

Venezuelan migration in Northern Brazil: a system dynamics approach for the internalization program

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Abstract

Purpose – This paper aims to present the internalization process by which Venezuelan migrants and refugees are resettled. Using system dynamics, the authors model a Brazilian humanitarian operation (“Acolhida” – Welcome), simulate the internalization process, propose policies and provide lessons learned for future migratory operations.

Design/methodology/approach – Using system dynamics simulation, the authors use Acolhida Operation’s historical data to recreate the reception and resettlement process of Venezuelan migrants and refugees. The authors identify the main bottlenecks in the system and propose policies to respond to scenarios according to the number of internalization vacancies, that is, available places in Brazil where migrants and refugees can be resettled. Finally, based on interviews with former decision-makers, the model represents a first attempt to convert the pressure of public opinion on authorities into temporary shelters as a way of reducing the number of unassisted people.

Findings – The results confirm that internalization vacancies are the main constraint when resettling Venezuelan migrants and refugees. Had the internalization program been promoted since the operation’s beginning, there would have been fewer unassisted people in Roraima and fewer shelters. The pressure-converting mechanism presented in this study, although incipient, constitutes a first attempt to support decision-makers in determining when to build temporary shelters.

Practical implications – This study can be useful to public authorities and humanitarian organizations when developing policies to enhance resettlement in migratory crises. In Acolhida’s case, the internalization program should continue to be the operation’s priority and can be enhanced by investing more resources to create internalization vacancies while maintaining logistical capacities.

Social implications – The authors suggest policies to improve the Acolhida internalization program: give more people the choice to relocate in other cities, increase turnover in shelters and provide a more efficient and effective response to Venezuelan migration in Roraima.

Originality/value – Although a number of studies have applied system dynamics to humanitarian operations, few models have focused on migratory emergencies, such as those occurring in northern Brazil. The model is applied to the largest humanitarian operation carried out in the Brazilian territory and provides decision-makers with valuable insights and alternatives for better implementation in the future. Furthermore, this study narrows the gap between the social sciences and modeling and simulation techniques by proposing ways of predicting migratory implications in the construction of shelters and resettlement policies.

Keywords Migration, Refugees, System dynamics, Relocation and resettlement

Paper type Case study

Plain language summary

This study simulates the welcoming process for Venezuelan migrants and refugees arriving in northern Brazil and proposes policies to accelerate their relocation to other cities. The model

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Journal of Humanitarian Logistics and Supply Chain Management
13/3 (2023) 293–310
Emerald Publishing Limited [ISSN 2042-6747]
[DOI [10.1108/JHLSCM-01-2022-0011](https://doi.org/10.1108/JHLSCM-01-2022-0011)]

This research was funded by Coordination for the Improvement of Higher Education Personnel-Brazil (CAPES), Procad Defesa 8887.387760/2019-00 and National Council for Scientific and Technological (CNPq), 404803/2021-0 and 313687/2019-6.

Received 27 January 2022

Revised 4 July 2022

23 October 2022

Accepted 15 February 2023

also supports the creation of shelters based on the number of people on the streets.

1. Introduction

Forced migration has become increasingly frequent throughout the world. According to the UN Refugee Agency (UNHCR), by the end of 2019, 79.5 million people had been forced to leave their homes, representing more than 1% of the world's population. Almost $\frac{3}{4}$ of this population is estimated to reside in neighboring countries that face the challenge of providing migrants with security, food, sanitation and health among other needs.

Venezuela is one of the migrant source countries facing complex social, economic and political turmoil since 2017. Its economy shrank by 86% from 2013 to 2020, according to the Inter-American Development Bank (Abuelafia and Saboin, 2020), forcing hundreds of Venezuelans to leave their country in an exodus that was considered the second largest in the world (UNHCR, 2020a). The interagency platform Response for Venezuelans (R4V) estimates that there were at least 5.5 million Venezuelan migrants and refugees in the world (R4V, 2021a), corresponding to almost 20% of the country's population in 2019 (World Bank, 2021).

Brazil is the fifth country in terms of Venezuelan migrants and refugees received, after Colombia, Peru, Ecuador and Chile (R4V, 2021b). However, Kanaan (2019) notes that, for half of Venezuelans arriving at the border, Brazil is simply a first step along the way to another country. Of those who decide to stay, only 40% can migrate on their own and 10% are considered unassisted; that is, they have nowhere to go and lack basic support. Roraima state is at the Venezuelan border and is one of the least developed and populated states in Brazil. It has a population of approximately 600,000 people, of which 400,000 live in the capital, Boa Vista (IBGE, 2019).

The population growth created by migration has not been harmonious because of low labor absorption, as the state is isolated from other states in Brazil and is not economically diversified (UNHCR et al., 2020). In 2021, the Brazilian authorities claimed that more than 272,000 Venezuelan migrants and refugees requested migratory regularization (Acolhida Operation, 2021).

To provide a solution to the worsening living conditions of migrants, the Brazilian Government, alongside the United Nations, launched the multiagency humanitarian operation "Operação Acolhida" (Portuguese, meaning Welcome Operation) in April 2018, which became the main component of Venezuelan migration crisis management in Brazil (Simão, 2018). This operation is based on three pillars: border control, shelter and internalization.

Three durable solutions allow recognized refugees to rebuild their lives: repatriation, local integration and resettlement (UNHCR, 2020b). Of these, the solution being implemented in Brazil is considered a form of local integration: migrants and refugees are offered the possibility to restart their lives in another city in Brazil, with transportation and accommodations sponsored by the government or their new employer. This choice differs from resettlement because it encompasses more than simply people who are recognized refugees and because it

is carried out within the borders (vs across borders, as in resettlement).

The internalization program represents a substantial logistical challenge in terms of matching the number of people willing to travel to the internalization vacancies offered in cities across Brazil. Roraima has several logistical constraints, as it is isolated from other large cities; has no access to the sea; and connects with few roadways or air bridges, leading to increased flight ticket prices. To provide logistical alternatives and cheaper flights to large cities, the government implemented a hub strategy: instead of flying directly from Roraima to the host city, migrants and refugees are first transferred by bus to hubs and then flown to their final destination, boosting the internalization program.

The present study combines the description of an internationally recognized humanitarian operation in Brazil with system dynamics (SD) modeling. We find SD suitable for analyzing complex systems, such as migration crises since it considers the relationships between a large number of variables and simulates the delays between cause and effect. Many studies have expanded the SD application field to the humanitarian sector (Besiou et al., 2011; Gonçalves, 2008) and find that it can offer important outcomes when applied to migration and forced displacement (Frydenlund, 2021). To the best of our knowledge, this study is the first to apply SD to a large migratory operation providing organizations and authorities with policies that improve the reception and relocation of migrants and refugees. Thus, this study sheds light on important mechanisms, such as the sheltering process, the endogenous creation of internalization vacancies and the relocation of migrants and refugees to other cities.

Furthermore, this study introduces a mechanism by which the unassisted migrant population can be identified by translating it into the building or demobilizing of shelters. This mechanism was created by interviewing decision-makers about how these pressure relations behave and how they can affect organizations and authorities.

This paper is structured as follows. Section 2 describes the application of SD tools, such as causal loop diagrams (CLDs) and stock-and-flow diagrams (SFDs), to the present problem. Section 3 compares the results and reference modes, analyzing how well the model maps onto reality. Section 4 presents four scenarios that allow decision-makers to analyze the effects of policies, such as early hub opening and early internalization, which could substantially improve the humanitarian response. Finally, Section 5 summarizes our main findings and suggests future work.

2. Literature review

The System Dynamic Society (2008) described SD as a computational simulation methodology that is particularly well suited for policy analysis and design. This is especially true for systems characterized by interdependence, mutual interaction, information feedback and circular causality. SD allows managers to learn from the behavior of complex systems and to identify short- and long-term effects (Gonçalves, 2008).

According to Besiou et al. (2011), SD can be a powerful decision-making tool when applied to humanitarian operations, as these are characterized by an unstable environment, long-

term effects that are difficult to predict and potentially conflicting goals among stakeholders. [Gonçalves \(2011\)](#) noted the relationship between these operations and SD, considering it a typical complex system consisting of feedback, delays, stocks and flows and nonlinearity. SD can also provide insight into and inform long-term policy in complex social systems ([Gonçalves, 2019](#)).

[Besiou and Van Wassenhove \(2021\)](#) extended and updated the previous work by reviewing all issues of the *Journal of Humanitarian Logistics and Supply Chain Management* from 2011 to 2021 to grasp how SD has been used in humanitarian operations. As a result, the authors confirmed SD's suitability for understanding complex environments and supporting decision-makers. The authors' found that none of the six reviewed papers were related to the dynamics of migration or refugee.

[Galindo and Batta \(2013\)](#) noted that SD models are an appropriate tool for studying complex problems and that SD applications have a clear gap in terms of development contexts and long-term crises.

As [Seifert et al. \(2018\)](#) noted, humanitarian operations involving migrants and refugees attract the interest of researchers, government decision-makers and humanitarian workers. This interest has arisen not only because of the increasing occurrence and considerable challenges such humanitarian operations represent but also because studies are lacking that combine this topic with the perspective of operations management and beneficiary needs. [McAdam \(2014\)](#) defined migratory crises as the result of a combination of complex social, political, economic and environmental factors that can be triggered by an extreme event but not caused by it. Policymakers normally see displacement as a one-off, short-term humanitarian problem, but it is a long-term situation that must be assessed holistically.

[Frydenlund \(2021\)](#) suggested that modeling and simulation tools can incorporate the dynamic characteristics of migration and forced displacement and are an accessible way of integrating academia, practitioners and policymakers. Nevertheless, a gap remains between simulation techniques and migratory operations. The literature review on simulation techniques applied to humanitarian logistics conducted by [Pareja Yale et al. \(2020\)](#) showed that 80% of the selected articles focused on sudden-onset disasters rather than slow-onset disasters, such as migratory crises.

[Table 1](#) lists further examples of SD applications in humanitarian logistics divided by research problem or focus: disaster management, pandemic/endemic emergencies and humanitarian logistics. Half of the studies presented in the table have focused on sudden-onset natural disasters, and one-third have used SD to simulate operational logistics problems, such as fleet and supply chain management. Starting in 2021, interest increased in the use of SD to analyze the effects of COVID-19 in emergency situations. Nevertheless, with the exception of [Allahi et al. \(2021\)](#), who used SD to improve health and education services for Syrian refugees, none of the selected works have used dynamic simulations in a migratory and/or refugee crisis.

Thus, SD is an appropriate method for studying this context because it challenges decision-makers to understand migratory crises as the result of complex interactions among many factors. This situation makes assessing its causes difficult, particularly when long delays are involved. This paper expands the use of

SD in these dynamic and difficult contexts, differing from the disaster-management application and bringing the discussion into a more social and development-related field, as suggested by [Seifert et al. \(2018\)](#).

3. Methodology and system dynamics model development

During the past decade, the migratory crisis in Europe reinforced the need to discuss a sustainable solution for migrants and refugees arriving from the Middle East. [Gonçalves \(2017\)](#) presented an SD application in the European migratory context to analyze how migratory policies impact migrants' willingness to migrate in the short and long terms. The author's approach was generic and showed how authorities might react to migratory flows by increasing the economic expenses in migration policies to decrease the number of migrants and refugees trying to migrate. Such reactions include increasing border control, expanding barbed wire fences and disrupting smugglers' operations.

This study, on the other hand, is specific to the Brazil–Venezuela migration crisis and focuses on ways to welcome migrants and refugees by internalizing them across Brazil.

To do so, we identified the variables that are important for understanding the system's behavior, set boundaries to the studied system and determine the simulation complexity. Equilibrium was found, so the generated conclusions are not obvious and the research is viable. We developed a qualitative model using a CLD to illustrate the main variables affecting the system while indicating the effect type (reinforcing or balancing) of the resulting feedback loops.

The quantitative model was based on an SFD as a way of first recreating the main processes of Acolhida, such as the border entrance, sheltering and internalization programs. The model was tested under different conditions of internalization vacancy availability, first by using only historical data for internalizations and later by extrapolating these limits. Once the model robustness was verified, new policies were proposed regarding the improvement in internalization processing capacity and early hub openings. Finally, we proposed a political and social pressure mechanism that first measures the popular pressure generated by the increase in unassisted people and then converts it into the construction of temporary shelters. This tool, using estimated and complex variables, innovatively supports managers' decision-making regarding sheltering and internalization policies for migrants and refugees.

The SD modeling were performed using Vensim® DSS simulation software, version 5.11a. The simulation spanned the period from January 2018 until April 2021, representing approximately 1,200 days.

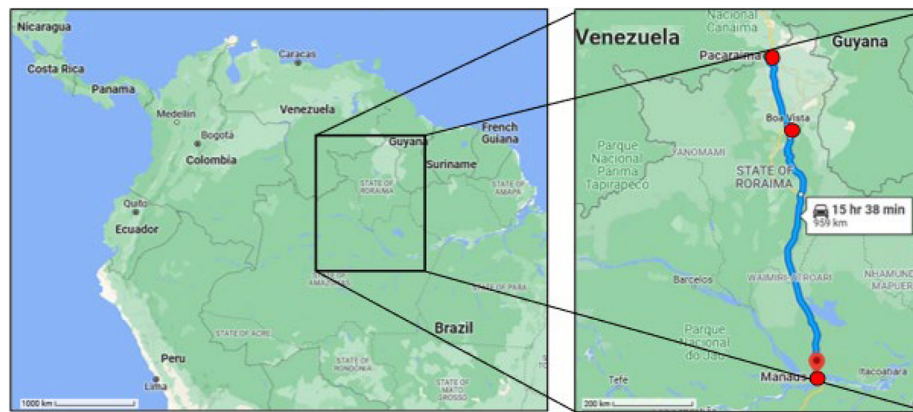
3.1 Case background

After crossing the border, migrants and refugees proceed to present their documents in the border town of Pacaraima at the main Acolhida's triage points. Once this process is finished, they go to the capital, Boa Vista, by themselves on a 200-km journey that takes approximately five days when walking ([G1, 2018](#)) or, when supported by Acolhida, by bus. Manaus is also an important destination, as it is the largest Brazilian city near Boa Vista ([Figure 1](#)).

Table 1 Examples of SD applications in humanitarian logistics

Author(s)	Objective
<i>Focus</i>	<i>Disaster management operations</i>
Cooke (2003)	The authors use SD to analyze the 1992 Westray technological (mining) disaster in Canada. The paper examines the causal structure of the system, including the relationships that could have led to the conditions that caused the disaster
Ho and Wang (2006)	Based on the 1999 earthquake in Taiwan, the authors propose an SD model to simulate urban disaster prevention mechanisms and to minimize the loss of human lives and property in urban areas
Ramezankhani and Najafiyazdi (2008)	The authors make a case study of the earthquake that struck the city of Bam, in southeastern Iran, in 2003. They propose a simulation of activities in the disaster zone and some post-disaster policies to be applied in future disasters
Bhushan and Tirupati (2013)	The authors use SD to simulate a humanitarian supply chain and propose measures not only to support better disaster responses but also to enhance the effectiveness and speed of response, thus increasing community resilience
Kunz et al. (2014)	The study entails the preparation phase for natural disasters as a way of optimizing the resources used in the response phase. The authors propose a simulation model that compares prepositioning inventory with disaster management capabilities
Peng et al. (2014)	The study simulates a response to a seismic disaster by considering the road conditions, transport capacity, inventory planning and information flow to identify how these factors influence relief operations
Diaz et al. (2015)	The authors build a model to simulate the process of rebuilding houses after a disaster, especially focusing on the material resources necessary for repair and reconstruction
Voyer et al. (2015)	The authors propose a simulation model for a humanitarian response to a rapid-onset disaster to analyze the dynamics of the logistical processes of the humanitarian supply chain
Berariu et al. (2016)	The authors use an SD model to simulate the distribution of humanitarian aid and fulfill increasing demand in situations of sudden disasters, supporting decision-making by fostering an understanding of systemic behaviors and interdependencies
Octavia et al. (2016)	The authors make a case study in East Java on the planning of humanitarian logistic coordination to minimize the response time in emergencies. The proposed model involves the Indonesian Red Cross as a core team in humanitarian operations
<i>Focus</i>	<i>Pandemic/endemic emergencies</i>
Allahi et al. (2021)	The study evaluates the effect of different scenarios considering policies of isolation, social distance/hygiene behaviors and financial aid to determine the best response to COVID-19 to improve refugees' health and education
Cardoso et al. (2021)	The authors develop an SD framework representing the interactions among food supply-chain variables to analyze famine as an impact of the COVID-19 pandemic
Harpring et al. (2021)	The study describes the compound factors in a complex emergency that exacerbated a cholera epidemic among vulnerable populations in the context of the Yemeni Civil War due to supply chain disruptions
<i>Focus</i>	<i>Humanitarian logistics</i>
Besiou et al. (2011)	The study applies the SD methodology to humanitarian operations exemplified by the simulation of a vehicle fleet-management system
Gonçalves (2011)	The study proposes a simulation model that quantifies the tradeoff that humanitarian organizations face between providing relief and building capacity in stressful and demanding environments
Heaslip et al. (2012)	The study proposes a simulation model that analyzes the relationships between civil and military organizations in humanitarian operations and proposes measures to improve coordination during the phases of the aid lifecycle
Besiou et al. (2014)	The authors use SD to simulate a vehicle supply chain to support humanitarian field operations considering three dimensions: decentralization, operational mix and earmarked funding
Costa et al. (2016)	The authors discuss how donors, media and organizations interact in a humanitarian operation, creating policies focused on a better application of resources despite an unfavorable and poorly coordinated system
Diedrichs et al. (2016)	The study quantifies the effect of efficient communication, information sharing and informed decision-making as a way of reducing material waste and enhancing assistance to victims
Anjomshoe et al. (2017)	The study identifies the conceptual interdependencies among key performance indicators and represents them in the form of a conceptual model to provide a dynamic perspective on the factors that drive the organization's behavior regarding its mission
Obaze (2019)	The study presents a dynamic model that provides insight into the complexities of supplying, distributing and transporting charitable resources to underserved communities
Guo and Kapucu (2020)	The study simulates different scenarios to identify influencing factors affecting the performance of humanitarian operations and tests improvement options

Source: Authors

Figure 1 Venezuelan migratory route in Brazil

Source: Map data: Google Earth® 2022, Mountain View, CA, USA

The Acolhida Operation was designed to support local authorities in receiving and assisting the most vulnerable among migrants and refugees. Not every person crossing the border is considered unassisted (thus, represented in the model) since most people have a host in Brazil or are simply crossing the border to get to another country. According to Kanaan (2019), approximately 10% to 15% of migrants and refugees crossing the border are extremely vulnerable and, therefore, dependent on the operation's support for survival. This percentage is Acolhida's target audience and is represented in the SD model.

In March 2020, the Brazilian overland border was closed due to COVID-19 sanitary restrictions. Legal entries were prohibited, which prevented migrants and refugees from continuing their document-presenting process. As a result, many took alternative routes to cross the border (*trochas*). Roraima state authorities estimated that approximately 100 people crossed the border per day during this period (Portal Roraima 1, 2021).

Shelters are considered foundational to the resettlement process (Douglas et al., 2017). For months, they were used as an immediate response to assist migrants and refugees living on the streets by providing them with food, sanitation and safety, among other essential services. Four shelters were opened before the Acolhida Operation began, half of them focused on the Indigenous community, and most of them were managed by public authorities. To integrate these migrants and refugees into the host community, shelters were built as part of the Acolhida Operation in the urban perimeter of Boa Vista and Pacaraima. This situation contrasts with other humanitarian operations addressing mixed migration flows (Kanaan, 2019). Consolidating the information about the shelters described above, we outline three phases:

- 1 Maximum shelter occupancy (March 2018 to March 2020): all migrants and refugees could be sheltered as long as there was available space.
- 2 Unused shelter vacancies (April 2020 to December 2020): due to COVID-19 sanitation restrictions, the closing of the overland border hampered the recognition of migrants and refugees within the Brazilian territory, making it harder for migrants and refugees not only to be sheltered

but also to access essential public services. During this phase, shelter capacity increased and new shelters were created.

- 3 Sudden increase in occupation (January 2021 to April 2021): as the border closed due to the pandemic and undocumented entries continued to occur, the unassisted population in Pacaraima and Boa Vista suddenly started to grow at the end of 2020. Thus, Acolhida created a joint board alongside UN agencies, selecting vulnerable migrants to shelter, regardless of documentation status.

In addition to organizing the border in Pacaraima and providing migrants and refugees with shelter, Acolhida's intended to successfully integrate this population nationally using different means of transport. From the beginning, the internalization program underwent transformations that increased the number of available seats and the frequency of flights leaving Roraima. In October 2019, Acolhida began chartering aircraft for its internalization program, boosting Acolhida's logistic capacity (Operação Acolhida, 2021a). As a result, the final internalization rate more than tripled, increasing rapidly from an average of 550 people/month in 2018 to 1850 in 2019. Thus, aircraft capacities and flight frequencies differ throughout the simulation.

3.2 Causal loop diagram for the Acolhida operation

As the research problem is to reduce the unassisted migrant population, the first CLD versions considered two main forces: reducing the number of entering migrants and increasing reception. In the process of validating the model with Acolhida's decision-makers, it became clear that the decision-maker had no control over the number of migrants crossing the border, as Brazilian migratory law does not allow migrants and refugees to be restrained from entering the country.

The CLD was then refined to represent three strategies that boost reception: increase the sheltering rate by building more shelters, increase the number of internalization hubs and increase the availability of internalization vacancies.

We focused on the last two strategies. Internalization vacancies can be increased both externally by adding more vacancies to the system and internally by increasing the

percentage of the internalized population that can host other traveling migrants.

By altering these processes, people are removed from the streets and spontaneous occupations, meeting the Acolhida objective (Figure 2). The CLD consisted of four loops, described below and exogenous highlighted variables.

As more migrants and refugees cross the border and enter Pacaraima (the Brazilian city closest to the border with Venezuela), the number of unassisted people increases because not everyone has a place to stay or go. This population is then reduced by three factors: sheltering, transferring and internalizing. The sheltering rate is endogenous, and the transfer rate is exogenous. However, the internalization rate has both an exogenous component (i.e. directly creating vacancies) and an endogenous component (i.e. the hosting mechanism).

Loop B1, in red, represents the shelter solution and follows the hypothesis that when the number of unassisted people is greater, the host population becomes more concerned, which reacts by pressuring local authorities and organizations. One way to relieve this pressure is by opening more shelters, which increases the available space and the sheltering rate (B2, in blue), thus removing more people from the streets and closing the loop.

Similarly, when new hubs are opened, the transfer rate increases, more people are removed from the streets and shelters (B3, in green) and the number of available flights increases, boosting the internalization rate. That is, by opening more internalization hubs, the unassisted population can be reduced both directly and indirectly. This reduction is possible only because internalization hubs are located in cities with greater flight availability, which also makes them cheaper. Therefore, unassisted and sheltered migrants can be directly internalized or transferred to hubs and then internalized.

The last loop (R1, in magenta) explains the hosting mechanism and is directly affected by the creation of

internalization vacancies. This creation, however, is mainly outside of the model boundaries, and future research is expected to explore its causes more deeply. In the hosting loop, when more vacancies are made available, the interiorization rate increases, removing more people from the streets, shelters and internalization hubs. These already-resettled migrants, after a certain period, can receive other migrants into their homes, thus creating more internalization vacancies and closing the reinforcing loop. This closure is possible because of internalization modalities, such as familiar and social reunifications, which give migrants and refugees in Roraima more options when applying for the internalization program. Hence, this program removes vulnerable people from the streets in Roraima both directly and indirectly in the short and medium-long terms.

The model does not explain the reasons people migrate. Instead, it considers border entrance as exogenous and explains the balancing forces that reduce the unassisted population by increasing the number of shelters and the hubs of internalization vacancies.

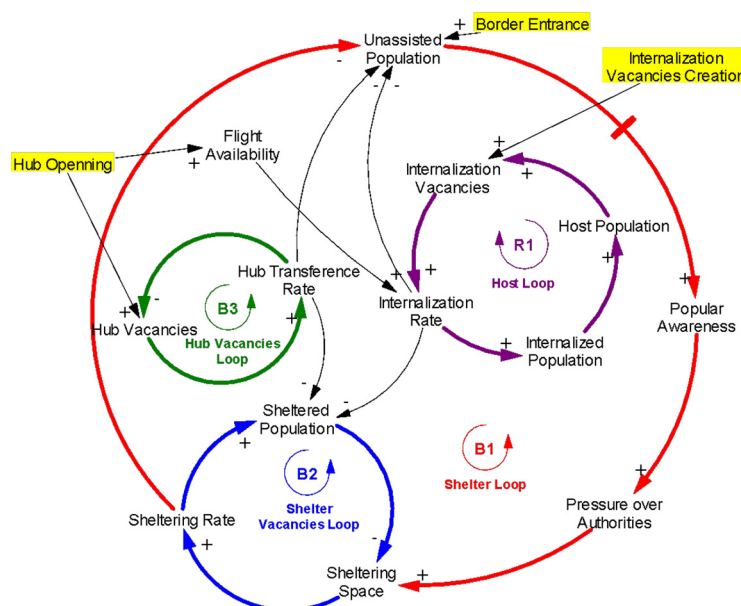
3.3 Stock-and-flow diagram for the Acolhida operation

As the present problem is to reduce the number of unassisted migrants in the system, the main stock in the model is measured in people or vacancies. Unassisted migrants flow from the reception at the border in Pacaraima to the flights leaving Roraima from Boa Vista or Manaus.

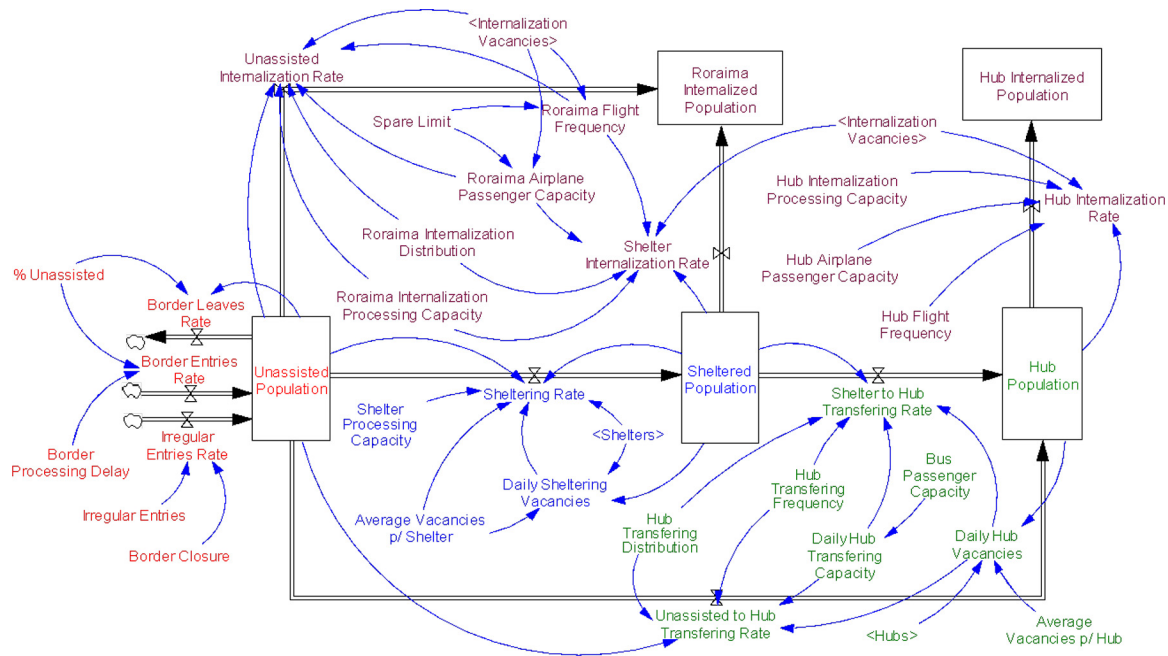
Our model focuses on three stocks from a population perspective: unassisted, sheltered and inside the hubs. The populations from these stocks can be internalized both directly (from the stock toward the host city) and indirectly (moving through one or two stocks before being internalized).

Figure 3 shows a simplified version of the SFD, with four of the six model steps: (I) border control (red), (II) sheltering

Figure 2 Validated CLD



Source: Authors, using Vensim® software

Figure 3 SFD steps: (I) border control (red), (II) sheltering (blue), (III) hub transferring (green) and (IV) internalization (magenta)

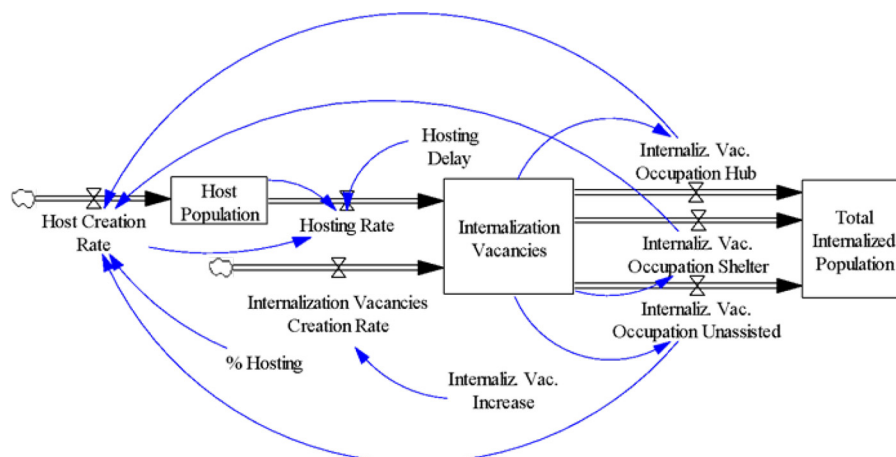
Source: Authors, using Vensim® software

(blue), (III) hub transferring (green) and internalization (magenta). The other two steps – (V) hosting process and (VI) pressure mechanism – are shown in Figures 4 and 5. Table A1 presented in the Appendix contains the model's main equations.

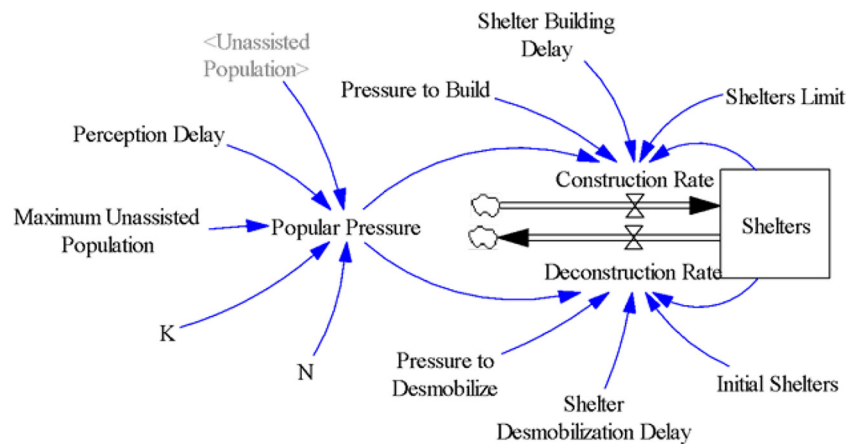
Step (I) begins when migrants and refugees cross the border, entering Pacaraima legally (by submitting identifying documentation to the Federal Police) or by irregular means. From January 2018 until June 2018, no border entries and exits were made public. The Federal Police shared with the authors the average number of people who entered and stayed in Brazil per month during that period (entries minus exits). From July 2018 until the border closed in March 2020, the daily average

number of migrants and refugees who arrived and stayed in Brazil was 412, with a standard deviation of approximately 150 people (International Organization for Migration, IOM, 2021a). The simulation considers that 50 people crossed the border daily without registration and did not move directly to another state or country. During this period, the model does not consider only 10%–15% of people to be vulnerable, as every person crossing the border irregularly can be assumed to be in a grave state of vulnerability (Kanaan, 2020).

Migrants and refugees on the streets and in spontaneous occupations in the cities of Pacaraima and Boa Vista thus became of the unassisted population stock. According to monthly data provided by the IOM, from June 2019 to April 2021, the average

Figure 4 Hosting mechanism, Step (V)

Source: Authors, using Vensim® software

Figure 5 Pressure mechanism

Source: Authors, using Vensim® software

unassisted population in Boa Vista and Pacaraima was 3,800 people, with a standard deviation of approximately 520 people. Data before this period are not publicly available. However, these numbers may not precisely represent the unassisted population in Roraima, as the state does not count those who share housing under extremely precarious conditions or who rely on Acolhida's support for survival. In addition, a small number of migrants would rather be on the streets than in shelters or the reception post at the bus terminal (IOM, 2020).

Step (II) of the SFD illustrates how Acolhida removes people from the streets in Pacaraima and Boa Vista and provides them with temporary shelter. The sheltering rate relies on the daily processing capacity and the space available in the camps. To simplify, the maximum processing capacity is estimated at 150 people per day and the average camp capacity is 400 people (UNHCR, 2021). Data from September 2019 until February 2020 are not publicly available, and the opening and closing dates are estimated based on field experience.

Step (III) illustrates the construction of hubs and the transportation of sheltered and unassisted populations toward the hubs and later to the host cities. While hub transfer is performed by bus every two days, internalization is performed by plane, with varying frequencies. The unassisted population transfer rate and the sheltered population transfer rate rely on hub space availability, processing capacity, seat availability and trip frequency. Once these populations are in Roraima, processing capacity and available bus seats must be shared between the two transfer rates. To simplify the model, each rate can reach a maximum of 50% of the available seats and capacities to address the great variability of this percentage over the years. For example, before the social reunification and work integration modalities, internalization was available to only sheltered people. Currently, the shelter modality represents a much smaller percentage than the other three (IOM, 2020).

Step (IV) describes the internalization process using three rates: the unassisted and sheltered internalization rates in Roraima and the hub internalization rate outside of the state. Similar to Step (III), as the unassisted and sheltered populations are both located in Roraima, they must share the

same processing capacity, aircraft seats and flight frequency, while the hub internalization rate has a separate process. Internalization vacancies are available for the three population stocks, with priority being given first to the hub population; followed by the sheltered population; and, finally, the unassisted population stock.

Interviews confirmed the modeling premise that all available internalization vacancies would be filled by Acolhida. Therefore, when internalization vacancies reach a certain level, the capacity is automatically adjusted. Thus, by analyzing the internalization history over the past three years, it is possible to identify how the processing capacities (frequency and aircraft space) changed. That is, once the decision-maker knows how many people are internalized, the available aircraft sizes and flight frequencies, it is possible to predict how and when Acolhida will adjust its capacity.

Internalization hubs have their own fixed aircraft capacity and frequency, gathering migrants from the unassisted and sheltered population in Roraima who shares the same bus seats during the transfer. Therefore, the hub-processing capacity is not influenced by Roraima's internalization rates. When more hubs are built, more buses, airplanes and processing capacities are available, assuming that hubs are built in different cities.

Step (V) models the hosting mechanism created by the positive feedback of internalized people hosting their families and peers after being resettled in a new city (Figure 4). Acolhida estimates that 8% of the total internalized population became hosts three months after they settled (Operação Acolhida, 2020).

The internalization vacancy stock is fed by two rates: the historical internalization data (exogenous) and the hosting mechanism (endogenous). The historical data showed a sudden increase in internalizations from May to October 2019 due to the new internalization and flight modalities and a sudden decrease caused by the COVID-19 travel restrictions in March, causing internalizations to stagnate at 1,300 people/month.

Finally, Step (VI) models the pressure mechanism, which shows how the accumulation of the unassisted population can result in shelter creation or demobilization (Figure 5).

As the street population and spontaneous occupations increase, the host population may feel an increase in public safety and health issues. Such issues include increases in theft and violence, prostitution, sex for survival, overcrowding of hospitals and basic health stations and irregular trade and begging. As a result, xenophobia and public demonstrations may increase, as well as protests from both the host and migrant populations. An example is those that occurred in August 2018 in Pacaraima, when locals drove migrants off the border and burned their belongings (BBC News, 2018). Events such as this pressure local authorities and international organizations working in the Acolhida Operation to respond.

This study assumed that popular pressure is nonlinear and directly proportional to the number of unassisted people. Decision-makers at Acolhida were presented with four types of pressure behaviors and selected Option 4 (S-shaped curve) as the one that best fits reality. According to the decision-makers, initially the pressure remained low, and it grew exponentially after reaching a certain number of people. When approaching the system population limit, the population increase did not generate the same increase in pressure, creating a stabilizing behavior (Figure 6).

The S-shaped curve was modeled using an exponential function to allow for scenario-specific flexibility [Equation (1)]. Changing parameters k and n while holding all else constant, decision-makers can identify the most accurate scenario in terms of how the unassisted population (t) stock influences pressure $F(t)$ on authorities and organizations. As shown in Figure 7, this perception ranged from smooth behavior, as in Option 1 ($k = 5$, $n = 3$), to aggressive behavior, as in Option 4 ($k = 6$, $n = 2$). For this simulation, we used Option 3, that is, $k = 8$ and $n = 1.5$:

$$F(t) = A * (1 - e^{-k * t^n})$$

Once the curve that best approximates behavior is defined, the decision-maker can estimate the minimum pressure needed to open a new shelter. When the minimum pressure is lower, the

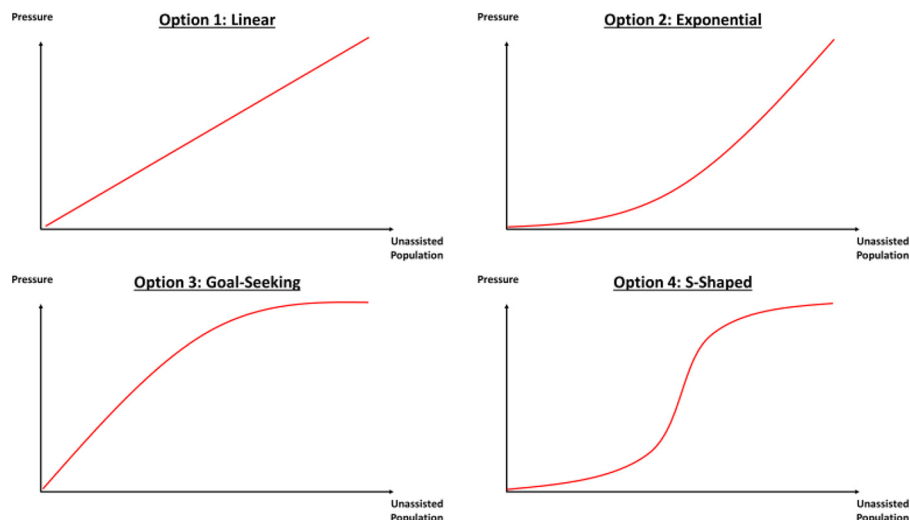
system will be more sensitive, resulting in more shelters and fewer migrants and refugees on the streets. For this simulation, we use 0.7 as the pressure needed to build a shelter and 0.4 as the pressure needed to demobilize it.

4. Model validation

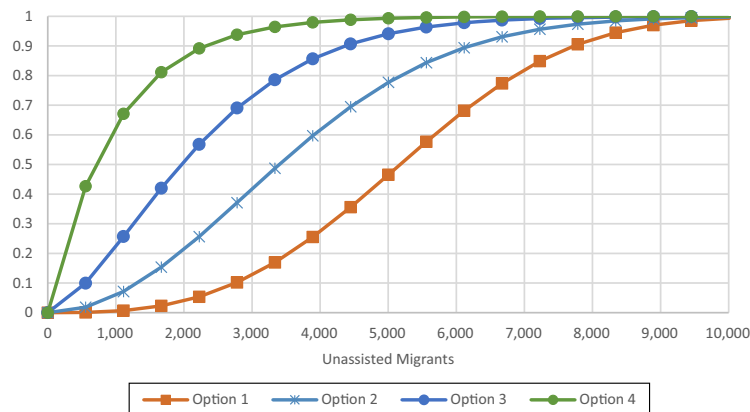
Model validation was divided into three sections: unassisted population, sheltering and internalization processes. Although border movement was one of the model's most important parameters, it was used as external data; hence, it was not influenced by any behavior in the system. Table 2 shows all the parameters used in the simulation and their sources.

Figure 8 shows the comparison for the unassisted population between the reference mode ("RM_Unassisted") and the simulation ("Current status"). For the reference mode, IOM monthly reports from July 2019 to April 2021 were used, and data before this period either did not exist or were not found. The large disparity between the reference mode and the simulation, especially before the border closure, at approximately day 800 of the simulation ("Current status"), is explained by several factors. First, the model accounted only for people on the streets and spontaneous occupations, omitting those living in rented houses, despite their vulnerability. This population is also eligible for the internalization program, which means an important number of migrants have been internalized but were not accounted for in the model. Second, the 15th percentile might be inaccurate and variable regarding unassisted migrants and refugees arriving in Brazil, who are targeted by Acolhida. Finally, the model did not consider the spontaneous internalizations that occurred during Acolhida's first months, carried out mainly by churches and small nongovernmental organizations. Only months after Acolhida was implemented was an integrated system developed to gather and organize every internalization process from different organizations to optimize the use of airplanes. These changes might indicate fewer people on the streets than the model suggests.

Figure 6 Curve options for decision-makers



Source: Authors

Figure 7 S-shaped curve options

Source: Authors

Figure 9 focuses on the sheltered population by comparing the simulation results (“Current Status,” blue line), the reference mode for the shelter maximum capacity (“RM_Shelter Capacity,” red line) and the sheltered population (“RM_Sheltered,” green line). These results are very similar during the maximum occupation and spare shelter vacancy phases until border closure (at approximately day 800). After that, the simulation does not follow the increase in shelter capacity and the decrease in sheltered migrants of the reference mode for several reasons. First, the simulation limits cannot be extrapolated as they were in reality: additional people were sheltered by making simple structural arrangements or purchasing extra mattresses, for example. Second, the simulation model does not consider the change in the shelters’ average capacity, which started at 370 people per shelter and increased to 500 at the end of two years.

Finally, the third set of stocks represents the internalized populations from Roraima and the hubs. Together, these

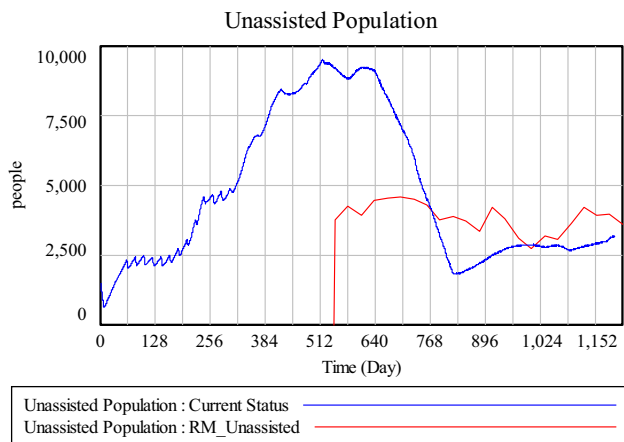
stocks represent the accumulation of the entire internalized population throughout the system. The internalization vacancies stock had two incoming rates: the external vacancy creation rate, which was exogenous to the system and was derived from the monthly historical internalization segregated in days to obtain a daily average of vacancies, and the hosting rate, that is, the 8% of the internalized population who, after three months, can host other people, creating new internalization vacancies. Figure 10 illustrates the average number of daily available vacancies (a) and their accumulation throughout the simulation (b).

In Reference Mode b, the simulation result (“Current Status,” blue line) is equal to the two internalization rates in Roraima (from the unassisted and sheltered population), plus the hub internalization rate. The result is almost identical to the reference mode (“RM_Internalized Total,” red line), as most internalization vacancies are generated externally based on historical data.

Table 2 Model parameters

Variable	Value	Units	References
% Hosting	0.08	Dmnl	(Operação Acolhida, 2020)
% Unassisted	0.15	Dmnl	(Kanaan, 2019)
Hub Airplane Passenger Capacity	150	People	(Operação Acolhida, 2021a)
Average Vacancies p/Hub	250	People/Shelter	(IOM, 2020)
Average Vacancies p/Shelter	400	People/Shelter	(UNHCR, 2021)
Border Closure	808	Day	(IOM, 2021a)
Border Processing Delay	2	Day	(Kanaan, 2020)
Hub Flight Frequency	3	Day	(Operação Acolhida, 2021b)
Hub Opening	638	Day	(UNHCR, 2020c)
Hub Transfer Frequency	2	Day	(Operação Acolhida, 2021a)
Initial Unassisted Population	1500	People	(Kanaan, 2019)
Hub Internalization Processing Capacity	150	People/Day	Field Estimate
Roraima Internalization Processing Capacity	150	People/Day	Field Estimate
Irregular Entries	50	People/Day	(Portal Roraima 1, 2021)
Shelter Processing Capacity	150	People/Day	Field Estimate
Social Reunification Beginning	500	Day	(Operação Acolhida, 2021a)
Unassisted Internalization	300	Day	(Operação Acolhida, 2021a)

Source: Authors

Figure 8 Reference mode comparison – unassisted population

Source: Authors, using Vensim® software

5. Discussion and scenario analysis

In this section, we present the simulation results divided into four scenarios. Each scenario results from the combination of a condition and a policy (Table 3). Conditions are a given model setup, such as the number of available internalization vacancies. Meanwhile, policies are reactions driven by public authorities to improve the system, such as the time to open a new hub or the internalization processing capacity.

In Condition 1, the internalization vacancies were the same as are those observed in reality. That is, the number of vacancies was identical to the number of internalized people during the simulation period. In Condition 2, the internalization vacancies were infinite, and the system must operate at its full capacity, as the vacancies were no longer the bottleneck. Policy 1 proposed the early opening of hubs at 12 months, 6 months and immediately after Acolhida was launched, instead of at 15 months when the Manaus hub was inaugurated. Policy 2 set the maximum capacity of the operation to be available from day one of the simulation instead

of to be gradually increasing. The results of the key variables in both conditions are shown in Figures 11 and 12.

5.1 Comments on Condition 1

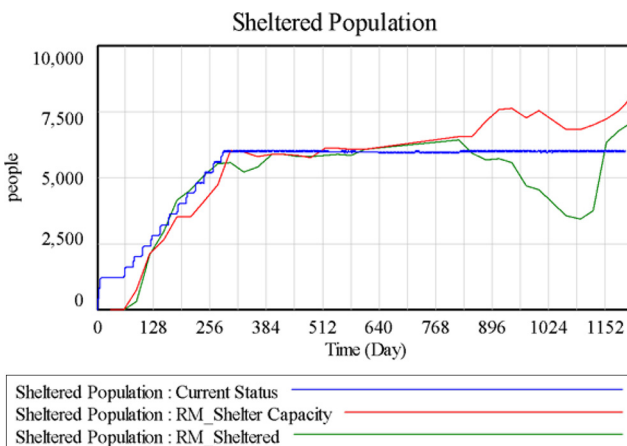
Condition 1 included Scenarios 1 and 3 and combined the limited internalization vacancies (historical data) with the early hub opening and immediate maximum processing capacity for internalization. Figure 11 shows that, since internalization vacancies were the main bottleneck and remained limited, the policies differed little in most key variables, such as the number of unassisted and internalized populations.

The main difference between the key variables was the number of internalizations from Roraima and the hub once the migrants in the hubs were prioritized, increasing the rotation when compared to the internalizations made in Roraima. Although the total internalized population did not change significantly, internalizations carried out from the hubs were expected to be cheaper due to the greater flight availability (more options for commercial flights) and the proximity to other Brazilian capitals. Therefore, optimizing this channel could represent efficiency gains for the operation. Table 4 compares the indicators for each policy in Condition 1.

5.2 Comments on Condition 2

Internalization vacancies were limitless in Condition 2, so the system could operate at its full processing capacity. As expected, the total number of internalized migrants and refugees was much greater than it was in the previous scenario, reaching 60,000 people by the end of the simulation, as shown in Table 5.

The other stocks in the system, such as the unassisted and sheltered populations, were also significantly smaller than were those in the reference mode, indicating a higher rotation in shelters and on the streets. As a result, there were no unassisted people by the time the border is closed, regardless of when the hub was opened. When the shelters were built after six months of operation, the unassisted population remained significantly smaller, not reaching the mark of 2,000 people. Additionally, in three years shelters were not needed, so demobilization could start by the middle of the simulation period.

Figure 9 Reference mode comparison – sheltered population

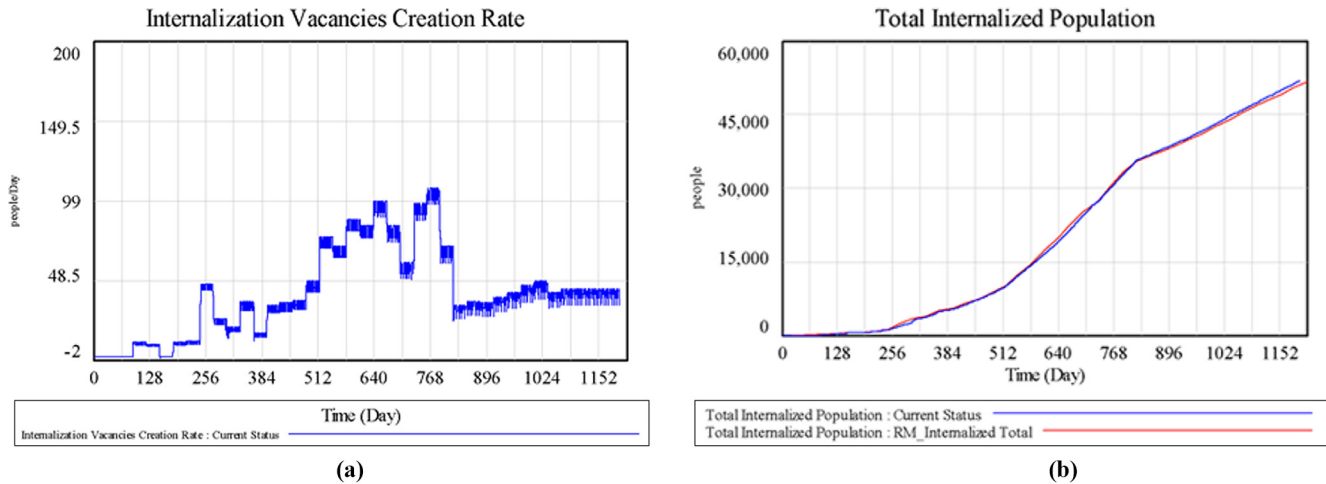
Source: Authors, using Vensim® software

6. Sensitivity analysis

The variables selected for the sensitivity analysis were chosen based on two criteria: availability and/or reliability of the source and preimpact on the system results. The latter criterion was assessed by making changes to the variable values and observing their impact on critical variables. If the impact was significant, the variable was selected for a more detailed analysis.

To systematize the analysis, the selected variables were categorized into two groups: those related to the border entrance and the internalization program. This segregation allows the variables to be assessed first together and then individually, depending on their impact on the system. The main variable in Groups 1 and 2 were altered, and the changes in the key stocks can be seen in Figure 13.

The variables in Group 1 significantly impacted the system. The percentage of the unassisted population crossing the border, in particular, was an estimate given by Acolhida to

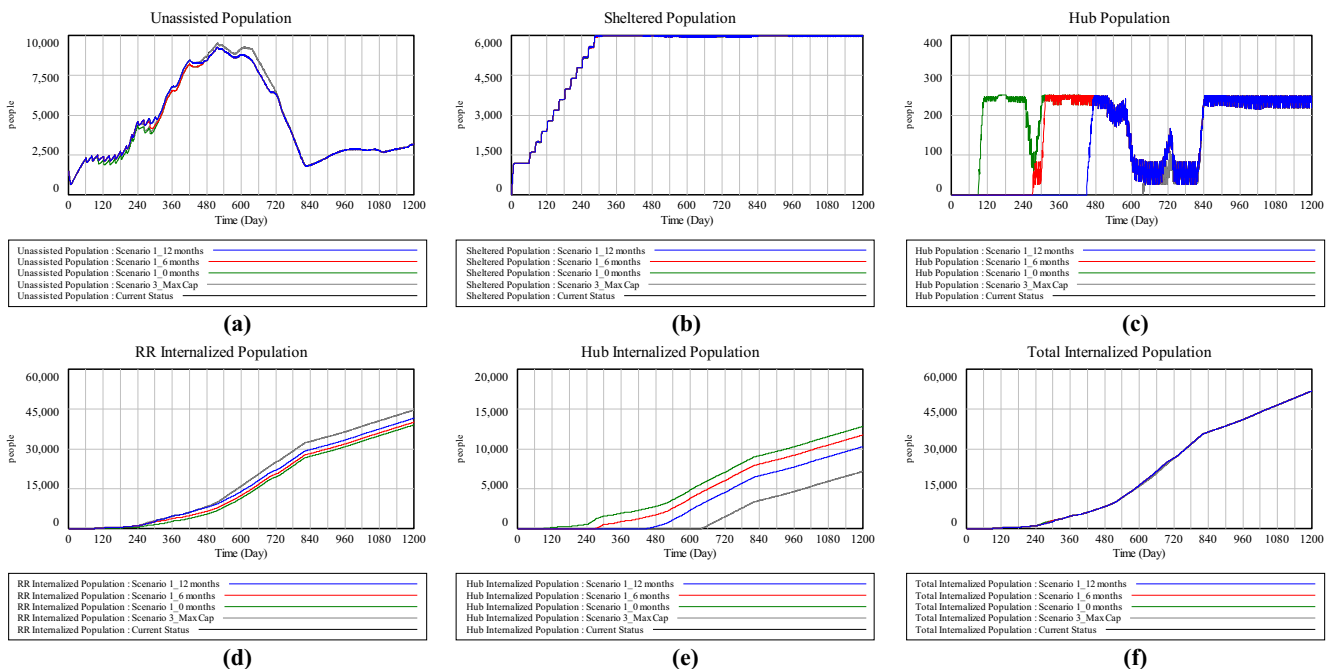
Figure 10 Reference mode comparison – creation of internalization vacancies (a) and vacancy accumulation (b)

Source: Authors, using Vensim® software

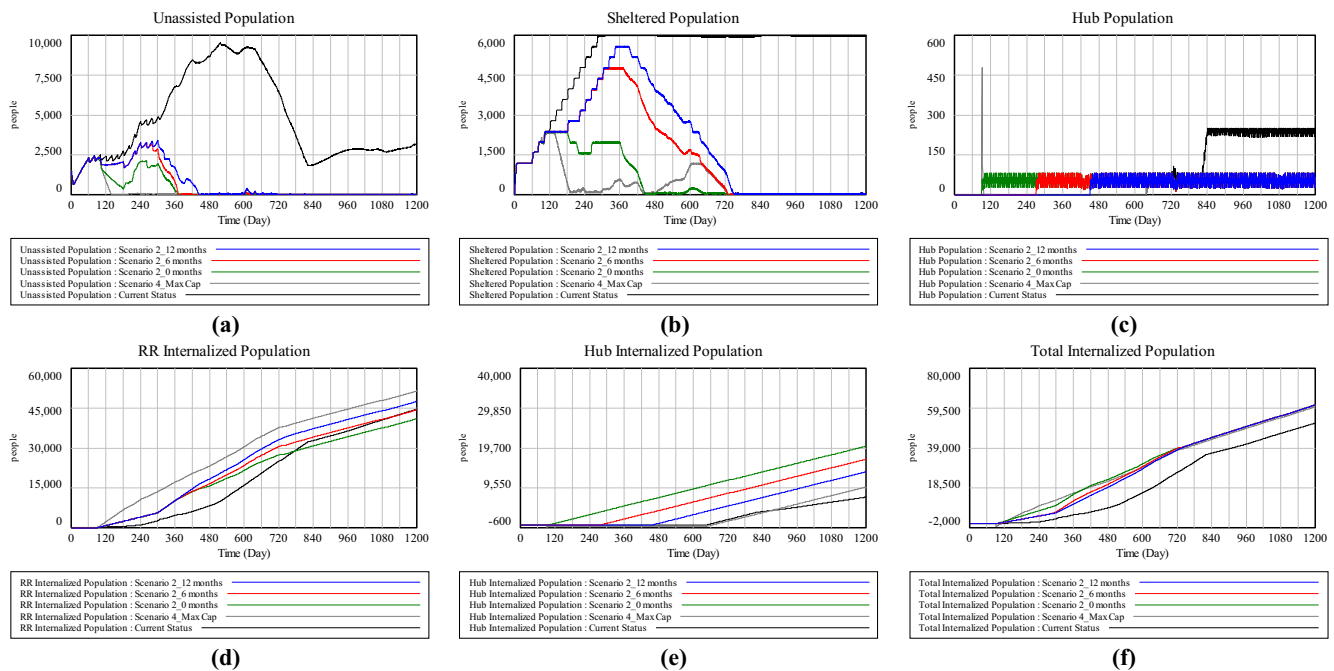
Table 3 Simulation scenarios

Policy	Condition 1: Limited vacancies	Condition 2: Unlimited vacancies
Policy 1: <i>Early Hub opening (12 months, 6 months and immediate)</i>	Scenario 1	Scenario 2
Policy 2: <i>Immediate maximum internalization processing capacity</i>	Scenario 3	Scenario 4

Source: Authors

Figure 11 Simulation results for Condition 1

Source: Authors, using Vensim® software

Figure 12 Simulation results for Condition 2

Source: Authors, using Vensim® software

separate those migrants and refugees who will probably use Acolhida's services. This variable had a large impact on the unassisted population stock and, consequently, on the sheltered population. Increasing or decreasing the variable by 20% moved the system from an unassisted population of zero by the 700th simulation day to almost 15,000 during the same period.

Nevertheless, the final internalization stock did not change significantly. Even when the percentage of people entering Roraima is lower than the Acolhida estimation, other

population stocks, such as shelters, were consumed to fill the internalization vacancies.

Group 2 consisted of most of the system's endogenous variables, from the internalization capacity (processing and available space) to the vacancy availability, mainly influenced by the host percentage and raw increase in available vacancies. Changes in the percentage distribution of vacancies for unassisted individuals, shelters and hubs did not impact the system. They only marginally increased the processing steps (e.g. for sheltered people).

Table 4 Policy comparison for Condition 1

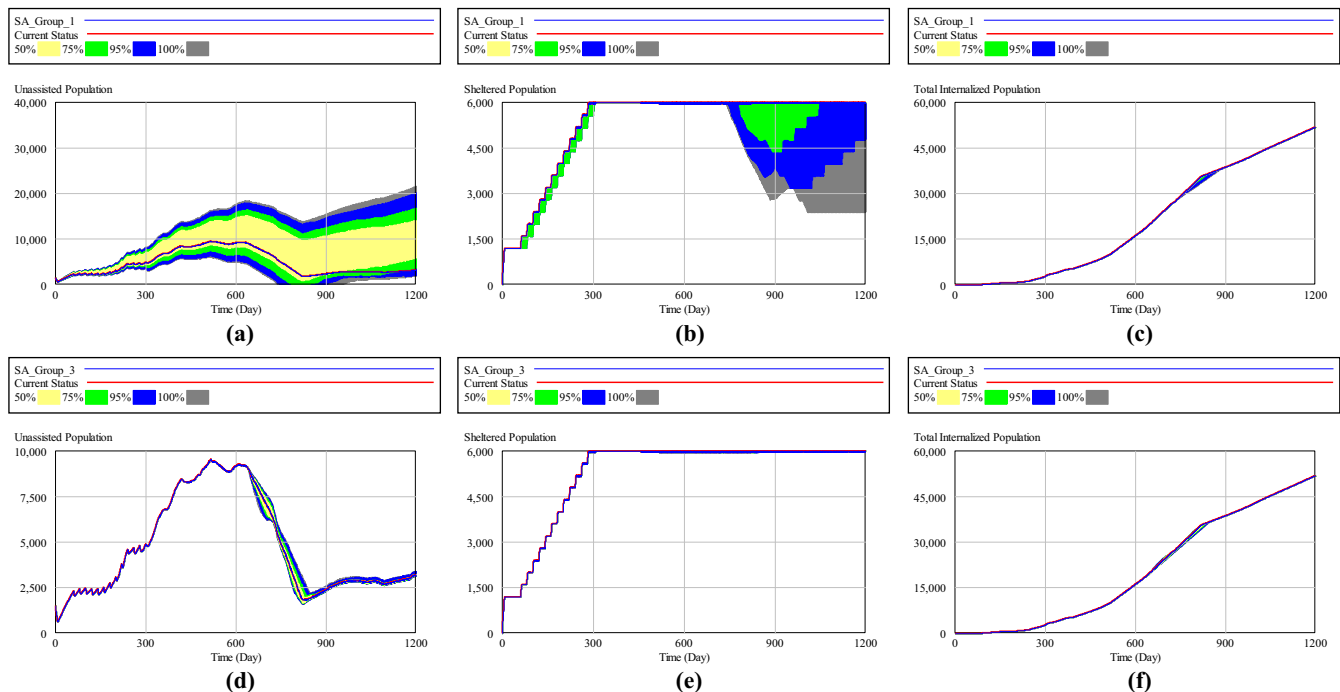
Indicator	Current	12 months	Scenario 1		Scenario 3	
			6 months	Immediate	Maximum capacity	Maximum capacity
Max. Internalized Stock from Hub (people)	7,168	10,264	11,735	12,794	7,168	7,168
Max. Internalized Stock from Roraima (people)	44,599	41,504	40,033	38,973	44,599	44,599
% Internalized Stock (Hub/Roraima)	14/86	20/80	23/77	25/75	14/86	14/86

Source: Authors

Table 5 Policy comparison for Condition 2

Indicator	Current	12 months	Scenario 2		Scenario 4	
			6 months	Immediate	Maximum capacity	Maximum capacity
Max. Unassisted Stock (people)	9,530	3,416	3,251	2,428	2,428	2,428
Time to reach zero shelters (day)	—	750	730	450	200	200
Max. Internalized Stock from Hub (people)	7,168	13,615	16,825	20,132	9,741	9,741
Max. Internalized Stock from Roraima (people)	44,599	47,534	44,355	41,060	51,456	51,456
% Internalized Stock (Hub/Roraima)	14/86	22/78	28/72	33/67	16/84	16/84

Source: Authors

Figure 13 Sensitivity rest, Groups 1 and 2

Source: Authors, using Vensim® software

The vacancy increases resulting from a larger and faster hosting percentage were more impactful after the border closure by the 800th day of simulation. During this period, generating internalization vacancies was even more challenging, according to historical data. Hence, increasing the hosting percentage while reducing the hosting delay might be economic ways of creating vacancies, acting significantly to reduce the unassisted population stock.

Changing the system-processing and passenger capacities boosted internalizations by hubs in contrast to those made in Roraima. Such changes did not significantly affect the key variables, as the main bottleneck was the availability of internalization vacancies. The most significant impact occurred when those variables were changed simultaneously with other variables, such as the frequency of flights and buses.

To summarize, the simulation confirmed Acolhida's belief that vacancies were the system's main bottleneck, and few changes in the variables were related to the hosting process, for example, generated better results than did increasing the internalization capacity.

7. Conclusion

The Acolhida Operation was the first large-scale interagency humanitarian operation in Brazil and has served as a benchmark for good coordination between civil organizations and the military. Acolhida's logistical effort and the number of beneficiaries assisted (more than 70,000 people since April 2018) shed light on the differences between this operation and other resettlement processes carried out in Brazil (IOM, 2021b).

The SD simulation proved to be a suitable tool to analyze the complexity of migratory contexts, such as those experienced in Roraima. It allowed decision-makers to adjust the system's capacity, estimate variables and foresee long-term behaviors, thus enhancing planning and preparation.

The objective of the study was to simulate Acolhida's internalization program to identify the main bottlenecks affecting the system and to propose policy improvements to boost the program's processing capacity. By doing so, this model can also be applied to other migratory contexts that implement similar measures to receive, shelter and resettle migrants and refugees, providing humanitarian organizations and authorities with insights based on the Acolhida experience.

Our study confirms that the availability of internalization vacancies is the operation's main bottleneck and suggests policies to boost the resettlement program. We suggest that humanitarian actors and authorities prioritize policies designed to increase the number of internalization vacancies. Without such vacancies, the increases in processing capacity or frequency and airplane passenger capacity have little impact on the number of resettled migrants. According to the results, for example, the hub alternative would not be necessary if Acolhida's processing capacity in Roraima started at its current increased levels.

Both policies suggested in this study might save costs, as they allow vulnerable people to spend less time in shelters and lead to a smaller number of shelters needed. They also increase well-being, as reception and border control in Pacaraima become more organized. That is, by more easily documenting migrants and refugees and allowing them to safely enter the country, authorities reduce migration-associated risks, such as human trafficking, violence and theft.

The policies presented in this model can support decision-makers when forecasting the number and size of temporary shelters in migratory operations as well as when anticipating the internalization effects as vacancies are created. The main takeaway from this study is that operations should increase the internalization process from day one, as stated by one of the interviewees. By creating scenarios of influxes at the border, Acolhida can forecast the needed processing capacity for shelters and open hubs to boost the internalization capacity.

This study was limited to a simulation of the flow of people and did not consider the monetary flow or other financial aspects that could be of great value for adding more capacity to shelters or opening new hubs. The pressure mechanism was also limited to the number of unassisted migrants living on the streets, even though many other factors might interfere with how the host population and local authorities perceive the migratory pressure. Such factors might include the neighborhood where migrants are gathered, election periods and the overcrowding of public services (health, education, etc.), among others.

Because the simulation model uses only official data and minor estimations, it is difficult to precisely grasp some of the aspects pertaining to the population of migrants, such as the number of migrants and refugees entering the border unofficially; the number of unassisted people living on the streets; and the number of spontaneous internalizations, that is, those occurring without any official support from Acolhida. Therefore, we suggest that more studies examine the percentage of the unassisted population because it is a critical aspect of the simulation output, yet it is difficult to determine and monitor in the field. Furthermore, the COVID-19 pandemic imposed restrictions on field visits and impacted the reference model, for example, during border closures.

As observed through Acolhida and suggested by Seifert *et al.* (2018), more studies are needed on the integration of migrants and refugees with the host community analyzing the impact on public services and health-care systems. Furthermore, the factors affecting the creation of internalization vacancies – such as the federal benefits for host cities, marketing campaigns and roundtable discussions with enterprises to raise awareness of migration – should be introduced into the simulation. Finally, the pressure mechanism is the first attempt to move the unassisted population into shelters. It can be improved, either by better evaluating the perceptions of authorities and the local population or by converting this pressure into ways of boosting the internalization process.

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Appendix

Table A1 SFD variables, equations and units

Variable	Equation	Units
Border Entry Rate	SMOOTH((Entries Lookup(Time))* "%Unassisted", Border Processing Delay)	People/day
Border Leaving Rate	MIN(Unassisted Population/HTGC, Leaves Lookup(Time)* "%Unassisted")	People/day
Daily Hub Vacancies	(("Average Vacancies p/Hub "*Hubs)/HTGC)-(Hub Population/HTGC)	People/day
Daily Sheltering Vacancies	(Shelters* "Average Vacancies p/Shelter"/HTGC)-(Sheltered Population/HTGC)	People/day
Host Population	INTEG(Host Creation Rate-Hosting Rate,0)	People
Hub Internalization Rate	PULSE TRAIN(INITIAL TIME,1,Hub Flight Frequency, FINAL TIME)*MIN(Hub Population/HTGC,MIN (Hub Internalization Processing Capacity, MIN(Internalization Vacancies/HTGC,(Hub Airplane Passenger Capacity/HTGC))))	People/day
Hub Internalized Population	INTEG (Hub Internalization Rate,0)	People
Hub Population	INTEG (Shelter to Hub Transferring Rate+ Unassisted to Hub Transferring Rate-Hub Internalization Rate,0)	People
Hubs	INTEG (Construction Hub Rt,0)	Shelter
Internalization Vacancies	INTEG (Hosting Rate+ Internalization Vacancies Creation Rate-"Internaliz. Vac. Occupation Hub "- "Internaliz.Vac.Occupation Shelter"- "Internaliz.Vac.Occupation Unassisted",0)	People
Irregular Entry Rate	IF THEN ELSE(Time>Border Closure, Irregular Entries,0)	People/day
Roraima Airplane Passenger Capacity	IF THEN ELSE(Time<"Social Reunif. Beginning", MIN("Airplane Cap. Lookup"(Internalization Vacancies*Spare Limit),80), "Airplane Cap. Lookup"(Internalization Vacancies*Spare Limit))	People
Roraima Flight Frequency	IF THEN ELSE(Time<"Social Reunif. Beginning", MAX("Flight Freq. Lookup"(Internalization Vacancies*Spare Limit),3), "Flight Freq. Lookup"(Internalization Vacancies*Spare Limit))	Day
Roraima Internalization Distribution	IF THEN ELSE(Time<"Unassisted Internaliz. Start",1, "%Shelter Internaliz.")	Dmnl
Roraima Internalized Population	INTEG (Shelter Internalization Rate+ Unassisted Internalization Rate,0)	People
Shelter Internalization Rate	PULSE TRAIN(INITIAL TIME, 1, Roraima Flight Frequency, FINAL TIME)*MIN(Sheltered Population/ HTGC,MIN(Internalization Vacancies/HTGC, (Roraima Internalization Distribution*MIN(Roraima Internalization Processing Capacity,(Roraima Airplane Passenger Capacity/HTGC))))	People/day
Shelter-to-Hub Transfer Rate	PULSE TRAIN(INITIAL TIME,1,Hub Transferring Frequency, FINAL TIME)*MIN(Sheltered Population/ HTGC, MIN(Daily Hub Vacancies, Hub Transferring Distribution*Daily Hub Transferring Capacity))	People/day
Sheltered Population	INTEG (Sheltering Rate-Shelter Internalization Rate-Shelter to Hub Transferring Rate,0)	People
Sheltering Rate	IF THEN ELSE(Shelters* "Average Vacancies p/Shelter" <Sheltered Population,0,MIN(Unassisted Population/HTGC,MIN(Shelter Processing Capacity, Daily Sheltering Vacancies)))	People/day
Shelters	INTEG (Construction Rate-Deconstruction Rate, Initial Shelters)	Shelter
Total Internalized Population	INTEG ("Internaliz.Vac. Occupation Hub" + "Internaliz.Vac. Occupation Shelter" + "Internaliz.Vac. Occupation Unassisted",0)	People
Unassisted Internalization Rate	PULSE TRAIN(INITIAL TIME,1, Roraima Flight Frequency, FINAL TIME)*MIN(Unassisted Population/ HTGC, MIN(Internalization Vacancies/HTGC, ((1-Roraima Internalization Distribution)*MIN(Roraima Airplane Passenger Capacity/HTGC, Roraima Internalization Processing Capacity))))	People/day
Unassisted Population	INTEG (Border Entries Rate+ Irregular Entries Rate-Border Leaves Rate-Unassisted Internalization Rate-Sheltering Rate-Unassisted to Hub Transferring Rate, "Initial Unassisted Pop.")	People
Unassisted Hub Transfer Rate	IF THEN ELSE(Time<"Unassisted Internaliz.Start",0, PULSE TRAIN(INITIAL TIME,1,Hub Transferring Frequency, FINAL TIME)*MIN (Unassisted Population/HTGC,MIN(Daily Hub Vacancies, (1-Hub Transferring Distribution)*Daily Hub Transferring Capacity)))	People/day

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