HurricaneLog: A humanitarian logistics game on hurricane preparedness and response operations

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ABSTRACT
Natural and man-made disasters are recurrent on the planet, causing structural, economic and social damages. More particularly, Caribbean hurricanes originated in the Atlantic annually affect the lives of thousands of people. The damages caused by such events often exceed national coping capacities, requiring the aid of non-governmental organizations (NGOs) to help the impacted population. Due to the stochastic nature of climatic disasters, humanitarian agents must be trained over diversified scenarios to improve their decision-making process, making links between past and new events. In this paper, we present a serious game that simulates Atlantic hurricane seasons and whose objective is to serve as a training tool for humanitarian logistics teams regarding disaster relief actions under time and resource constraints. We describe how the game is played, its features and learning objectives, the game design challenges and deployed solutions.

Keywords
Serious game; simulation; humanitarian logistics; disaster management; hurricane preparedness; hurricane response.

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INTRODUCTION

Global climate change is the greatest challenge facing humanity today. It can be observed through several natural events e.g., higher sea surface temperatures, receding glaciers, floods, etc. The increase in frequency and intensity of such extreme natural events has been affecting populations worldwide (Pachauri et al. 2014). As the most significant representatives of these events, intense floods, droughts, and storms have been accounting for 90% of all natural disasters each year (World Food Programme 2018a).

In consequent periods of need, governmental and non-governmental organizations act to support the impacted populations by offering relief supplies, medical assistance, and other humanitarian services. Humanitarian organizations, such as the World Food Programme (WFP), World Health Organization (WHO) and the International Committee of the Red Cross (ICRC), are then mobilized through major logistic operations, making procurement and delivery of relief items according to forecasted needs. The WFP, for example, assists about 80 million people in 80 countries each year, delivering food assistance in emergencies, and working to improve nutrition in the most vulnerable communities (World Food Programme 2018b). WFP won the Nobel Peace Prize as a recognition of their important work on communities affected by hunger, war and conflicts (NobelPrize.org 2020).

Some natural disasters are recurrent and end up generating constant needs for humanitarian actions in the affected regions. Among them, hurricanes cause humanitarian crises every year in different regions of the globe. They are formed when the temperature difference between aloft and sea surfaces create a self-feeding heat engine that gains power as the sea temperature gets warmer. When such powerful natural formation encounters populated regions, infrastructure damages is almost certain. These natural formations are known for their stochastic behavior and yearly recurrence in the Atlantic Ocean from June to December (National Oceanic and Atmospheric Administration 2016). The Caribbean region, for example, known by its tropical characteristics, possesses a favorable environment for these natural formations. It is estimated that the 2017 hurricane season affected millions of lives, and left hundreds of thousands of people homeless and displaced (United Nations Office for the Coordination of Humanitarian Affairs 2017). The hurricane *Maria* brought the media's attention by its power of destruction and the impact that it caused, killing more than 4,600 people (Kishore et al. 2018). Due to the recurrence of substantial damages caused by hurricanes in the region, Caribbean countries have worked together with organizations, such as the United Nations (UN) and the World Bank, to improve their resilience against hurricanes. One of these initiatives is the Caribbean Disaster Emergency Management Agency (CDEMA), an inter-governmental agency responsible for disaster management in the Caribbean region, having as primarily responsibility coordinating emergency response and relief activities (CDEMA n.d.).

While assisting the population during natural disasters, humanitarian organizations must prepare logistic plans to make the response faster and less expensive. Thomas and Mizushima (2005) define humanitarian logistics as the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption to meet the final beneficiary's requirements. That is, in case of a natural disaster, to prepare storage, to receive or send supplies, to control the transportation and negotiations with different suppliers, as well as making the operation cost-effective and capable of helping the maximum number of people. As an example of the scale of such logistics operations, WFP delivered almost 10 tonnes of food, water, blankets, and other relief items to Panama, benefiting around 4,800 people in the most affected areas in the aftermath of hurricane *Irma* in 2017 (World Food Programme 2017).

Making decisions during response operations requires adequate training and preparation by humanitarian logistics managers (Gralla et al. 2015). Due to the stochastic nature of natural disasters, training processes must be diversified to stimulate managers towards progressive thinking regarding the target situation, allowing them to establish links between past and new events. Training in this context is critical given that the decision-making process is often carried out under pressure and stress. Logisticians (agents) are prepared to work with few hours of sleep and make decisions based on the information provided by governmental and non-governmental institutions (Gralla et al. 2015). By analyzing the available data (e.g., regional infrastructure, demographic population data) and forecasted events (e.g., hurricane predicted trajectory, weather prediction), logisticians must decide when, how and where to send the necessary relief items.

Moreover, one crucial factor in the decision process in humanitarian logistics is time since long delays may result in deaths (Kovács & Spens 2007). The pressure to make fast decisions and the significant number of variables to be considered require considerable efforts from the decision makers. Additionally, determining the best decision is not trivial. Because of the fragile nature of infrastructures and societies, the consequences of each decision are also hard to be accounted (Harteveld & Suarez 2015), making more difficult for logistics agents to learn from their previous decisions. For all these reasons, decision-makers often implement non-optimal solutions leading to losses of resources and lives. In order to reinforce the decision-making process in such a context, training is indicated to keep agents prepared and updated regarding potential relief actions (Gralla et al. 2015; Thomas & Mizushima 2005).

In this paper, we present a serious game, called *HurricaneLog*, aimed to serve as a training tool for humanitarian logistics agents, as a complementary teaching tool regarding disaster preparedness and response for university students, or even as a tool to bring awareness to non-expert players regarding the importance of natural disaster preparedness. The game allows players to acquire knowledge and training directly from their interactions with the game, by observing the outcome of their actions in a safe and inexpensive way. Besides, our game contains entertainment elements which are aimed to gain greater retention and learning.

HurricaneLog is designed to make players learn about the importance of four humanitarian logistics aspects:

(i) *preparedness*: presenting options extracted from the literature with different impacts on the response operations;

(ii) *quick decision-making*: exposing players to potential hurricane damages and deadly dangers to affected populations;

(iii) *tailored decisions*: concerning nations with different characteristics and logistical shortcomings;

(iv) *situation awareness*: limiting the budget available for preparedness investments.

Finally, *HurricaneLog* uses data from previous humanitarian operations and hurricane disasters to develop the game dynamics and its narrative, as well as to recreate real-life decision-making scenarios for humanitarian logistics operations.

This paper is organized as follows. Firstly, it presents a brief literature review of games used for learning in general and in humanitarian contexts. Next, we describe the game,

how it is played, its features, and the mechanics implemented to achieve its learning objectives. In the sequel, we discuss the challenges encountered during the game development and how they were approached. Finally, conclusions are given in the last section.

LITERATURE REVIEW

Games have been widely used not only as entertainment but also to teach and learn (Gee, 2003; Harteveld 2011). When games primarily focus on learning instead of amusement, they are called serious games (Abt 1970). In the literature, it is possible to observe the application of serious games to a wide number of domains such as education (Shin et al. 2012), training (Sabri et al. 2010), advertisement (Edery & Mollick 2008), health care (Fergus et al. 2009), etc. Backlund and Hendrix (2013) conducted an extensive survey on serious games, finding 40 studies that used games in different educational contexts, methods, and topics. These papers were analyzed regarding their impact on the educational development of their target public. The results showed that 90% of them had either positive or neutral results, demonstrating that serious games can be effective tools to be used on learning processes.

Bogost (2008) argues that games have the power to combine elements and processes that persuade the player to learn about an argument or ideology. This persuasion, according to the author, is implied in how the game elements are coordinated to make the player follow a certain set of actions to succeed. Consequently, these elements lead the player to learn and act according to the creators' ideals or arguments to obtain a positive result or complete the game's narrative.

Gee (2007) has long advocated the learning power that games have over players. The author mentions that the fact that games have their learning process linked to experience, leads to a better fixation and generalization of knowledge. Furthermore, good games provide the player with the possibility to perform under very reduced risks and dangers before acquiring competencies and skills, allowing them to still feel the sense of authenticity and accomplishment (Gee 2005). According to Bertazzo et al. (2018), game simulations enable players to make decisions and analyze their impacts in a safe manner, thus making games a valuable tool for learning and training. By means of games, live exercises can be supplemented or replaced giving more opportunities for agents/players to interact and try different approaches. Besides, games allow players to verify the impact of their actions without cost limitations, an approach that would often be prohibitive in the case of real-life experiments.

In the context of humanitarian operations, simulations and games have been used for two purposes: (i) training specific skills of the audience on real-life situations, and (ii) educating players on humanitarian problems as well as on social and disaster awareness.

Training through simulation has also been widely used as part of the humanitarian logistics agents' educational process. Among the variety of studies and courses in that area, we can mention the following:

- Gralla et al. (2015) describe a simulation exercise applied to train logistics response teams by simulating real-case scenarios. In that game, the teams experience a disaster simulation and are evaluated regarding their actions by more experienced decision-makers for seven days. At the end of each simulation day, the teams receive feedback about their performance regarding time management, critical information communication, information sharing, goals, priorities, and more.

- Stuns and Heaslip (2019) study the effectiveness of humanitarian logistics training. In this study, they interview multiple delegate trainees who participated in a Logistic Emergency Response Unity training exercise organized by the Finnish Red Cross (FRC). Based on interviews and field observations, the authors evaluated the training outputs in four dimensions: reactions, learning, behavior and results. They observed positive feedback from respondents in three out of the four analyzed dimensions.
- The *Logistic Cluster*, one of the most important global humanitarian operations collaborators, also offers training by simulation on logistic responses. In a seven-day period, skilled logistics professionals are exposed to realistic emergency experience through working in field-like conditions. The objective of the simulations is to enhance their knowledge about emergency response, project management and technical leadership.

Regarding education, many serious games have been developed, for example:

- *Food Force* is a game developed by WFP where players act in different roles through six missions with the objective of distributing food to a country suffering from hunger. During the game, players learn about hunger in the world and how to prevent it.
- In *Disaster Detector*, developed by the Smithsonian Institution, players have to protect citizens of a city by learning how to analyze and interpret data on natural disasters to mitigate their effect on the population.
- *Inside Haiti Earthquake*, funded by the Canadian International Development Agency, is a simulation with the objective of immersing the player into the context of the 2010 Haiti's earthquake to observe the impacts from one of three perspectives: as a survivor, a humanitarian agent or a journalist. In each role, the player has the opportunity to make decisions and experience their consequences.
- *Stop Disasters*, funded by the United Nations Office for Disaster Risk Reduction and developed by *Playerthree* development studio, simulates situations where the player has to protect a city and its citizens from natural disasters by reinforcing buildings and accommodating homeless people. In this game, the player learns how disasters affect people every day and what the necessary measures to reduce the damages are.

In the broader spectrum of disaster risk management, over 40 serious games were studied in Solinska-Nowak et al. (2018). These games show that simulations and serious games have been applied in different humanitarian applications with different objectives. As a valid way to communicate the problems complexity, games are in increasing demand for humanitarian logistics (Harteveld & Suarez 2015).

Despite their success on presenting one narrative and teaching players on an interactive environment, the current humanitarian games have not yet focused on the process of preparation and response to humanitarian disasters. As an attempt to fill this gap perceived, the next sections present a new serious game that addresses both processes using real life data. It aims to teach players about the importance of situation awareness, resilience investments, rapid actions and tailored decisions on humanitarian operations. To that purpose, we created the *HurricaneLog* to simulate humanitarian logistics operations before and during Atlantic hurricane seasons. We focus on the Caribbean region which is stroked by hurricanes every year, causing damage to homes, energy, communication and transport infrastructure, in addition to generating a major financial impact on the region and affecting the lives of hundreds of thousands of people.

GAME DESCRIPTION

The player is called to coordinate humanitarian logistics operations to decrease operational costs and minimize the response time as to ensure a successful operation. Their success is quantitatively measured by the number of people benefited by relief items, the average time required to meet the relief items demands, and the operational cost. Thus, the player acts as a member of an inter-governmental agency responsible for coordinating the disaster management activities in the region. The game decisions are split into two phases: (i) preparedness, and (ii) response. On one hand, the preparedness phase concerns anticipated investment decisions taken before the hurricane season. They consider the region's risk profile, population characteristics, logistic performance indexes and gross national income. On the other hand, during the response phase, the player has to manage resources while the hurricane season occurs, being responsible for making decisions on transportation of relief items to the affected populations.

The game uses data from online databases and scientific journals on previous natural events (EMDAT n.d.), tracks (Google Cloud Platform 2019), forecasts (NHC n.d.) and humanitarian logistics operations (Balcik et al. 2019; Rodríguez-Pereira et al. 2020) to create a realistic but not directly recognizable environment for players to interact with and learn from experience.

How the game is played

The game starts with a short video about the upcoming hurricane season. It stresses the important role humanitarian logistics operations on mitigating the damages caused by hurricanes. In the sequel, the player is introduced to the game and to the four islands that compose the game (see Figure 1). The game also presents the player's role as member of an intergovernmental agency responsible for coordinating disaster response activities.

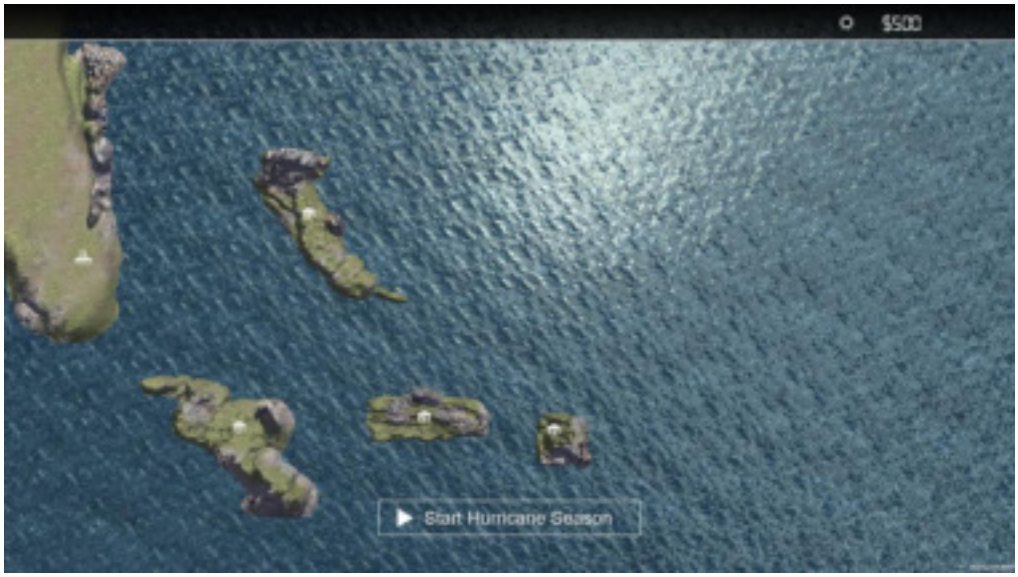

Figure 1: Four islands that make the focused region.

In the target region, each island represents a different nation with its characteristics. In order to profile each nation, four characteristics are used: population, gross national income, humanitarian risk index and logistics performance index. These characteristics allow the player to infer by how much each nation will be affected in case a hurricane hits it. The population size serves to give an idea of the magnitude of the inhabitants who may be affected in the event of a disaster. The gross national income represents the nation's wealth. Its value indicates greater (or less) preparedness and resilience to

respond to disasters. The risk index represents how much a nation is prone to disasters that can exceed its response capacity. Finally, the logistic performance index is proportional to the robustness of the nation's logistic chain. To illustrate how these characteristics can be interpreted, Figure 2 shows a summary of the characteristics of each island in the target region.

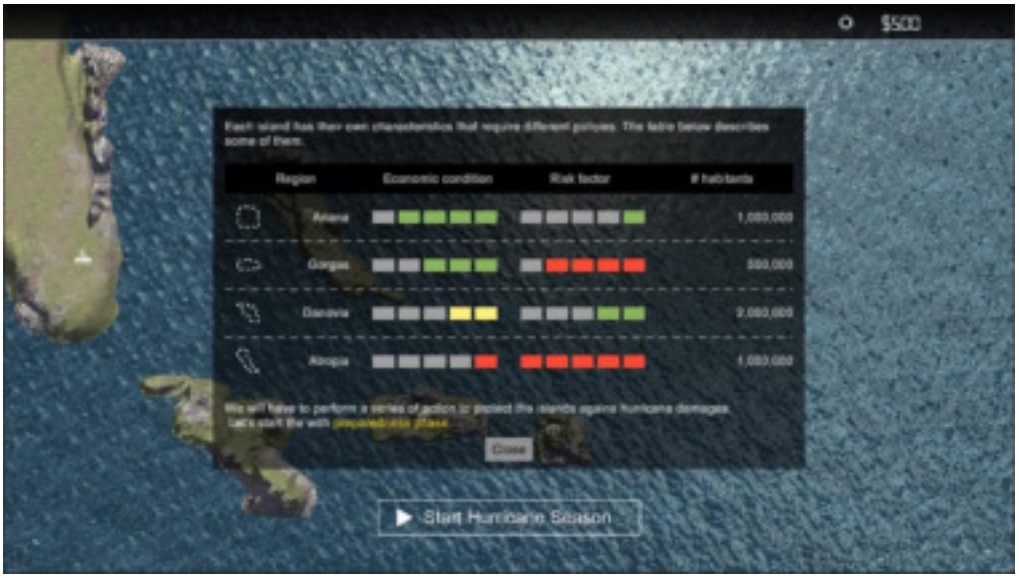

Figure 2: Summary of the islands' profiles presented to the player on the preparedness phase.

Considering these four points mentioned above, the player must take actions to improve the region's resilience to natural disasters.

Preparedness phase

In humanitarian operations, the preparedness phase consists of the set of actions and mechanisms put in place before a disaster (Cozzolino 2012). These actions and mechanisms aim to prepare governments, response teams, communities and individuals to anticipate and respond effectively to potential disasters. By improving awareness, agility and quality of the operations, preparedness can result in an increase of saved lives and lower operational costs.

In our game, preparedness of the nations is sought by different investment options, which are listed below:

- Preposition: represents the pre-purchase of relief items. These items are stored in local warehouses to guarantee immediate availability in case of a disaster.
- Warehousing: represents investments made to the local warehouse facility building and inventory management. This type of investment may reduce the loss of relief items in the warehouse facilities, shall a hurricane strike. It also decreases the required time to set up relief items distribution in case of a disaster.
- Transportation Infrastructure: represents investments in local ports and airport infrastructures to improve their response capacity. This investment option yields faster international transportation by reducing loading and offloading times.
- Supplier Agreements: represent investments in agreements with international suppliers to guarantee availability of relief items in case the local or regional

capacity is exceeded. This investment guarantees access to international suppliers and decreases the prices of relief items bought from them.

- Shipping Agreements: represent investment in agreements among the nations and transportation companies to guarantee a rapid availability of transportation vehicles. In our game, these vehicles can be of two types: planes and ships. Planes are fast transportation units with low capacity limit and high transportation costs whereas ships are slow but provide more capacity at lower costs. Investing in this option yields a time reduction for preparing relief items for international shipping. This reduction affects the shipping processes in the region and on international suppliers.
- Custom Clearance and Sharing Agreements: represents investing in trade facilitation agreements and on improving the customs system to create faster tracks for humanitarian relief items on border entry points. It reflects on lower custom clearance processing times.
- Communication and Information Sharing: represents investments made to improve training in the use of communications technologies and to improve information sharing between all parts of the logistic operation. Investing in this option yields lower relief item distribution and international transportation times and accurate information on available relief items from local warehouses.
- Contingency Plan and Training: represents investments in the creation of a contingency plan to ensure that response policies are updated. It also represents investments in training coordination between national stakeholders to have a multifaceted approach during response activities. The impact of this investment is perceived as reduction of relief item distribution time and international transportation times.

Each of these investment options has a different cost. To make an investment, the player has to use the money from the available budget. Given its limited nature, the player must think wisely about the selected investments. Figure 3 presents the player's investment options for a single nation.

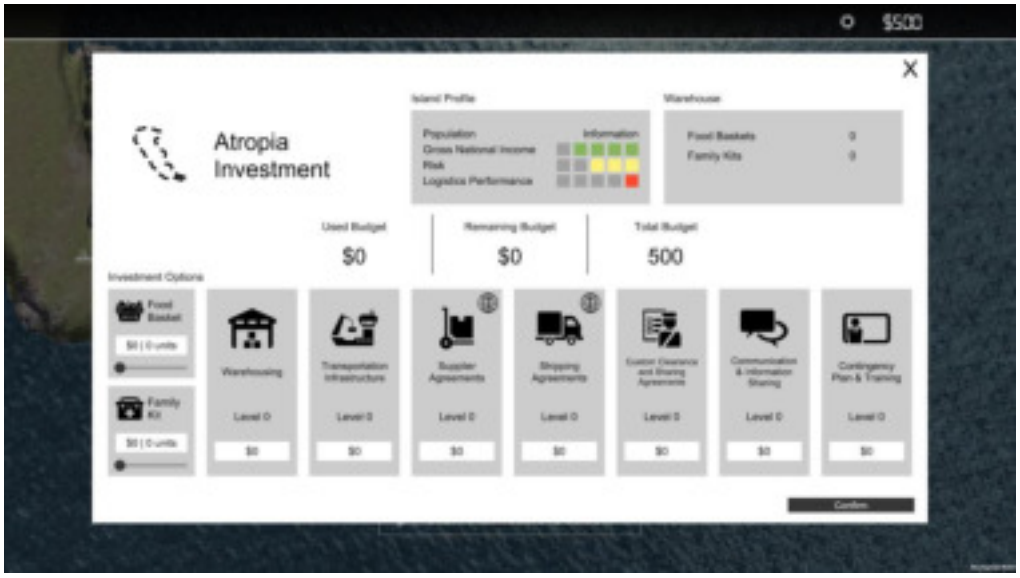

Figure 3: Investment options for each island.

Finally, investments can have national or regional effect. The national investments are applied to and affect a unique island (e.g., warehousing), while regional investments are those which affect all islands at the same time (e.g., supplier agreements).

Response phase

After making all investment decisions in the region, the player is then directed to the start of the hurricane season. In this new phase, called response phase, tropical storms start to pop up in the game panel representing potential danger to the islands (see Figure 4). The storms can be watched out by the player via forecast information which shows cones of uncertainty with the predicted movement of the hurricane.

Figure 4: Hurricane season on focused region during the response phase.

Damages are accounted whenever the hurricanes encounter the islands, what is simulated in our game by means of immediate demands by the affected population. In humanitarian logistics operations, a more immediate way of helping people is through the delivery of relief items. These items are composed of products that are essential for the survival of the affected population. In response operations, the definition of the content of these relief items varies according to the population and the damage suffered. However, its objectives focus on meeting the following needs: food, shelter, water, sanitation, hygiene and medication (Robinson 2004; Thomas & Kopczak 2005). One of the humanitarian organizations operating in the Caribbean region is the International Federation of Red Cross and Red Crescent Societies Panama. This organization uses family kits as relief items. In their context, family kits comprise shelter needs (e.g., shovel), water (e.g., water purification tablets), sanitation and hygiene (e.g., hygiene parcels). Thus, the family kits were chosen to compose our relief items. Regarding food needs, we decided to use the same relief item used by the WFP, i.e., food baskets. As for medication needs, we decided not to include them in our game due to their complexity of handling and importing.

The player's role in the game's response phase is to meet the generated demand for relief items as fast as possible while minimizing the logistics operations' used budget. The demands for relief items can be met either by using the relief items stocked on the island (if available), or by transferring items from other nations, or, finally, by purchasing from international suppliers. The Figure 5 shows an example of transference of relief items between two islands.

The player can adopt multiple strategies during the response phase to meet their objectives. For example, once a hurricane is regarded as a potential danger to an island, the player can immediately decide to send relief items to that island via ships (slower means of transport), targeting to reducing operational costs; or wait until they are more certain that the island will be affected and then send relief items by planes (faster but

more expensive transport mode). In both cases, the player will have sent relief items to the island if it has been affected. However, if the observed hurricane later changes its trajectory, the player who adopted the first strategy will have spent resources sending relief items to an island that was not hit by the hurricane, while the player who adopted the second strategy will have saved more budget for future damages.

Figure 5: Transference of relief items between two nations.

The player's performance can be evaluated through KPIs computed throughout the game. Basically, players are evaluated regarding four measures over time:

average response time: how many days on average the player met a single demand;

total operational cost: how much money the player spent;

population in need: how many people are in need and how many have been affected;

relief items required in the region: how many relief items are required by the affected population.

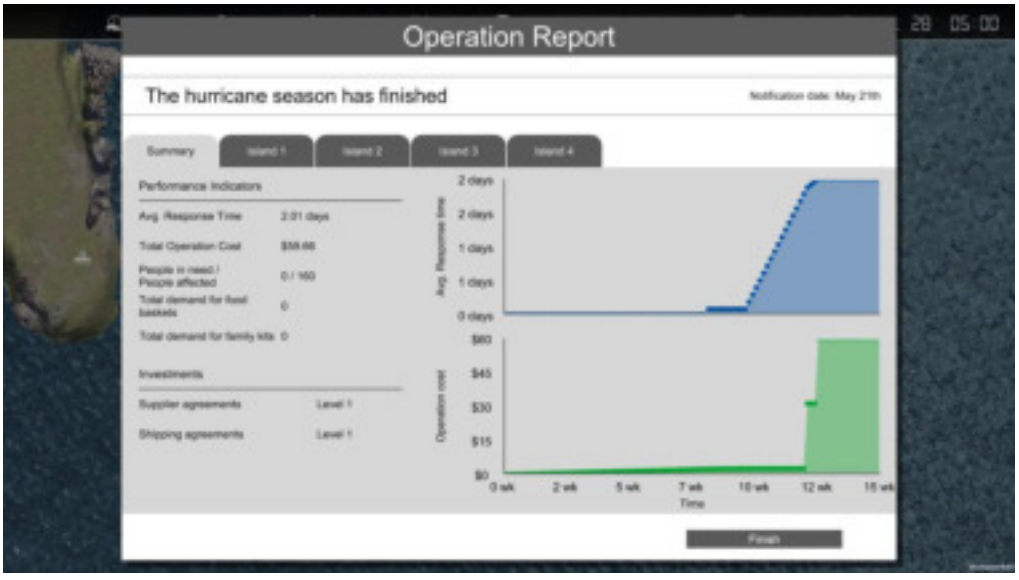

Figure 6: Operations report presented at the end of the response phase.

The game finishes at the end of the hurricane season. At this moment, the player is called to visualize their operations report. Figure 6 illustrates an example of operation report. It displays a summary of the player's investments and their KPIs evolution over time regarding each island and the set of the islands as a whole.

Learning objectives

The entire game was created focused on simulating a similar environment to what humanitarian logistics agents experience in their decision-making processes. This design choice aims to create a familiar environment for experimentation and learning. We expect that this game could be used in three contexts with different learning outcomes. First, it could be used in supply chain management classes as a complementary teaching tool to the concepts of the humanitarian supply chain, allowing students to experiment learned concepts of preparedness and their link to response operations. Second, it could be used in training exercises for either novice or expert humanitarian logistics agents to simulate different preparedness scenarios and response strategies observing and evaluating the impact of decisions using the game performance indexes. Lastly, the game could be used as an information spreading tool to inform the general public of the issues faced by humanitarian organizations while preparing and delivering help.

More particularly, our expectation is that our game can induce players to learn the importance of preparedness, context knowledge and tailored decisions in humanitarian logistics operations. We discuss each of these in more detail in the following sections.

Preparedness impacts

Logistics is the most important element in disaster relief operations, being crucial to determine the success or failure of a humanitarian mission (Van Wassenhove 2006). It is also the costliest part of the intervention. Van Wassenhove (2006) estimates that it represents about 80% of the total operation cost, which demonstrates the importance of designing and implementing an effective and efficient logistics chain. In addition, that incurs greater responsiveness, resulting in more lives saved (Kovács & Spens 2007).

Logistics efficiency in disaster relief operations is directly linked to how much prepared the affected region in the event of a disaster. The regional preparation takes place at both the local and national levels and requires identification of the population's vulnerabilities (Goldschmidt & Kumar 2016). Disaster preparedness includes emergency operations plans, warning systems, emergency public information, mutual aid agreements, resource management plans, etc. (McLoughlin 1985). To get a sense of the importance of preparedness in the humanitarian context, we can mention the Sendai framework created at the 2015 World Conference on Disaster Risk Reduction (United Nations Office for Disaster Risk Reduction n.d.) which lists common standards, a comprehensive framework with achievable goals and a legal instrument for reducing the risk of disasters. As a priority action, the Sendai framework mentions the need for better preparedness for effective response, and to *Building Back Better* in recovery, rehabilitation and reconstruction. Therefore, we expect the player to learn the importance of preparedness through the analysis of investments and their impacts. For this, the game investment options and their descriptions were extracted from the literature and from meetings with disaster risk management professionals.

Knowledge translates into performance

Knowledge of preparedness options is crucial for its effectiveness. In games, as in real-life, knowledge of available options during a decision-making process reflects on increased probability of choosing the best subset of options given limited resources.

The knowledge about a game can be assessed by the knowledge of the following characteristics: narrative, objectives, controls, mechanics (i.e., declarative knowledge) and strategies (i.e., procedural knowledge). Thus, we hypothesize that the player who has more knowledge of what the game can offer (options) has more chances to obtain higher scores.

Many studies mention that expert players show different behaviors compared to non-expert ones. For example, Maglio et al. (2008) showed evidence that expert players use the world more efficiently than novice players. For example, in *Tetris*, expert players often rotate game pieces to quickly confirm if it fits into a game board. In another study, Hong and Liu (2003) identified that the expert players are more analytical in the game *Klotski*, while the novice players tend to use *trial-and-error* reasoning. Iacovides et al. (2014) state that, although *trial-end-error* strategy can work for initial game exploration, more sophisticated strategies are required to gain more knowledge about the game.

In humanitarian operations, the main objective is to save lives, either by implementing disaster preparedness measures, or by sending immediate aid after a disaster. Indeed, *trial-and-error* is unwise in the humanitarian logistics context. Therefore, to increase players' knowledge about humanitarian logistics operations and preparedness, we have imposed a limited budget on the preparedness phase. It mimics the scenario to which humanitarian logistics managers are exposed to before a natural disaster occurs. Thus, players are compelled to better understand investment options before choosing them. We expect that this limit will result in increased knowledge related to the investment possibilities for disaster preparedness.

Tailored decisions

Disasters occur when hazards affect people, causing human, material, economic, and environmental losses. For this reason, governments and organizations try to implement policies to mitigate the factors that influence disaster damages. However, there exists no universal formula that yields guaranteed success in mitigating risk factors for all societies. As each community or nation works on its own way and has its own characteristics, a solution that works for one does not necessarily work for the other. According to Wisner et al. (2003), vulnerability "is generated by social, economic, and political processes that influence how hazards affect people in varying ways and with different intensities" (p. 7). Further, it is "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process)" (p. 11).

In humanitarian logistics operations, decisions must be made according to the societies' characteristics. Regarding preparedness, investment decisions and measures must be taken considering such characteristics so that the available resources are focused on the areas that need it most. For example, in nations where the logistic performance is low, investments may be needed in the local transport chain (e.g., improvement of transportation routes, creation of alternative routes for relief operations), and in their entry infrastructure points (e.g., machinery for loading and unloading products in ports and airports). Likewise, response operations must also consider the installed infrastructure, capacity of logistic infrastructure, the nation's wealth, human development indexes, amongst others.

After a disaster, humanitarian aid organizations conduct damage assessments to determine the real impact suffered by the population, as well as their needs (International Federation of Red Cross and Red Crescent Societies n.d.). Thus, the operation can focus on the resources that will be needed to assist that population. These tailored decisions occur in various segments of response operations, from deciding the

relief items type to be used to how they will be transported. For example, the IFRC and WFP make use of personalized food baskets for the affected society considering their nutritional needs, local preferences, demographic profile and others (International Federation of Red Cross and Red Crescent Societies n.d.; World Food Programme n.d.).

The different islands that compose our game were inspired by real Caribbean nations and their characteristics. This information was used to create nations that require different types of preparedness investments and to define the different impacts that hurricanes may have on them. Thus, we expect that the player learns to consider the different characteristics of each nation when making decisions.

Game design challenges

A game development process hardly presents a linear trajectory. Most of these projects are reviewed and redone multiple times to achieve the desired objective. During our development process, after repeated interactions between the development team, we realized some challenges that deserve to be highlighted.

Firstly, intending to produce a game that simulates a familiar environment to humanitarian logistics agents, we decided to use real data and processes as functionalities. However, faithfully reproducing real processes in rich detail made the game's development complex and prone to distract the player from our learning goals. Abstraction is part of the design process of all games and defines the relationship that rules and fiction have regarding the elements of a game. It allows players to determine which actions can be taken and what can be observed (Jesper 2007). For example, in humanitarian supply chain logistics, the relief supplies' shipping process can be divided into several stages, including: purchasing supplies and deciding to where they will be shipped, shipping arrangements, preparation of documents for international transport, decisions on transport modalities, communication with different stakeholders at different stages of the process, which routes will be made to reach the destination, and how the supplies will be distributed to the population. In the game, this supply chain could be faithfully reproduced in the smallest details, but it could also be represented only as a decrease in the amount of relief items in one nation accompanied by an increase in the amount of relief items in another. The balance of this level of abstraction, therefore, must be defined at the moment of defining the game's objectives.

Although the learning component is the primary focus of our serious game, the fun component must also be present to allow greater engagement of the players. Thus, by increasing the complexity of the game in terms of details, the player may lose interest and feel overwhelmed by the number of decisions to be made and the amount of information to be analyzed. Therefore, the game's supply chain was simplified, requiring less decision actions by the player while keeping as much as possible the most important elements of the humanitarian supply chain logistics. That simplification was achieved by grouping stages of the logistics process into four categories: preparation for transportation, transportation, customs clearance, and distribution. Once the relief items are transported between two nations, these four processes are executed in order without the player's intervention. The performance of each process is then subject to the investments made by the player in the preparedness phase.

Another challenge faced on balancing game realism and entertainment was on the use of real hurricane data. As mentioned in the previous sections, data on hurricane trajectories and forecasts have been obtained from online databases that contain accurate information about most Caribbean hurricanes from past seasons. Thus, it was possible to accurately reproduce past hurricane seasons in the Atlantic. However, to guarantee realism concerning hurricane and shipment displacements as well as the

duration of the processes carried out during the response phase, it was necessary to introduce the concept of time in the game. Its definition involves determining a relationship between game time and the actual player time. At first, this value was determined for an hour in game time to be equivalent to ten seconds in real time. However, as Atlantic hurricane seasons typically last 5 months and one of our game's objectives is to simulate an entire hurricane season, the game ended up being too long. In addition, we have noticed that some hurricanes did not appear in the focused islands' region due to the vastness of different trajectories that hurricanes can take in the Atlantic region. Consequently, there were times in the game when the player could believe that there was no need for interaction which could lead to a loss of player's engagement.

These issues were solved in three steps. First, we redefined the ratio between game time and the player's time. After experimentation, we reached the ratio of one hour in the game equivalent to one second in real life. This choice allowed for good balance between the time that a player has to make a decision and the speed of hurricanes and processes. It also maintained accuracy in hurricane and transportation displacements, while decreasing the total playing time. Second, we reduced to two days the time in which no hurricane appears in the game. Thus, if a hurricane appears, follows its trajectory and disappears, the next hurricane will appear within a maximum of two days. Lastly, hurricanes that did not appear in the region of interest during the game were removed.

The last challenge encountered was related to the definition of the impact caused by hurricanes on the nations that make up the target region. It is hard to confidently estimate the damage caused by a hurricane because of the stochastic dynamics of a natural disaster and population characteristics. Balcik et al. (2019) quantifies hurricane damages to a population by considering the nation's historical record of hurricane damages and the hurricane category. Let P be the size of the nation's population, L the largest percentage of that population affected by a hurricane in the past, and h a random variable which depends on the hurricane category. The damage d_f incurred to a nation by a hurricane of category f is then expressed as:

$$d_f = h_f \times P \times L$$

where:

$$h_f = \begin{cases} [0.5, 1.0], \text{for } 4 \leq f \leq 5 \\ [0.2, 0.5], \text{for } f = 3 \\ [0, 0.2], \text{otherwise.} \end{cases}$$

Rodríguez-Pereira et al. (2020) also present in their work a formula to quantify damages to relief items stored in warehouses of a hit region. It basically states that half of the relief items are lost for hurricanes of categories 4 and 5, 20% is lost for hurricanes of type 3, and 0% otherwise.

These works are examples of literature contributions that allowed us to link in our game hurricane data to the characteristics of the affected population so that the population's needs and damages could be assessed. The complete dynamics of our game can be found at https://thiagocorreiap.github.io/hurricane-game/.

CONCLUDING REMARKS

Training is essential to reinforce the decision-making process and keep humanitarian agents prepared for disaster relief operations (Gralla et al. 2015). In a humanitarian mission, logistic operations represent about 80% of its total cost. The decisions made by humanitarian agents can be determinant to an operation's success or failure (Van

Wassenhove 2006). Furthermore, the impact of such decisions can influence the lives of millions of people who are assisted each year throughout the globe.

In this paper, we presented the serious game *HurricaneLog* that uses real life data to simulate humanitarian logistics operations before and during Atlantic hurricane seasons. In the game, the player is introduced to various preparedness investments which may result in different outcomes to the islands represented in the game depending on the simulated hurricanes' trajectories and stochastic damages. Additionally, the game stimulates collaborative actions among the islands to assist people at risk. Its narrative focus on the Caribbean region which is hit by hurricanes yearly causing important damages and risks to their population, economy, and installed infrastructure. The *HurricaneLog* was developed to serve as a training tool for humanitarian logistics agents, so that they learn about the importance of situation awareness, resilience investments, rapid actions and tailored decisions during humanitarian operations. To meet such learning objectives, the game uses mechanics such as limited investment capital, a range of investment categories with different impacts, and nations with different infrastructure, economic and population characteristics. We also addressed in this paper the challenges faced by our project to balance the game's level of abstraction to determine the relationship between game time and real time as well as the impact caused by hurricanes on the nations represented in the game.

As future work, we would like to study the decision-making process of the humanitarian logistic agents by means of in-depth data analysis. During humanitarian disaster relief operations, gathering information about the actions of decision makers to different disaster cases is almost infeasible since most of the decisions are not documented. It seems to be impractical to ask every decision maker to register what has been decided at any particular time and to evaluate the impacts of such decisions. Further, it is too time-consuming to register the decisions taken by the decision makers (Silver et al. 2017). Thus, taking advantage of game's engagement power to collect user-generated data we can provide insights to assist future decision-making processes and improve the skill and performance of trainees (Loh, Sheng, & Ifenthaler, 2015).

Finally, we expect that *HurricaneLog* could be used as a training tool for humanitarian agents, supply chain management students and other logistics agents, allowing them to learn through interaction and experimentation in the very particular context of humanitarian logistics. Additionally, we hope that the learning facilitated by our game could yield better decisions and more efficient operations, ultimately helping to assist every year approximately 80 million beneficiaries of humanitarian operations worldwide (World Food Programme 2018b).

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