	0,16412	0,83436
Internalised VNZ	0,0012694	0,995	0,000513	0,007788	0,991699

R^2 measures the fraction of variance in the data "explained" by the model, in other words, is the square of the correlation coefficient, which measures the degree to which two series covary (Sterman, 2000). If the model exactly replicates the actual series, then $R^2=1$.

The Theil inequality statistics provide an elegant decomposition of the error by dividing the mean square error (MSE) into three components: bias (U^M), unequal variation (U^S), and unequal covariation (U^C). Bias arises when the model output and data have different means. Unequal variation indicates that the variances of the two series differ. Unequal covariation means the model and data are imperfectly correlated, that is, they differ point by point (Sterman, 2000). As $U^M + U^S + U^C = 1$, a small U^M and U^S, lead to small and unsystematic error (concentrated in U^C).

Table 12 shows that in out model, theil inequality statistics generally show low bias and unequal variation (U^M and U^S), suggesting unsystematic error. The variable for the number of Venezuelans Occupations presents the poorest fit, with about 2% bias and 4% unequal variation, and the variable for the number of Sheltered Venezuelans, with about 0.9 % bias and 17 % unequal variation.

5.5.4.1 Model policies and scenarios definition

Considering the focus of our research (scalability of migrant-receiving HO), the problem statement, and the Operation Welcome case presented, two groups of policies are analysed in our research: admission control and capacity control policies. Admission control policies are adopted so that the capacity of the system can change according to determined restrictions. Capacity control policies, in turn, are aimed at directly controlling the system's capacity, by controlling the capacity of lodge, shelters, and internalisation.

From the admission control policy, we adopted two streams in our research: (i) extreme control of accepting or rejecting migrants; (ii) varying the arrival process in an intermediate manner. From the capacity control policy, we considered the lodge, the shelter, and the internalisation capacity. Table 13 presents the scenarios simulated and analysed.

Table 13 - Scenario Analysis

	Policy	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16	Scenario 17	Scenario 18
Admission Control Policy	Accepting migrants	X	X	X	X	X	X												
	Rejecting migrants							X	X	X	X	X	X						
	50% decrease in the arrivals													X	X	X	X	X	X
Capacity Control Policy	50% increase in lodge capacity	X	X	X				X	X	X				X	X	X			
	50% decrease in lodge capacity				X	X	X				X	X	X				X	X	X
	50% increase in shelters capacity	X	X			X	X			X	X			X	X			X	X
	50% decrease in shelters capacity			X	X			X	X			X	X			X	X		
	50% increase in internalisation capacity	X				X		X				X		X				X	
	50 % decrease in internalisation capacity		X	X	X		X		X	X	X		X		X	X	X		X

5.6 Results

The base run (Figure 25) considers the period with real data from March 2018 (beginning of the operation) to February 2022 (the pandemic period took place between months 25 until 40). The simulated scenarios consider 70 months; therefore, the simulations continue until December 2023. We assumed a similar behaviour before the pandemic of entry and leave rates of migrants in Brazil (Figure 26) for the months from March 2022.

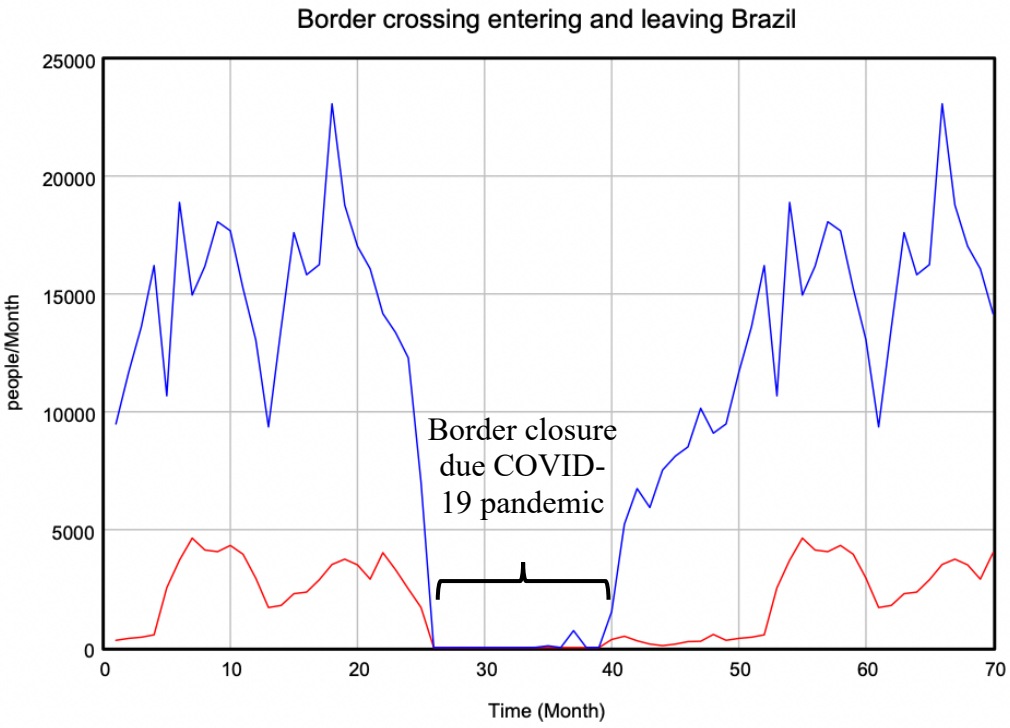


Figure 26 - Assumption of Venezuelans border crossing entering and leaving Brazil

Figure 27 presents the results of the eighteen scenarios simulated. The results are threefold: (1) analysis exclusively of the rejection of new entries; (2) analysis considering greater assistance to vulnerable migrants; (3) analysis considering the cost minimisation or internalisation maximisation.

By rejecting the entry of new vulnerable migrants (scenarios 7 until 12), the number of Venezuelans lodged and sheltered decreases substantially. While the number of people lodged can reach four thousand (4,000) when accepting the entry of Venezuelans, this value reaches a maximum of thirteen hundred (1,300) in the scenarios rejecting the entry of migrants. Similarly, while shelters can accommodate seventeen thousand (17,000) Venezuelans considering the entry of

new vulnerable people, shelters do not reach eight thousand (8,000) in the scenario rejecting new entries. It should be noted that there is a queue of migrants waiting to be sheltered. Therefore, even considering the policy of rejecting new entries and continuing internalisation, the number of Venezuelans in shelters is still constant until the period 70. The sum of migrants internalised in scenarios where the admission of new migrants is plausible reaches one hundred and fifty thousand (150,000) in the period 70, while the same sum reaches one hundred and ten thousand (110,000).

As a result, we can also notice that, by increasing the capacity of lodges, shelters, and interiorisation, there is an increasing trend in the graphs referring to the allocation of vulnerable migrants. Aiming to document, provide food, sanitation, and support the vulnerable migrants, the scenarios with capacity increment allow for greater allocation of Venezuelans. Therefore, considering the acceptance of migrants (scenarios 1 until 6), scenarios 1-3 reach approximately 4,300 Venezuelans lodged, while scenarios 4-6 around 1,800 Venezuelans lodged (Table 14). However, scenarios 1 and 2, besides considering the increase in lodge capacity, also consider the increase in shelter capacity. In scenario 1, the number of Venezuelans sheltered reaches 12,886, while in scenario 2, it reaches 17,848. The difference in sheltered Venezuelans exists because of the increase or decrease in the ability to internalise. Therefore, aiming to assist the greater number of Venezuelans, in scenario 1, we have 157,561 Venezuelans assisted, while in scenario 2, we have 116,282 Venezuelans assisted, being scenario 1 (the three pillars capacity increase) the best option. A similar analysis can be done for the acceptance of half vulnerable migrants.

Table 14 - Scenarios 1 and 2 results on month 70

Time (Time)	70
Internalized VNZ : Scenario1	140350
Internalized VNZ : Scenario2	94061.8
Sheltered VNZ : Scenario1	12886.7
Sheltered VNZ : Scenario2	17848.4
VNZ lodged : Scenario1	4325.04
VNZ lodged : Scenario2	4382.78

However, the actual operations focus is to internalise the greater number of migrants - which means socio-economically integrating them into Brazil. In Figure

27, scenarios 1 and 5 stand out regarding the internalisation process, as they consider the increase in internalisation capacity while considering the greater influx of Venezuelans. However, while in both scenarios, the number of internalisations and sheltered are close (Table 15), the number of lodged differs. This finding demonstrates that the operation can internalise a great number of Venezuelans even not increasing the lodge capacity. An interesting result regarding the financial aspect. In March 2022, Venezuelan sheltering costs approximately 900 Brazilian reais per month. Therefore, considering the cost of the operation and the objective of internalising Venezuelans, it could be interesting not to increase the spending with lodges and increase the spending with internalised.

Table 15 - Scenarios 1 and 5 results on month 70

Time (Time)	70
Internalized VNZ : Scenario5	140455
Internalized VNZ : Scenario1	140350
Sheltered VNZ : Scenario5	12899
Sheltered VNZ : Scenario1	12886.7
VNZ lodged : Scenario5	1766.92
VNZ lodged : Scenario1	4325.04

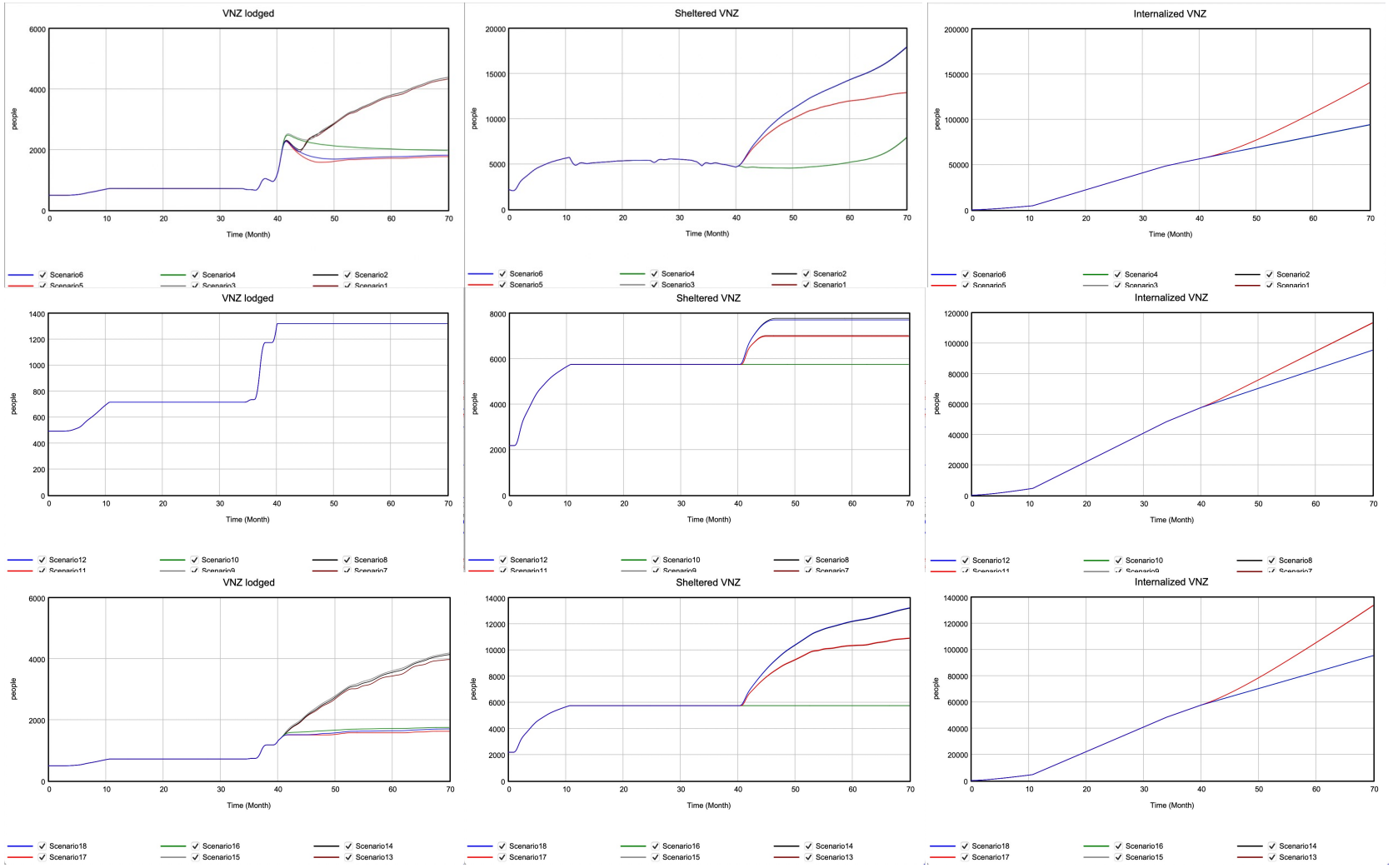


Figure 27 - Scenario Results

Schematic representation - first line presents the results of the simulations considering the admission of migrants, followed by the results of the simulations considering the rejection of the entry of migrants, and the scenarios considering a 50% reduction in the admission of migrants.

5.7 Discussion

We investigated the impact of scaling a HO designed to receive, shelter, and internalise migrants. We built an SD model based on empirical data collected from the Operation Welcome. We focused on two main policies – admission control and capacity control. This section presents the practical discussion (Sect. 6.1) and the theoretical discussion (Sect. 6.2) concerning our main findings, from the operation point of view (governmental point of view).

5.7.1 Practical discussion

HO to support migrants needing assistance is indisputable important; thus, we should be careful in analysing our results. The better scenario depends on the primary needs of the beneficiaries and the Operation objectives. Therefore, we have different better scenarios considering alleviating human suffering and helping more migrants, or costs minimisation and increase in internalisation. Table 16 illustrates the discussion regarding aspects beyond simulated that deserve attention.

Except for the closure due to the COVID-19 pandemic, Brazilian borders have always been open because of the open-door policy. Therefore, as accepting migrants is the Brazilian "modus operandi", there is no need to increase or decrease the number of stakeholders involved; thus the barriers to maintaining this policy are low, so as the time to implement, the cost of implementation and maintenance. Regarding rejecting and managing the number of arrivals, as it never occurred in Brazil, it was not possible to discuss the analysis with Operation military personnel who chose not to assume on the subject. However, considering our knowledge, changing the admission control policy would not be possible without involving other stakeholders, for example, law-creation politicians. Therefore, for an admission control policy to reject or reduce the flow of migrants to be taken, a series of barriers would have to be broken, needing this definition to occur through a legal tool and a public debate on the subject. Due to the need to break these barriers, the time to implement such a policy is extended. However, once the policy is implemented, the result is quickly achieved. The cost of implementing and maintaining the frontier open, closed, or reducing the inflow is relatively low since the change is in the contingent involved to maintain order at the border, allowing or not the entrance. However, it is worth noting here that once the border is closed,

a side effect begins to exist, the undocumented and illegal entry of migrants through borders other than the city of Pacaraima, for example, through the Amazon Forest.

Unlike the admission control policy, we discussed the capacity control policy analysis presented in Table 16 with Operation military personnel. The decision to increase or decrease the lodge and the shelter capacity is more focused on the operation managers; however, it also involves the Ministry of Citizenship, Civil House, and UNHCR (which assists in shelter management). The barriers to implementing this policy are low but existent and change according to the specifics of different actions to increase capacity. For example, increasing the capacity of existing shelters (adding new physical structures and beds) presents fewer barriers than increasing capacity by creating new shelters. Similarly, the time to implement depends on creating the physical space (in an existing or not lodge/shelter) and allocating more supplies (e.g., food and hygiene products). Quickly new migrants are accommodated, presenting a short time to achieve results. The cost of implementation also depends on the action to increase capacity. In February 2022, the operation spent an average of 900 Brazilian reais monthly on keeping a migrant sheltered, considering food, container rental, space rental, generators, septic tank cleaning, garbage collection, water, electricity, internet, surveillance, and concierge. Therefore, the maintenance cost increases along with increased shelter capacity.

Considering the internalisation, the decision to increase or decrease the capacity also involves stakeholders such as the Brazilian Air Force due to its support with flights, organisations involved in the prevention of human trafficking and exploitation of slave labour, and articulation with federal entities (state and municipality). As barriers, we can mention the necessity of more aircraft and socio-economic insertion, that is, more job opportunities in other Brazilian states. Besides, it is worth noting that it is a voluntary process, depending on the number of migrants desiring to be internalised. Implementation time can be prolonged according to the mentioned barriers, and the implementation and maintenance costs are high. On average, the cost of internalisation per migrant is 3 thousand reais a month (considering data from February 2022).

Table 16 - Policies Implementations Practical Discussion

Policy		Stakeholders' involvement	Barriers	Time to implement	Time to achieve results	Cost of implementation	Cost to maintain
mission ntrol Policy	• Accepting migrants	"modus operandi" 					
	• Rejecting migrants • Decrease in the migrant arrival rate						
Capacity Control Policy	• Increase/decrease in lodge capacity • Increase/decrease in shelters capacity						
	• Increase/decrease in internalisation capacity						

5.7.2 Theoretical discussion

Several HO are taking place around the world in migrant-receiving countries. Overall, HO are focused on controlling its borders and sheltering needing assistance migrants. Lischer (2017) demonstrates that past experiences with displacement lead to political variations in refugee crisis response. However, regarding the Brazilian responses to migratory flows, past experiences have not made the country change its open-door policy. Whilst maintaining an open-door policy (admission control policy), Brazil has created pathways to regularize and allow needing assistance migrants access to the same rights as its nationals (Leomil, 2021).

Regarding shelter capacity control, Operation Welcome corroborates the literature related to government establishment of their shelters capacity to control the needed supplies, staff, and have some control over the migrants (Lischer, 2017; Gökalp et al., 2022). Therefore, in Brazil, Venezuelans access to shelters is regulated as an attempt to order maintenance. Shelter gates close at 10 pm for those who want to sleep in as an attempt to avoid consumption of alcohol, drugs, and prostitution. Cases of violence, theft, drug trafficking, and disobedience have been systematically reported, and disciplinary measures have usually revolved around stricter controls (Moulin Aguiar and Magalhães, 2020).

In Western studies, socioeconomic insertion is often referred to as "integration" (Zou and Deng, 2021). In addition, there is no unified integration measurement index in the literature. Some literature argues that integration should be measured within seven aspects: cultural contacts, structural assimilation, intermarriage, ethnic identity, prejudice, discrimination, value and power conflict. Other studies consider seven indicators (economic, cultural, social, political, self-awareness change, attitudes towards acceptance and internalisation of value, and life satisfaction after immigration), while others consider three dimensions (social order and social control; social networks and social capital; and local attachment and identity) (Zou and Dang, 2021).

The EU decision to relocate migrants who arrived in Italy and Greece through the Mediterranean migration crisis demonstrates the socio-economic migrant's insertion attempt within a block of countries (Šabić, 2017). However, although the EU has constitutional principles, each country has its independence, government, and decision-making capacity. What makes this specific case different from the

Venezuelan migration to Brazil, since in Brazil the migrants relocation is within the same country (different states) and not between countries. Therefore, the Brazilian geography makes Venezuelan migrants crossing the border through Roraima unable to travel to states in the country's centre, south, and southeast because of natural barriers (Rio Negro and Rio Amazonas). In addition, Brazil has a vast territory, making it difficult for migrants to travel to capitals (more developed cities with more job opportunities). Therefore, the integration process takes place through Operation Welcome itself, which internalises migrants according to job vacancies, family, or social reunification.

Although each migrant-receiving country has particularities, our research demonstrates how to adapt the first representation of HO in the receiving-migrants country model to their realities. Therefore, our results potentially apply to other regions worldwide.

Besides the theoretical discussion regarding the main pillars of migrant-receiving operations and the recurrent policies, as migration is a multifaceted issue, it needs to be understood and accounted for the multitude of stakeholder roles upstream, midstream, and downstream migratory movements (Kovács and Spens, 2009; Prasad et al., 2020). Our research highlighted the military role in Operation Welcome; however, the operation involves several stakeholders. All stakeholders involved must collaborate for the operation to work in the best possible way. For example, the request for refuge and temporary residence is carried out by IOM and UNHCR. If these organizations do not collaborate and coordinate with the federal police to regularize the documentation of migrants, the operation will have setbacks. Humanitarian organizations such as Fraternity without Borders are also present in Roraima and help manage shelters. For shelter order to be maintained, these organizations and the military involved in shelter security must work in alignment. As an example, from the internalisation pillar, the humanitarian organization Caritas is responsible for sheltering and receiving many internalised migrants. For the internalisation process to continue to grow and expand, organisations must apply to carry out this work. Thus, the debate regarding collaboration and coordination between stakeholders in migrant-related HO is essential.

5.8 Conclusion

This study aimed to comprehend a migration-related HO in a migrant-receiving country. The reception, shelter, and the socio-economic insertion of migrants were mapped as main elements of migration-related operations, also represented in the case study with its particularities (border control, shelter, and internalisation). To the best of our knowledge, it is a first attempt to describe, through SD, a response operation to a disaster of this magnitude.

We analyse the main challenges involved in the Operation Welcome scalability. From the development of the CLD and simulation model, it became evident that the shelters capacity is an operation bottleneck, as it presents a queue of Venezuelans waiting to be sheltered, and as we have spontaneous occupations with migrants that could not be sheltered. Besides, the internalisation process has become the most significant bottleneck once we are concerned with internalising those Venezuelans with jobs or family/friends who can be responsible for them. This means that the internalisation process is time-consuming because, in addition to the necessary logistics (flights and financial resources), it is necessary that the Venezuelans can be internalised and consequently, socio-economically inserted in Brazil.

We also focused on understanding how humanitarian operations scale capacity to meet the migrant's needs. With our analysis, it became clear that the operations scalability depends on strategic decisions: the focus will be on having the highest possible migrants assisted, or the focus will be on their socio-economic insertion, for example.

Our research has some limitations, which bring possibilities for future research. As the operation under analysis was developed according to the immediate needs of the migrants, it ends up being very dynamic. Therefore, since we started modelling, changes in the operations processes have occurred. The operation, for example, expanded its facilities to Manaus city; part of the migrants was transferred there. In addition, migrants with families already in Brazil get permission to internalise more quickly, sometimes without having to go through shelters. However, our model captures the central flows of the operation, then, the research objective was achieved.

6
Discussion and main thesis contributions

This chapter discusses the findings previously described and points out the main contributions of each research paper.

6.1 Thesis discussion

The thesis was developed around a central research question, the focus of analysis of this section: *A SD simulation model (simplified representation of reality) can generate valuable analysis that help in HO decision making?*

To answer this research question, two distinct HO were studied through the development of SD models. The operations in question are extremely complex and the models developed are simplifications capable of representing the behaviour of systems, and therefore have limitations. For example, in Paper 2 we added a classic, however simple, epidemiological model (SIR model). As our research focus was not on epidemiological modelling, we opted for the classic SIR model. We also believe that the isolation rates are limitations of out model, as we do not have specific data. In Paper 3, as the operation under analysis was developed according to the immediate needs of the migrants, it ends up being very dynamic. Therefore, since we started modelling, changes in the operations processes have occurred. The operation, for example, expanded its facilities to the Manaus city; part of the migrants was transferred there. In addition, migrants with families already in Brazil get permission to internalise more quickly, sometimes without having to go through shelters. However, the model was developed to capture the main and central flow of the operation, and this objective was achieved.

Therefore, even though the models are simplified representations of reality and, although we can point out their limitations, both were able to capture the behaviour of the systems, going through validation steps to ensure the findings' validity. When capturing the behaviour of the systems, different analyses were made with the models. These analyses can help HO decision-makers (answering the research question).

It should be noted that the two articles present CLD, qualitative diagrams that help in understanding the operations. These diagrams are a valuable tools for decision makers who understand that their mental models can be flawed. Therefore, through these representations, it is possible to identify countereffects of an action and pay attention to specific loops before making a decision. In addition, the two papers presented SFD that, together with the discussions raised, enrich the correct knowledge of the theme and operations, helping decision makers.

Paper 2 generated discussion and analysis regarding the impacts of donating food and cleaning supplies to the vulnerable population in the BoP. We focused on two main aspects, i.e., affordability (food donations) and epidemic control (cleaning supply donations). Besides, our paper discusses the involved stakeholders (donors, NGOs, beneficiaries), the donations channels (direct donations, transfer to NGOs, online donations), the mode of assistance (cash, voucher, or in-kind donations), and the allocation modes (earmarked or unearmarked), and the last mile distribution. In all those topics, insightful discussions were presented that together with the model results can serve as a basis for policymakers to aid vulnerable communities.

Paper 3, in turn, brings discussions and analyses regarding scalability of the migrant-receiving country HO, adopting the admission control and capacity control as analysed policies. A practical discussion regarding stakeholders' involvement, we highlight barriers to the policy implementations, time to implement, time to achieve results, cost of implementation and cost of maintenance. This analysis, together with the results of the simulations, may help decision makers in defining the scalability of operations.

6.2 Summary of the paper's contributions

Table 17 presents a summary of the contributions made by each paper that built up this Thesis.

Table 17 - Paper contributions summary

Paper	Contribution to academics	Contribution to practitioners
Paper 1	State of the art summary regarding the application of SD in the context of HO.	The findings can help decision-makers understand issues in the HO context and make more effective decisions.
Paper 2	• Applicability of SD in HO. • Research with empirical data.	• The results and the discussions raised can serve as a basis for policymakers to aid vulnerable communities. • Provide a straightforward experience for decision makers with the availability of the model on the forio platform.
Paper 3	• Applicability of SD in HO. • Real case study with empirical monthly data.	• The simulation results and the discussions raised can help decision-makers understand issues in the HO context and make more effective decisions. • Provide a straightforward experience for decision makers with the availability of the model on the forio platform.

7
Conclusions and future research directions

To achieve the general objective of the thesis (to model the complex dynamics of HO using SD as a tool to help decision-makers), specific objectives were adopted, and different papers were developed to address each specific objective. First, to map the literature gaps, we developed a SLR (Paper 1) with a sample of 80 papers, where taxonomic tables, frameworks, and research agenda were delivered. With these deliverables we were able to outline current research trends applying SD in HO, and literature opportunities (specific objective).

Two papers were developed based on opportunities in the academic literature. Therefore, Paper 2 encompass research opportunities highlighted in Paper 1 as "development of case studies with interaction among different stakeholders", "use of historical data to look at humanitarian organizations resource use", "logistical challenges at the nodes legs of the supply chain connections", and Paper 3 encompass the research opportunity highlighted the "disaster-affected population migration".

The operation studied in Paper 2 through a survey involves collecting and distributing donations to vulnerable population from Rio de Janeiro, Brazil amid the COVID-19 pandemic. As a result, we demonstrated that: (i) increasing access to cleaning products in communities can significantly reduce transmission; (ii) food donations can increase the populations affordability; (iii) accessibility increases by 20% in vouchers/cash donations compared to all in-kind donations. Through the development of Paper 2 we answer our specific objective to analyse the impacts of donations in BoP communities.

The operation studied in Paper 3 through a case study involves the Brazilian operation to receive, shelter, and internalise Venezuelans in Brazil. Since the flow of Venezuelans to Brazil has grown and, the pandemic aftermath presents itself as a concern for the operation capacity, Operation Welcome is modelled to understand the bottlenecks for its scalability. As a result, we demonstrate that: (i) the internalisation process is a strategic bottleneck as in addition to the necessary

logistics, it is necessary the socio-economical insertion (through job vacancies, for example); (ii) shelters capacity is an operation bottleneck, as it presents a queue of Venezuelans waiting to be sheltered. Through the development of Paper 3 we answer or specific objective of analyse the scalability challenges of HO in migrant-receiving countries.

Finally, with the HO models development, simulations, results, and analysis, we could answer to our main research question: *What strategic and operational insights from HO complex dynamics can SD models provide?*

Paper 2 discusses, at an operational level, the impacts of HO on the population through donation channels, forms of service, and last-mile distribution. At a strategic level, Paper 2 highlights the duality in the HO definition between the focus on reducing COVID-19 infected cases and on food accessibility for the population. Paper 3 discusses at the operational level the barriers to policy implementation (e.g., lack of physical space for expansion of shelters), time and cost of policy implementation (e.g., increase in shelter capacity), and time to obtain results. At a strategic level, Paper 3 sheds light on the duality of Operation Welcome between assisting the most significant number of Venezuelans or maximizing internalisation, also considering the operation costs.

Ultimately, since SD models can generate varied analyses, we present several opportunities for future studies in Paper 1, such as: development of multi-case studies for cross-case analyses, and with interaction among different stakeholders, case studies permeating the intersection between pre- and post-disaster stages, reverse logistics impact on sustainability, Humanitarian Organisations development programs and Humanitarian Organisations dependency. Besides the broad subjects identified in Paper 1, through Paper 2 we could identify future research avenues as the development of models regarding the impact of donations considering the variation in food prices during the pandemic, and models analysing food security through the triad affordability, availability, and quality. Other research opportunities arise from Paper 3 as the specific management of each one of the pillars (border management, shelter, internalisation) of migrant-receiving HO, and the model expansion to accompany changes in the Operation Welcome.

8
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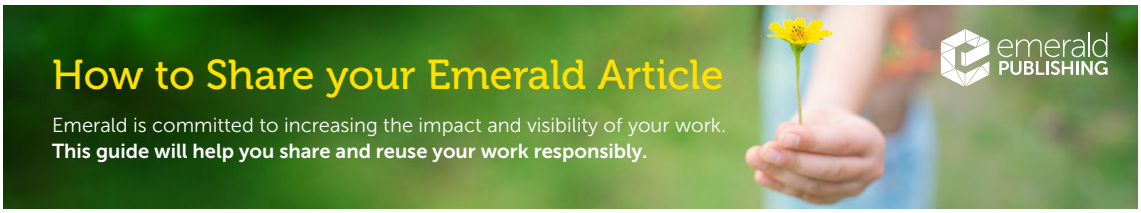

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Appendix 3 – Curriculum Vitae

LUIZA RIBEIRO ALVES CUNHA

EDUCATION

Pontifical Catholic University of Rio de Janeiro – PUC-Rio 2018 – 2022
D.Sc. Production Engineering

Pontifical Catholic University of Rio de Janeiro – PUC-Rio 2016 –2018
M.Sc. Production Engineering

Pontifical Catholic University of Rio de Janeiro – PUC-Rio 2010 –2015
B.Sc. Production Engineering

PROJECTS PARTICIPATION DURING DOCTORAL PERIOD

CAPES Procad Defesa 88887.387760/2019-00 2019-Current

FAPERJ Apoio a Grupos Emergentes de Pesquisa 211.029/2019 2019-Current

World Bank –
Scaling-up actions for disaster management in Brazil 2020 – 2021

Pro-Alertas CAPES 88887.091739/2014-01 2019 - 2021

AWARD

2022 EMERGING ECONOMIES DOCTORAL STUDENT AWARD (EEDSA – LATIN AMERICA AND CARIBBEAN), FROM PRODUCTION AND OPERATIONS MANAGEMENT SOCIETY (POMS)

PUBLICATIONS DURING DOCTORAL PERIOD

Journals Publications

CUNHA, Luiza R. A.; ANTUNES, Bianca B. P.; RODRIGUES, Vinicius P.; CERYNO, Paula S.; LEIRAS, Adriana. Measuring the impact of donations at the Bottom of the Pyramid (BoP) amud the COVID-19 pandemic. Annals of Operations Research. https://doi.org/10.1007/s10479-021-04378-5

CUNHA, Luiza R. A.; LEIRAS, Adriana; GONÇALVES, Paulo. Looking Back and Beyond the Complex Dynamics of Humanitarian Operations. Submitted to the Journal of Humanitarian Logistics and Supply Chain Management.

CUNHA, Luiza R. A.; LEIRAS, Adriana; GONÇALVES, Paulo. Challenges to Scale Migration-related Humanitarian Operations. In preparation.

CARDOSO, Brenda; **CUNHA, Luiza**; LEIRAS, Adriana; GONÇALVES, Paulo; YOSHIZAKI, Hugo; JUNIOR, Irineu de Brito; PEDROSO, Frederico. Causal Impacts of Epidemics and Pandemics on Food Supply Chains: A Systematic Review. Sustainability, v. 13, p. 9799, 2021. https://doi.org/10.3390/su13179799

Book Chapters Publications

CUNHA, Luiza R. A.; DOS SANTOS, Joaquim R.; LEIRAS, Adriana. Disaster Influencing Migratory Movements: A System Dynamics Analysis. Springer Proceedings in Mathematics & Statistics. 367ed.: Springer International Publishing, 2021, p. 265-277. https://doi.org/10.1007/978-3-030-78570-3_20

CUNHA, Luiza R. A.; LEIRAS, Adriana; CERYNO, Paula. Modern Slavery Analysis in Global Production Networks. Springer Proceedings in Business and Economics. 1ed.: Springer Internacional Publishing, 2020, p. 1007-1014. https://doi.org/10.1007/978-3-030-23816-2_99

DE OLIVEIRA, Fabíola N.; **CUNHA, Luiza R. A.**; FONTAINHA, Tharcisio Cotta; LEIRAS, Adriana; CERYNO, Paula Santos. A System Thinking Approach for Social and Environmental Risks in Supply Chains. Springer Proceedings in Mathematics & Statistics. 1ed.: Springer International Publishing, 2020, p. 417-427. https://doi.org/10.1007/978-3-030-56920-4_34

International Conferences Presentations

CUNHA, Luiza; LEIRAS, Adriana; GONÇALVES, Paulo. Looking Back and Beyond the Complex Dynamics of Humanitarian Operations. In: 40th International System Dynamics Conference, 2022.

CUNHA, Luiza; LEIRAS, Adriana; GONÇALVES, Paulo. Challenges to Scale Migration-Related Humanitarian Operations. In: 40th International System Dynamics Conference, 2022.

CUNHA, Luiza; LEIRAS, Adriana; GONÇALVES, Paulo. Challenges to Scale Migration-Related Humanitarian Operations. In: Production and Operations Management Society (POMS) conference, 2022.

SILVA, Mayara; **CUNHA, Luiza**; LEIRAS, Adriana; SCAVARDA, Luiz Felipe; SILVEIRA, Rodrigo. Brazilian Air Force (BAF) Operation in response to migratory flow: the Welcome Operation case. In. International Joint Conference on Industrial Engineering and Operations Management (IJCIEOM), 2022.

CUNHA, Luiza; LEIRAS, Adriana; CERYNO, Paula. Social Supply Chain Risk Management: A Case Study in a Cosmetic Company. In. International Joint Conference on Industrial Engineering and Operations Management (IJCIEOM), 2022.

CUNHA, Luiza; LEIRAS, Adriana; GONÇALVES, Paulo. Scaling operations to address forced migration flows: the case of Venezuelan immigration. In: Production and Operations Management Society (POMS) virtual conference, 2021.

CUNHA, Luiza; DOS SANTOS, Joaquim Rocha; LEIRAS, Adriana. Disaster Influencing Migratory Movements: A System Dynamics Analysis. In. International Joint Conference on Industrial Engineering and Operations Management (IJCIEOM), 2021.

DE OLIVEIRA, Fabíola Negreiros; **CUNHA, Luiza**; FONTAINHA, Tharcisio Cotta; LEIRAS, Adriana; CERYNO, Paula Santos. A System Thinking Approach for Social and Environmental Risks in Supply Chains. In. International Joint Conference on Industrial Engineering and Operations Management (IJCIEOM), 2020.

CUNHA, Luiza; LEIRAS, Adriana; CERYNO, Paula. Social Supply Chain Risk Management: A Case Study in a Brazilian Company. In: 26th European Operations Management Association (EurOMA) Conference, Helsinki, Finland, 2019.

National Conferences (Brazil)

THOMPSON, Fernanda Infante de Castro; **CUNHA, Luiza**; LEIRAS, Adriana. Socioeconomic reintegration mapping process of Venezuelan immigrants in Brazil. In: XLI Encontro Nacional de Engenharia de Produção (ENEGEP), 2021. Available at: http://www.abepro.org.br/biblioteca/TN_STO_355_1833_42400.pdf

CUNHA, Luiza; NEGREIROS, Fabiola; LEIRAS, Adriana. Analysis of actions for social, environmental and disaster risks of the 100 largest Brazilian companies. III Brazilian Congress of Risk and Disaster Reduction (CBRRD), Belém, Pará, 2019.

BREMENKAMP, Leonardo; CARDOSO, Brenda; **CUNHA, Luiza**; LEIRAS, Adriana. Critical success factors and performance measurement criteria of humanitarian organizations. ENEGEP 2019 National Production Engineering Meeting, Santos, São Paulo, 2019.

Appendix 4 – Flows (rates) equations

Table 18 - Flows (rates) equations

Rate	Equation
Border crossing entering rate	Model input (direct data)
Border crossing leaving rate	Model input (direct data)
Non vulnerable migrant at migrant-receiving country rate	("Migrant at the migrant-receiving country border" / "Ave time at specific migrant-receiving country regulatory agency") * "Ave fraction non vulnerable"
Rate to regularize documentation	(1 – "Ave fraction non vulnerable") * "Migrant at the migrant-receiving country border" / "Ave time at border"
Non sheltered vulnerable migrants rate	("Vulnerable migrant before shelter allocation" / "Ave time to occupations") * (1 – "Ave fraction shelter")
Occupation outflow	"Vulnerable migrants at Spontaneous Occupations"/ "Ave time outflow occupation") * "Ave fraction outflow occupation"
Sheltered migrant rate	"Vulnerable migrant before shelter allocation"/ "Ave time to shelter") * "Ave fraction shelter") * "Delayed effect of capacity on rates"
Internalisation rate	"Sheltered vulnerable migrant" / "Ave time to internalization") * "Ave fraction internalization"