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POLYTECHNIQUE MONTRÉAL
affiliée à l'Université de Montréal

Innovative Data Collection Framework for Humanitarian Logistics: A Serious Game Solution

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Thèse présentée en vue de l'obtention du diplôme de *Philosophiæ Doctor*
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Innovative Data Collection Framework for Humanitarian Logistics: A Serious Game Solution

présentée par **Thiago CORREIA PEREIRA**
en vue de l'obtention du diplôme de *Philosophiæ Doctor*
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DEDICATION

To my incredible wife for all support,
with love. . .

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RÉSUMÉ

L'action humanitaire, qui permettent de fournir de l'aide à des millions de personnes dans le monde chaque année, dépendent fortement de l'efficacité des opérations logistiques efficaces. Cette dépendance est particulièrement évidente étant donné le rôle crucial que jouent les agents humanitaires dans la prise de décisions concernant l'allocation des ressources, le transport et la gestion de la chaîne d'approvisionnement pour aider les populations en situation critique. Dans de telles situations d'urgence, une évaluation rapide des besoins et une prise de décision efficace sont cruciales, étant donné les vies en jeu. Par conséquent, la formation continue et la préparation antérieure des agents humanitaires sont essentielles pour améliorer les opérations logistiques humanitaires et des stratégies de réponse.

Les catastrophes naturelles, telles que les ouragans, introduisent une complexité intrinsèque dans la prise de décision en raison de leur nature imprévisible et stochastique. Dans de telles circonstances, les efforts de formation doivent s'appuyer sur les expériences passées de catastrophes pour identifier les domaines à améliorer. Néanmoins, les environnements exigeants et les contraints en ressources dans lesquels évoluent les agents humanitaires présentent souvent des obstacles à la collecte de données lors des opérations.

Les techniques actuelles de collecte de données en humanitaire se concentrent principalement sur l'agrégation de données à partir de sources multiples telles que les organisations, les bases de données gouvernementales, les institutions de recherche et les médias. Leur objectif principal est de soutenir la prise de décisions éclairées et les stratégies de réponse efficaces. Cependant, les méthodologies actuelles manquent de la capacité à surveiller en continu les décisions prises par les parties prenantes clés et leurs impacts ultérieurs tout au long du processus de réponse d'urgence, un élément fondamental essentiel pour mener des analyses de données approfondies.

Parmi les multiples solutions de collecte de données utilisées dans la recherche, les jeux présentent un attrait considérable pour la collecte de données sur la prise de décision en raison de leur caractère engageant, de leur caractère non intrusif et de leur rentabilité. Cependant, la plupart des jeux sérieux dans le domaine ne parviennent pas à intégrer une fonction de collecte de données permettant une analyse approfondie des actions des joueurs. De plus, aucun de ces jeux ne propose une expérience qui simule efficacement à la fois les scénarios de préparation aux catastrophes et de réponse dans le cadre d'une opération multi-régionale coordonnée.

Cette thèse aborde le besoin d'améliorer la prise de décision et la planification en logistique

humanitaire en introduisant un nouveau cadre de collecte de données. Son objectif principal est de fournir des données de prise de décision sur la préparation et la réponse aux catastrophes d'ouragan, favorisant des études analytiques approfondies axées sur l'amélioration des procédures de formation et la compréhension des défis opérationnels rencontrés sur le terrain. Pour atteindre cet objectif, cette thèse présente un nouveau jeu sérieux appelé *HurricaneLog* conçu pour reproduire des scénarios de prise de décision réalistes dans le cadre des opérations de logistique humanitaire. En exploitant les données des événements passés de dommages et des saisons d'ouragans passées de l'Atlantique, ce jeu constitue le cœur de cette recherche, offrant un environnement dynamique et contrôlé pour la collecte complète de données de prise de décision dans le contexte de la logistique humanitaire. Composé de deux phases importantes - préparation et réponse - *HurricaneLog* offre aux participants la possibilité de prendre des décisions stratégiques face à des défis logistiques complexes. De plus, il présente un potentiel significatif en tant que ressource pédagogique précieuse dans les cours de logistique humanitaire, permettant aux étudiants de tirer des enseignements par l'expérience des conséquences de leurs décisions.

Cette thèse détaille le dévéloppement du jeu *HurricaneLog*, en décrivant ses caractéristiques, ses phases et les indicateurs de performance clés utilisés pour évaluer les performances des joueurs. Elle explore le processus complexe de combinaison de données provenant de sources diverses pour créer une expérience de jeu qui reflète fidèlement les défis auxquels sont confrontés les décideurs humanitaires tout en garantissant une expérience engageante et agréable. De plus, elle aborde les défis de l'intégration de données des saisons d'ouragan passées de l'Atlantique dans le jeu et explique les paramètres du jeu, y compris les profils des îles, les durées des processus, les coûts des investissements de préparation et leurs impacts associés. Le cadre de collecte et de stockage de données est également présenté, accompagné d'une analyse préliminaire des données recueillies lors des expériences de recherche.

ABSTRACT

Humanitarian operations, which provide aid to millions worldwide every year, heavily depend on effective logistics operations. This dependence is particularly evident given the important role humanitarian agents play in making critical decisions regarding resource allocation, transportation, and supply chain management for aiding populations in critical situations. In such urgent situations, quick assessment of needs and efficient decision-making are crucial, given the lives at stake. Consequently, continuous training and former preparation of humanitarian agents are essential to enhance the effectiveness of humanitarian logistics operations and response strategies.

Natural disasters, such as hurricanes, introduce even greater complexity to decision-making due to their inherently unpredictable and stochastic nature. Under such circumstances, training efforts must draw from past disaster experiences to identify areas for improvement. Nevertheless, the demanding, resource-constrained environments in which humanitarian agents operate often present obstacles to data collection during ongoing operations.

Present data collection techniques in humanitarian logistics predominantly focus on aggregating data from multiple sources such as humanitarian organizations, government databases, research institutions, and media outlets. Their primary objective is to support informed decision-making and efficient response strategies. However, the current methodologies lack the capability to continuously monitor the decisions made by key stakeholders and their subsequent impacts during the entire course of an emergency response, a fundamental component essential for conducting thorough and in-depth data analyses.

Among the multiple data collection solutions employed in research, games hold substantial appeal for collecting decision-making data due to their engaging nature, non-intrusive nature, and cost-efficiency. However, most serious games in the field of humanitarian logistics fail to incorporate a data collection feature that facilitates in-depth analysis of players' actions. Furthermore, none of these games provide an experience that effectively simulates both disaster preparedness and response scenarios within a coordinated, multi-regional operation.

This thesis addresses the need for improved decision-making and planning in humanitarian logistics by introducing a novel data collection framework. Its primary goal is to provide decision-making data on the preparation and response to hurricane disasters, fostering in-depth analytical studies focused on improving training procedures and deepening understanding of the operational challenges encountered in the field. To achieve this objective, this thesis presents a novel serious game called *HurricaneLog* designed to replicate real-life decision-making scenarios within humanitarian logistics operations. Leveraging data from previous damage events and past Atlantic hurricane seasons, this game serves as the core of this research, providing an dynamic and controlled environment for the comprehensive collection of decision-making data in the humanitarian logistics context. Comprising two important phases – preparedness and response – *HurricaneLog* offers participants an opportunity to make strategic decisions amid multifaceted logistical challenges. Furthermore, it holds significant potential as an educational resource in humanitarian logistics courses, enabling students to gain experiential insights into the consequences of their decisions.

This thesis details the gameplay of the *HurricaneLog* game, describing its features, phases, and the Key Performance Indicators (KPIs) employed to assess player performance. It explores the complex process of combining data from diverse sources to construct a gaming experience that authentically mirrors the challenges confronted by humanitarian decision-makers while ensuring an engaging and enjoyable user experience. Additionally, it addresses the challenges of integrating data from past Atlantic hurricane seasons into the game and explains the game parameters, including island profiles, process durations, preparedness investment costs, and their associated impacts. The framework for data collection and storage is also presented, accompanied by a preliminary analysis of the data obtained from the research experiments.

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LIST OF SYMBOLS AND ACRONYMS

ANOVA	Analysis of Variance
ASYCUDA	Automated System for Customs Data
CCPA	California Consumer Privacy Act
CDEMA	Caribbean Disaster Emergency Management Agency
DiGRA	Digital Games Research Association
EEA	European Economic Area
EM-DAT	Emergency Events Database
ERP	Enterprise Resource Planning
GDPR	General Data Protection Regulation
GFS	Group Facilitated Sessions
GIS	Geographic Information System
GNI	Gross National Income
IBTrACS	International Best Track Archive for Climate Stewardship
ICT	Information and Communications Technology
IFRC	International Federation of Red Cross and Red Crescent Societies
ISGS	Individual Self-Guided Sessions
KPIs	Key Performance Indicators
MAU	Monthly Active Users
MMOG	Massive Multiplayer Online Game
MMORPG	Massively Multiplayer Online Role-Playing Game
NGO	Non-Governmental Organization
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
PERT	Project Evaluation and Review Technique
PILP	Personal Information Protection Law
SQL	Structured Query Language
t-SNE	t-Distributed Stochastic Neighbour Embedding
UN	United Nations
UTC	Universal Time Coordinates
WFP	World Food Programme
WHO	World Health Organization

LIST OF APPENDICES

CHAPTER 1 INTRODUCTION

Every day we observe challenges faced by humankind all over the planet. We notice wars, severe droughts, devastating bushfires, hazardous smoke, pandemics, etc. Natural events are part of these challenges. Intense floods, droughts, and storms are the most notable examples of these catastrophes and account for 90% of all natural disasters annually [1]. Lately, these natural events have increased their frequency and intensity due to global warmth effects which can be observed and measured through higher sea surface temperatures and receding glaciers [2].

Hurricanes are natural formations generated by the difference of temperature between the aloft and the sea surfaces that self-feeds and grows as the temperature of the seas gets warmer. In the Atlantic Ocean, they are mostly recurrent every year from June through November, which is known as the Atlantic hurricane season [3]. The number of hurricanes that occur during a season, their starting points and movements vary according to diverse climate elements (e.g., temperature, humidity, wind) and atmospheric phenomena (e.g., African Easterly Waves, El Niño-Southern Oscillation, Madden-Julian Oscillation) [3].

Due to their destructive power, these extreme natural formations cause major struggle to populations as well as infrastructural damage once they meet populated areas. In 2017, more than 4,600 people were killed by Hurricane *Maria*, which attracted international attention [4]. During that same Atlantic hurricane season, *Harvey*, the costliest hurricane in the history of the United States, caused an estimated $125 billion in damages [5]. Recently, the hurricane *Fiona* (2022) affected not only the Caribbean but also Canada, causing more than $500 million in insured losses, and leaving hundreds of people displaced and hundreds of thousands without electricity [6].

The unpredictability of hurricanes and their impacts, coupled with climate changes, present significant challenges when taking decisions towards hurricane resilience. As these formations and their associated trajectories cannot be precisely predicted [7], governments are very often overwhelmed by the costly effects of the encounter between these extreme natural events and populated areas. Consequently, at these moments of need, humanitarian organizations as World Food Programme (WFP), World Health Organization (WHO) and the International Federation of Red Cross and Red Crescent Societies (IFRC) often act in favor of the affected populations helping them to cope with the struggles of finding shelter, food, water and other basic necessities.

1.1 Humanitarian action

Humanitarian organizations are entities with a mission to prevent or alleviate human suffering, particularly armed conflicts, famines, and natural disasters. The WFP, one of the world's largest humanitarian organizations, annually assists about 100 million people. As a recognition of their work on bringing relief to exhausted populations in conflict situations, WFP was awarded the Nobel Peace Prize in 2020 [8, 9].

Large-scale humanitarian operations typically require intense planning and coordination in order to assist the most number of people with limited resources. Logistics is indeed one of the most important aspects of these operations. Thomas and Mizushima [10] defines it as the process of strategically planning, executing, and monitoring the efficient and cost-effective movement and storage of goods, materials, and associated information from the point of origin to the point of consumption, in order to fulfill the needs of the end-user. In case of a natural disaster, it translates to coordinating a cost-effective operation to help the maximum number of people while controlling the flow of supplies (storage, reception and sending) and transportation negotiations with different suppliers. Due to the extent of some disasters, these operations can indeed reach considerable volume. To illustrate, WFP benefited more than 120 million people in 2021, and distributed more than 4 million metric tonnes of food [11]. They currently control a fleet of 5.6 thousand trucks, 100 aircraft and 30 ships to deliver vital food and other assistance [12].

Moreover, these operations require adequate training and preparation by humanitarian logistics managers [13]. According to Wielgosz [14], they must have an overview of the systems' interconnections allowing them to understand and predict the effect of system changes over time. Due to the stochastic nature of natural disasters, decision makers must undergo diversified training to be able to implement and adapt past actions to new events. On top of that, logistic managers have to be prepared to work under pressure and in stressful environments with few hours of sleep, while making decisions based on information provided by different sources (e.g., governmental and non-governmental institutions) [13]. These agents analyze available data from forecast events (e.g., hurricane predicted trajectory, weather prediction), population needs (e.g., size of the affected population, damage levels, needs assessment) and logistic information (e.g., transportation capacity, access roads, distance from the hub, cargo movement request) to decide when, how and where to send the relief items [15].

In humanitarian logistics, time is indeed one crucial factor for whole decision process since long delays may directly result in deaths [16]. Hence, decision-makers must devote a lot of effort to make optimal decisions under pressure to perform fast judgments given a enormous amount of variables to take into account.

In addition, the often fragile connection between populations and their infrastructures makes it challenging to fully consider the consequences of decisions, making it difficult to learn from past experiences [17]. Consequently, decision-makers often implement suboptimal solutions, resulting in the depletion of resources. These facts highlight the importance of good training to keep those agents up to date and ready for future disasters [10, 13].

1.2 Data collection

The effectiveness of interventions in humanitarian emergencies depends on the use of data for evidence-based planning and decision-making [18].

Data collection can be performed using various methods. One of the most common ways is through surveys, which are quick to perform, cheap, and easy to distribute to a large number of people. The major downside with surveys is that participants self-report their answers. Thus, depending on the topic, they may feel uncomfortable about their answers and change them if they violate social or company norms [19]. In the humanitarian operations case, surveys also have another drawback: asking decision makers to recall actions taken at a given time to evaluate their impact is impractical. Moreover, it can lead to imprecision; depending on the time frame between the action and the recall requests, participants may not remember the facts with exactitude. Finally, it has been observed that people's actions do not always match up with what they promise to do, due to overly positive self-presentation, for instance [20]. Therefore, surveys were not considered as a data collection method for this research.

Another data collection method would be to ask participants to make a diary about the decisions that they have made at each point during an humanitarian operation. However, this would certainly require additional work from participants, likely requiring financial compensation besides increasing the data collection cost. Additionally, the extra work could possibly lead to significant time wastes, compromising the whole humanitarian logistics operation.

Instead of asking participants to take notes of their actions, behavioural data could be collected *in loco* by direct observation. However, this method has a high operating cost and greatly limits the amount of data to be collected, as it requires repetition for many humanitarian logistics operations. In addition, many logistical operations occur in the places where disasters happen, so access to basic resources may be limited, yielding risk to the whole data collection process. Lastly, in addition to raising concerns about participants' privacy, this data collection mode can be biased, as people tend to act differently when they know they are being observed.

1.2.1 Gamification

In addition to the challenges regarding data reliability and costs, there is still a very pertinent problem associated with data collection. Indeed, finding enough volunteers who are motivated to participate and have their data gathered is challenging. Games or gamified experiences can effectively engage the public and transform initially unattractive activities into enjoyable ones [21]. They can increase participant engagement and motivation, leading to more accurate and detailed responses [22]. For instance, in a study by Dergousoff and Mandryk [23], a gamified experience was created to encourage players to complete surveys. Similarly, Corey [24] and Cechanowicz et al. [25] employed gamification in their surveys to increase responders' engagement during data collection for public health and market research. Flatla et al. [26] were capable of making players do system calibrations by encapsulating such activities with a game to make it joyful. Furthermore, games can also be used to collect data in a fun and non-intrusive manner, reducing the potential for participant dropouts, fatigue or boredom.

Games also enable large-scale data collection at a low cost, reducing the need for costly incentives to encourage participation. Overall, the use of these engaging tools in data collection experiments can provide a cost-effective and efficient way to gather high-quality data. Nevertheless, developing and deploying them for data collection purposes can be a time-consuming and expensive process, requiring specialized skills and resources.

Finally, data collection through gamification can guarantee data anonymity by design. Data about the participants' actions can be collected without interfering with the participant's experience while interacting with the game, therefore mitigating the issue of feeling watched and acting differently than what they normally would [27, 28].

1.3 Thesis objectives

Given the importance of training and planning for humanitarian operations, and how those processes can be improved by using insights from historical data, this research aims to provide a data collection framework that can be used to collect data about complex decision-making processes in the context of humanitarian logistics. It uses a controlled and simulated environment, providing a unique opportunity to assess the effectiveness of various decision-making strategies employed by humanitarian decision makers. Moreover, it can help identify opportunity for training improvement, offering a deeper understanding of the operational challenges faced in the field. Finally, the simulated environment can serve as a valuable educational tool in humanitarian logistics classes, enabling students to gain learn-by-doing experience through observing the real-world impacts of their decisions.

In the context of this thesis, the term “framework” refers to a systematic and organized structure that encompasses the design, implementation, and operation of the proposed data collection system. The framework proposed consists of three parts: (i) a serious game, called *HurricaneLog*, that simulates real-life decision-making scenarios in humanitarian logistics preparedness and response operations, using data from previous damages and from previous Atlantic hurricane seasons; (ii) a data collection infrastructure that tracks diverse decision information from the player’s interaction with the game and; (iii) a database that saves all information communicated to the server.

Creating a serious game is indeed a complex and challenging process. The *HurricaneLog* game must provide an engaging experience that is appealing for its target audience, at the same time reproducing as realistically as possible the simulated humanitarian logistics operations. Additionally, it must provide meaningful decision-making interactions to ensure that the user behaviour can be properly collected. To achieve this, the game must balance its realism with its level of abstraction. On top of that, the game must provide feedback mechanisms to ensure users play in an adequate difficulty level and sense progress making.

Yet, embedding a data collection process into the game itself requires further efforts regarding the user-experience, reliability and costs. It is important to ensure that the data collection process does not interfere with the player experience, as this can lead to the Hawthorne effect, where players change their behaviour simply because they know they are being observed [27]. To avoid this, data collection should be done in a subtle and unobtrusive manner. Also, it is important to carefully consider what data is needed, and to avoid over-communication between the game and servers. This is particularly important for players who may have a poor internet connection, as excessive data transfer can lead to slow performance and a poor overall experience. Moreover, the data collection solution must be robust and cost-effective. With inherent operational costs, such as the maintenance of a server for data storage and management, licensing fees for proprietary software, and others, it’s crucial that the chosen approach considers these factors in its cost structure.

Finally, implementing a database to store the data collected from a serious game requires careful planning and consideration of several factors, including data anonymity, scalability, data quality, and compliance with legal and regulatory requirements. This requires strict data handling policies, such as using pseudonyms and anonymizing techniques, besides implementing robust security measures to protect the data from unauthorized access. To ensure the scalability and quality of the database, the database must be capable of storing a variety of data types, including numerical, text, and array data, and must be able to perform complex queries to extract valuable insights. It must also be able to handle missing or inconsistent data that may appear when players drop out of the game or provide incomplete information. This requires the use of data cleaning and preprocessing techniques to ensure accuracy and consistency before data is stored.

In addition to the framework's components and the challenges involved in its creation, it is essential to emphasize the significance of data analysis in understanding the behaviour of players within the serious game environment. The data collected through the game, when appropriately analyzed, can offer valuable insights into the decision-making strategies employed by humanitarian decision makers. By examining the players' interactions and choices, we can gain a deeper understanding of how individuals approach complex logistics scenarios. This analysis can uncover patterns, preferences, and potential areas for improvement in decision-making processes.

In summary, this research aims to achieve the following objectives:

- RO1 - Develop a hurricane disaster simulation game focused on humanitarian preparedness and response operations;
- RO2 - Implement a data collection/storage system to gather data regarding the player's preparedness and response decisions during the game;
- RO3 - Perform statistics and data analysis on the collected dataset.

This thesis makes several significant contributions to the field of humanitarian logistics and decision-making. Firstly, it introduces a comprehensive data collection framework. It not only provides a controlled and simulated environment for assessing decision-making strategies but also enhances training and planning processes by leveraging insights gained from the analysis of the collected data.

Secondly, the research places a strong emphasis on the importance of data analysis, providing a platform to gain a deeper understanding of player behaviour and decision-making strategies within the serious game. By analyzing the data collected, the thesis identifies areas for decision-making improvement, reveals operational challenges, and enriches the educational value of the serious game.

Lastly, through the framework presented, this research offers an innovative approach that merges the practical application of data-driven decision-making with experiential learning. This approach provides students with a unique opportunity to witness the real-world consequences of their choices within the game.

1.4 Thesis outline

This thesis is presented in 7 chapters. This first chapter has motivated the research and situated its points of contributions in the humanitarian operations field. It has presented the three research objectives that guide the following work.

Chapter 2 The next chapter presents a literature review on data collection in the field of humanitarian logistics, presenting the existing gap in the literature due to the absence of data collection systems and games specifically designed for disaster preparedness and response operations. Through this review, the chapter demonstrates that although information systems and serious games have been utilized to support decision-making and raise awareness in humanitarian logistics, they often lack the capability to track and collect user decisions. This deficiency underscores the need for a novel data collection framework, a gap that the subsequent chapters aim to address by introducing the *HurricaneLog* game, which is designed to simulate and collect data on decision-making processes within humanitarian logistics operations.

Chapter 3 In sequence, the next chapter provide a detailed overview of the *HurricaneLog* game, which serves as the central element of our research. The chapter outlines the two primary phases of the game, “Preparedness” and “Response”, and the critical decisions players make during each phase. It also details the sources used in creating the game, providing an experience that closely simulates the challenges faced by humanitarian logistics managers in real-world operations. Lastly, it presents the performance indicators and key metrics that players use to evaluate their performance during the game. These metrics, including *Average Response Time*, *Operation Cost*, and *Demand for family kits*, offer insights into the player’s effectiveness in managing humanitarian operations.

Chapter 4 With the elements of the game well-defined, the next chapter provides a comprehensive view of our game’s design choices, ensuring a realistic and engaging experience. It describes the challenges of simulating hurricanes, revealing how real-world data was employed to create lifelike storms movements and damage. It also presents the process of selecting the Caribbean islands used in the game, along with defining their unique characteristics. The chapter brings out the role of investments in shaping the game’s strategy and the careful balance of budgets, mirroring the resource dilemmas faced by real-world humanitarian logistics managers. This chapter serves as a bridge between game design and practical logistics, illustrating how the integration of real-world data enriches the gaming experience, while also exploring the strategic design choices that shape the use of this data, as well as the creation of engaging elements that enhance the overall learning experience.

Chapter 5 In this chapter we explore the data collection part of the framework. We outline the data collection methodology, the tools used for data acquisition, and the privacy measures employed to ensure data security. Our ethical considerations and approval from the Ethics Committee underline our commitment to conducting research that respects participants' rights and privacy while adhering to regulations and guidelines. Furthermore, we provide an in-depth look at our data storage solutions, particularly the utilization of MongoDB, a non-relational database. The chapter explains the organization of the database, detailing how different collections (similar to tables in relational databases) facilitate the storage and retrieval of specific data events. The data collected is critical in analyzing diverse decision-making strategies employed by humanitarian agents in a simulated environment and offers valuable insights into the dynamics of humanitarian logistics in hurricane disaster preparedness and response.

Chapter 6 Next, we explore the experimental and analytical aspects of the research. We provide a detailed account of the methodology used in data collection experiments, including Group Facilitated Sessions and Individual Self-Guided Sessions. Subsequently, we offer a comprehensive overview of the experiment's participant population, supported by relevant descriptive statistics. The chapter then proceeds to offer an initial analysis of potential insights extracted from the collected data. This initial analysis focuses on three key aspects of players' strategies across the two game phases. First, we examine the impact of different island profile indexes in to players decision making, seeking to identify correlations between the total invested values in each island and its respective profile index. Following this, we explore the effects of preparedness and response strategies on players' performance. This involves clustering players' decisions into strategy clusters, analyzing the characteristics of each strategy, and assessing the statistical significance of the outcomes. Each investigation within the chapter concludes with the presentation of valuable insights gained from our analysis.

Chapter 7 The research culminates in the concluding chapter, where we synthesize our findings, reflect on the significance of our research, and explore future possibilities for game-based data collection in humanitarian logistics. Here, we connect the dots and highlight the overarching contributions of this work to the field.

Part of this research was published in the Digital Games Research Association (DiGRA) 2022 international conference [29].

CHAPTER 2 LITERATURE REVIEW

In this chapter, we explore the role of data collection in disaster preparedness and response operations, emphasizing its importance in facilitating quick and effective decision-making by humanitarian organizations. We proceed to examine existing data collection systems employed in humanitarian logistics operations, discussing how they contribute to decision-making analysis and research. Additionally, we explore the sphere of gaming and its impact on research, explaining how the engagement power of games has been used to facilitate data collection. The chapter aims to validate the effectiveness of these gaming tools in data collection and justify their integration into our data collection framework. We further investigate the application of games in the humanitarian logistics context, identifying their contributions to the humanitarian logistics field and interesting game elements used.

Throughout this investigation, we demonstrate the absence of data collection systems, in the current state of research, that are tailored specifically for humanitarian preparedness and response operations allowing for analysis of decision-making. The chapter emphasizes that while information systems and serious games have been used to support decision-making and raise awareness in humanitarian logistics, they often fall short in their capacity to systematically track and collect user decisions. This deficiency reveals a need for a novel data collection framework, one that can fill this gap and provide a way for deeper insights into decision-making processes within humanitarian logistics operations. Thus, this chapter establishes the foundation for the unique approach taken in this thesis: the development of the *HurricaneLog* game, which not only simulates humanitarian logistics operations in the context of disaster preparedness and response but also efficiently collects and allows for further analysis of player decisions. This innovative framework sets the thesis apart from previous research, addressing the deficiency in data collection that has been identified in the literature.

2.1 Humanitarian operations and data collection

During the preparedness and response to major disasters, the need for reliable and up-to-date information is crucial to enable fast and coherent decision-making by humanitarian organizations [30]. Given the nature of hurricanes, the faster organizations can collect, analyze, and act on available data, the more efficient the response will be [30]. In order to accomplish successful responses, a key factor is to gather accurate information to understand the situation as a whole, thus realizing how it will potentially evolve over time [31].

During logistic operations, humanitarian agents must deal with information from governmental and non-governmental organizations, companies, events descriptions, among others. In this process, humanitarian agents look for practical and straightforward forms of gathering accurate information to provide a faster response. Consequently, information systems have been proposed in the literature to support the decision process, with the goal of helping decision-makers to understand the situation they are dealing with, and provide accurate data [30].

Although information systems have great relevance for decision-making in humanitarian logistics operations, none of the currently available solutions have the capability of tracking the decisions made by the decision-makers and their impact during the course of an emergency response, which is essential to undertake further in-depth studies. Also, considering the conditions in which operations are conducted, asking decision-makers to create a registry of the decisions made and their impact is not realistic [29]. The humanitarian logistics data collection systems found in the literature are rather focused on concentrating information from multiple sources (e.g., humanitarian organizations, government systems, research institutions, media) to promote informed decision-making and effective response planning [30, 32, 33]. As an example, the *ReliefWeb* provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) offers practitioners with information on both complex emergencies and natural disasters worldwide using more than 4,000 key sources [34]. These are mostly tools that increase situational awareness.

Gathering information about the actions of decision-makers to different disaster cases is almost infeasible since most of the decisions are not documented. It is impractical to ask decision-makers to register what has been decided at any particular time, as well as evaluate the impact of these decisions in the curse of an operation [35]. Thus, an alternative tool that can collect decisions while responding to a disaster is paramount to understand and analyze decision-making in such complex context.

2.2 The engaging power of games

Games are extraordinary entertainment activities that have existed throughout human history. Nowadays, modern games are capable of engaging millions of players. The video game *Call of Duty: Warzone 2* , for example, surpassed the 25 million players mark one week after its launch date [36]. *Ubisoft*, a game development company, announced that its game *Assassin's Creed: Valhalla* surpassed the 20 million players mark [37].

Believing in the engagement power of games, many studies have advocated for its capabilities as a learning tool. According to Bogost [38], games can incorporate components and techniques that compel players to learn about a position or viewpoint. The author claims that this persuasion is implicit in the way the game's components work together to force the player to take a specific course of action in order to win. As a result, these components encourage the player to discover and follow the authors' principles or justifications in order to succeed or finish the game's story.

Games are also used for other purposes than amusement. In particular, when games' primary goal focus on learning over entertainment, they are called *serious games* [39]. Later, the definition of a serious game was expanded by Sawyer [40] to encompass any meaningful use whose ultimate objective is not entertainment. Serious games have been used in a variety of fields, including education [41], training [42], advertising [43] and healthcare [44]. Backlund and Hendrix [45] conducted a review of 40 studies about the use of serious games in various learning contexts. The authors assessed the impact of such games on the educational development of their target audience. According to their findings, 90% of the studies had either positive or neutral outcomes. These studies demonstrate that one can benefit from the entertaining and engaging power of games to make players perform tasks originally deemed unattractive.

2.3 Data collection in digital games

Games or gamified experiences are embedded in many devices of our daily lives. They can be found on smartwatches that track and award the user's physical activities, on smartphones in their traditional game format (e.g., *Chess*, *Candy Crush*, *Clash Royale*), or on personal computers. The omnipresence of games can be explained by the increasing processing power of modern devices, enabling access to games previously exclusive to dedicated consoles such as *PlayStation*, *Xbox*, and *Nintendo*.

This widely available access to games allows researchers to analyze larger and more diverse audiences than ever before. Iyadurai et al. [46], Lau-Zhu et al. [47] used the game *Tetris* to collect data from players about cognitive functions and spatial skills. Simons et al. [48], Lee and Probert [49] used the game *Civilization* to collect data on player creativity and problem-solving. The Massively Multiplayer Online Role-Playing Game (MMORPG) called *World of Warcraft* was used to collect data on player behaviour, social interactions, and decision-making [50, 51]. These are just a few examples of the many games that have been used for data collection studies.

Collected data is typically divided into two categories: *ex situ* and *in situ*. The first refers to data collected "out of the system" (e.g., impressions, pre- and post-surveys). These data are mostly commonly collected out of convenience or due to constraints (e.g., danger to researchers, costs). However, sometimes researchers do not have direct access to the system innards, i.e., they study them as a black box [52]. The latter is mostly the case for the above-mentioned studies with the games *Tetris*, *Civilization*, and *World of Warcraft*. While it is often more practical to collect data *ex situ*, the major drawback of this approach is that it might may prevent a complete understanding of the system. In that case, researchers only have a limited view of the game dynamics [52].

Conversely, *in situ* data is collected directly from the observed system. Thus, researchers are able to access the system's internals and manipulate its content to collect the desired events. This kind of data is mostly desired when compared to *ex situ* data, as it eliminates the subjectivity associated *ex situ* collection methods (e.g., interviews, surveys) [52]. Once researchers have access to the game generated data, they are able to retrace players' actions and reason about their behaviour based on empirical evidence.

Telemetry is the first kind of *in situ* data collection technique that game developers get in contact with. It transmits data generated from the game environment to remote servers for further analysis. Using *telemetry*, game development platforms like *Unity* offers an extensive list of in-game events that can be collected and processed by their analytics solution. Once developers opt-in for their service, *Unity* collects information regarding the players' game start events, their devices, for how long they played the game, if they started or completed a level, etc. This data is then processed by the analytics solution and present insights to developers.

2.4 Data analytics in digital games

Drachen et al. [53] define data analytics as the process of identifying patterns in data in order to solve business problems or make predictions that can aid decision-making and improve performance. It entails communicating these findings in a way that can be used to guide action. When applied to games, these are known as game analytics, and they aim to improve the gaming experience by making it more enjoyable then increasing player engagement. The most commonly metrics associated with game analytics include hours of continuous play, frequency of return to the game server, length of subscription for subscription-based Massive Multiplayer Online Game (MMOG)s, in-game/in-app purchases, among others [21]. These metrics are useful in determining which parts of the game captivate players, which have a higher likelihood of causing retention loss, and which are more profitable.

In the context of serious games, analytics involve actionable metrics developed through problem definition in training/learning scenarios, as well as the use of statistical models, metrics, and analysis for skill and human performance improvement and assessment, with serious games serving as primary training tools [21]. The study of the collected data aims to obtain insights with the purpose of improving the game or learning design, and improving the players' skills and performance.

Scarlatos and Scarlatos [54], for example, made a study involving the game *Energy Choices* that teaches players regarding the interrelated issues of global warming and energy use. They collected player in-game actions and used serious games analytics to create multiple-layered dynamic visualizations and communicate player actions in an easier way. As another example of serious game analytics, Cornforth et al. [55] used a game to help rehabilitation of stroke patients. They used the game to present challenges, including motor and cognitive tasks, and measured their physical condition. With the collected information they could, in real time, adjust the game parameters and improve the treatment outcomes. These examples highlight the use of serious games and analytics to improve learning, training and performance.

2.5 Humanitarian logistics games

Serious games have been used in the humanitarian logistics as a way to train and educate logistics professionals, volunteers and students. They can simulate various aspects of humanitarian logistics operations, such as disaster response, supply chain management, and coordination of goods and personnel. The multiplayer game *Disaster Response Game*, developed by Klein et al. [56], simulates disaster response operations in disaster-prone areas where players, working as humanitarian agents, must coordinate their operations and limited supplies to meet the needs of the affected populations. The game is customizable to different disasters so, depending on the customized events, players have to rebuild bridges, fix access roads, distribute relief items, build temporary shelters, reallocate supplies, etc. The game creators used a tropical cyclone scenario as proof of concept with students, and assessed their learning points through a short survey, then performing a debriefing session after the gameplay. Overall, the student feedback was positive, highlighting the realistic aspects of the game besides emphasizing the importance of collaboration.

Another example of a serious game for humanitarian logistics is the board game *THINKLog*, created by Abdul et al. [57], which is focused on teaching supply chain management within humanitarian operations. The game is composed of two stages: (i) in the first stage, called preparedness, players have to decide from a given set of locations where to build warehouses based on distance, coverage, cost, risk and congestion criteria; (ii) in the second stage, called response, players have to deliver requested relief items to the affected populations while taking in consideration disruptive events that occur. The game penalizes the player by giving them a failure token shall they fail to deliver the requested items in a stipulated amount of time. The player with the least amount of tokens at the end of the game is declared the winner. *THINKLog* was used in a workshop with government officials to collect data about warehouse location criteria decisions. The game creators pointed that players had a good overall game experience and were able to meet the game learning objectives.

In the same context of humanitarian supply chain management, Alaswad and Salman [58] created the *Humanitarian Aid and Relief Distribution Game*, which is a multiplayer turn-based game that simulates a humanitarian supply chain from its starting point (i.e., donors or suppliers) to their destination point (i.e., affected populations). Each player assumes a station on the supply chain (e.g., donors, suppliers, regional distribution centers, local warehouses) and must control their inventory levels by ordering and shipping relief supplies. The players are evaluated according to the fulfillment rate of their immediate costumers, their operation costs and transport resources utilization. The authors used this game as a complementary teaching tool to introduce the challenges faced in humanitarian supply chains and educate on supply chain strategies. They were able to attest the effectiveness of the game by performing pre- and post-surveys.

Logistics to the rescue [59] is another humanitarian serious game created to foster the idea of using social media to detect populations in need after a natural disaster. As an emergency dispatcher, players must carefully assess various demand locations to devise a safe and efficient rescue plan. They are asked to build routes between depots and demand locations which can be either reliable (assessed through 911 calls) or unreliable (generated by social media input). As the game progresses, unreliable locations become reliable then incurring saved lives; or not, leading to resource wastes. The ability of the game to educate about social media use was measured through a post-survey with secondary first and second graders (the target group), that confirmed a positive feedback.

In addition to the aforementioned games, we can still list below:

(i) *Food Force* that creates awareness on the difficulties of humanitarian food distribution in conflict and disaster-affected areas [60];

(ii) *Inside Haiti Earthquake* that educates players on challenges faced by survivors, humanitarian agents and journalists after an earthquake event [61]; and

(iii) *Disaster Detector* and *Stop Disasters* which teaches players on the different ways of preparing a community infrastructure to sustain damages from extreme natural events [62, 63].

Diving into the broader spectrum of disaster risk management, Solinska-Nowak et al. [64] were able to survey 45 serious games. These findings reveal that the engaging power of games and their risk-free environment have been widely used by the humanitarian logistics research community. Harteveld and Suarez [17] highlights the use of serious game in humanitarian logistics by recognizing their augmented capability for communicating complex humanitarian operations.

While the current humanitarian games have made valuable contributions to the literature, a significant gap exists in simulating and collecting player decision information for multi-region disaster preparedness and response. The few ones that focus on disaster preparedness concern almost exclusively about warehouse positioning. To address this gap, this research introduces *HurricaneLog*, a serious game designed to simulate disaster preparedness and response in a multi-region context, enabling comprehensive data analysis through data collection and enhancing our understanding of players' behaviour in humanitarian logistics. Further details regarding this gap are provided in the next section.

2.6 Closing the gap

On one hand, we have identified that many of the games lack an appealing interface which may affect player's engagement. On the other hand, those with richer interfaces, with the exception of *Inside Haiti Earthquake* game, offer cartoonist scenarios likely impacting on the games seriousness and their appeal to an adult audience. Further, none of the current response-based solutions offer real-time simulations of natural events, depriving players of the opportunity to track and respond to their evolution. Finally, while players can observe the impact of their actions through changes in gameplay, there is a lack of feedback during operations to enhance the learning experience.

The *Disaster Response Game* presents a good coordination schema and great flexibility through its customizable experience. However, it does not provide data collection regarding the decision-making process. The player's performance in the game is discussed by analyzing the evolution of the number of casualties over time. Additionally, the game does not have a distinct preparedness phase in which players can prepare the region for the disasters. The preparedness decisions must be taken when a disaster is announced to happen, limiting their activities to short-time actions (e.g., moving resources, reinforcing warehouses). Such lack of time for preparedness decisions is also observed in other games, notably, *Humanitarian Aid and Relief Distribution Game*, *Logistics to the rescue*, *Inside Haiti Earthquake*, and *Food*

Force.

In contrast, the *THINKLog* game comprises the preparedness and response stages. Players can prepare for disaster by selecting which candidate points they will turn into warehouses. The candidate selection process is assisted by their software application based on the player weighted preference points among the five available criteria. The weights distributed among the decision criteria and warehouse locations are collected by their application and further used to help build a simulation model to improve warehouse locations in real case scenarios. Still, no data collection is mentioned in the response state, which we believe could help understand the decision-making process and unveil interesting response strategies. The same data collection deficiency is also observed in the other mentioned games, such as *Disaster Detector* and *Stop Disasters*.

As an attempt to fill this gap perceived, the following chapters present a new data collection framework using a serious game that addresses preparedness and response operations in disaster-prone regions using real-life data. The *HurricaneLog* game simulates humanitarian logistics operations prior to and during Atlantic hurricane seasons. It uses the projected simulation to collect data on decision-making processes carried out in humanitarian logistics operations. We focus the simulation on islands inspired by the Caribbean region, which are hit by hurricanes every year, causing damage to homes, energy, communication, and transportation infrastructure, as well as causing a significant financial impact and affecting the lives of hundreds of thousands of people.

Moreover, through this framework, we aim to promote a better understanding and characterization of players' behaviour by facilitating comprehensive data analysis, an aspect unexplored in previous research. In essence, our work provides a valuable tool not only for enhancing decision-making strategies in humanitarian logistics but also for advancing the understanding of behaviour within this context.

CHAPTER 3 GAME DESCRIPTION

In this chapter, we present an overview of the *HurricaneLog* game, providing an in-depth understanding of the game's elements and how players interact with the game. The chapter's goal is to lay the foundation for comprehending the game's structure, mechanics, and the metrics used to evaluate player performance. This understanding is crucial for the subsequent chapters, which detail the design and data collection aspects of the game.

HurricaneLog simulates humanitarian logistics operations in a fictional region composed of four islands and an international supplier located in the continent. An image of this region is given in Figure 3.1. These islands work together, administered by a single coordination agency, to better prepare against hurricane damages. As a member of this inter-governmental agency, the player is tasked with regional collaboration to coordinate humanitarian logistics activities. The success of the player's operation is quantitatively measured by its average response time in serving the affected population, the total cost of the assigned operations, and the ratio between the number of people in need over the total number of affected people following the hurricane strike, which is the equivalent of the percentage of unsatisfied demands.

The player's operation is divided into two phases: (i) preparedness, and (ii) response. In the preparedness phase, the operation takes place before beginning of the hurricane season. Hence, the player's decisions are geared toward making disaster preparedness investments to increase the region's resilience to hurricanes. The response phase starts with the hurricane season which is triggered by the player after the preparedness phase. At this moment, the player must manage the transport of resources in the region to assist the affected populations. Assistance is provided in the form of relief items, which are among the most immediate forms of aid delivered during humanitarian operations. They are composed of essential items for the survival of the affected populations, focusing on supplying the need of shelter, food, water, sanitation, hygiene and medication [65, 66]. Actually, their exact content in real-life varies with the type of disaster and population needs. For instance, in the Caribbean region, the IFRC Panama delivered family kits as relief items [67]. These kits include a hygiene kit, jerrycan, blanket, mosquito net, tarpaulin, shelter tool kit, kitchen set and plastic bucket. In *HurricaneLog*, relief items are represented by family kits.

The game uses data from online databases such as the Emergency Events Database (EM-DAT) [68], the World Bank Open Data [69], the National Hurricane Center (NHC) Geographic Information System (GIS) Archive [70, 71], and the International Best Track Archive for

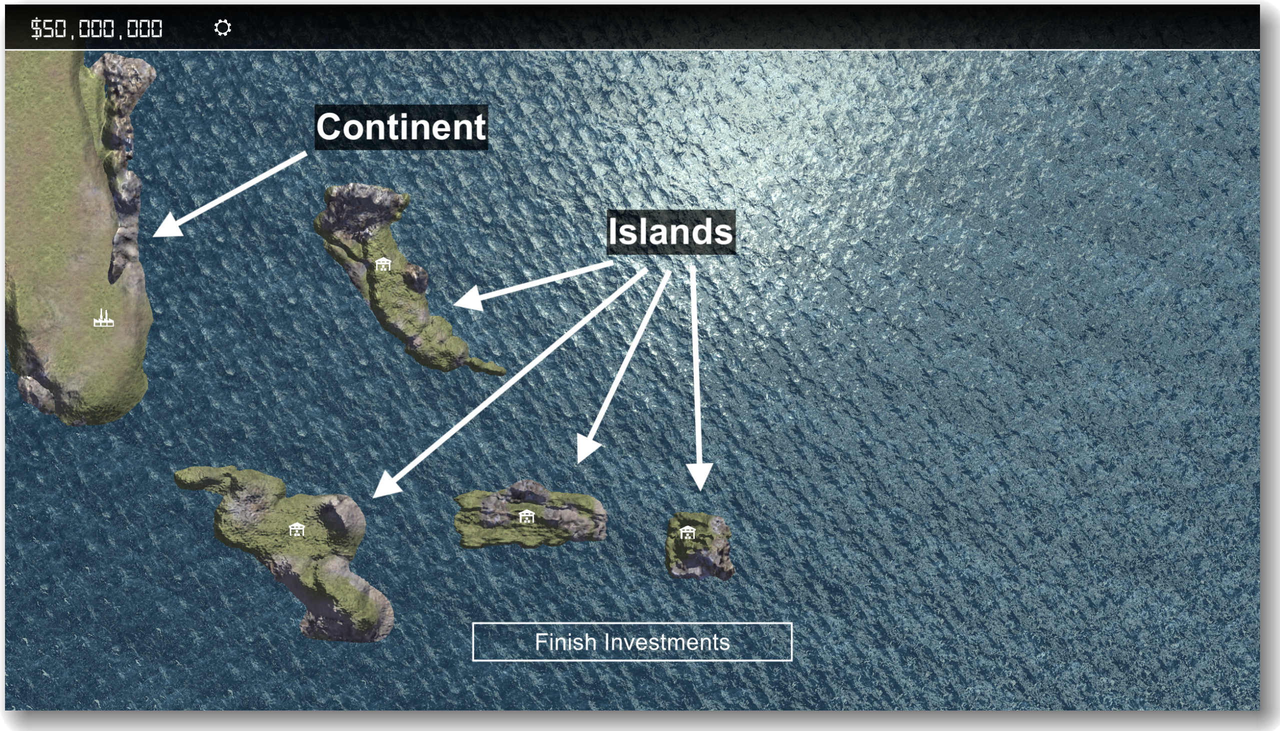


Figure 3.1 Region of focus in the *HurricaneLog* game.

Climate Stewardship (IBTrACS) [72, 73] to simulate hurricane damage events, tracks and forecasts. Additionally, it combines this information with data from humanitarian operations scientific publications [67, 74, 75, 76, 77, 78] in the region to create a similar environment to what humanitarian logistics managers encounter during a humanitarian operation. Details about the use of this information and how it was incorporated into the game are provided in Chapter 4.

3.1 How the game is played

HurricaneLog starts by presenting the player's role as an agent of an intergovernmental agency, thus explaining the context of the operation. Afterwards, the islands are presented along their key characteristics, i.e., population's size, risk factor, economic condition and logistics performance. An illustration of the islands presentation is shown in Figure 3.2. By considering this information presented on a colour scale, along with the islands' locations, the player can infer their preparedness needs and how much their populations will be affected in case of a hurricane event. More precisely:

- The population size is used to estimate how many island citizens might be affected by a hurricane.

- The risk factor indicates the likelihood of an island being hit by a hurricane.
- The economic condition reflects the island's financial wealth, and indicates the strength of its infrastructures regarding potential future disasters.
- The logistics performance reflects the robustness of the nation's logistic chain.

Figure 3.2 Islands' characteristics view.

3.1.1 Preparedness phase

The preparedness phase is a critical part of the game where the player must prepare the region for the upcoming hurricane season. The success of the response phase heavily depends on the quality of the preparedness phase, as investments made during the latter directly impacts family kits processing times and operations costs.

The preparedness phase offers a variety of investment options listed below:

- *Preposition*: allows the pre-purchase of family kits, which can be stored in the local warehouse up to its capacity limit. These kits can be used to assist local populations or be transferred to another island in the region.

- *Warehouse Capacity*: corresponds to improvements on the local warehouse building infrastructure and inventory management. This investment increases the warehouse capacity and may reduce the loss of family kits in case of a hurricane damage. It also reduces the time required to prepare family kits for distribution.

- *Distribution Capacity*: stands for investments on the local distribution resources (e.g., volunteers, equipment for handling materials, trucks). It increases the capacity to distribute family kits items, resulting in lower distribution and transportation times.

- *Communication and Information Sharing*: refers to improvements in the communications between the operation's stakeholders. This investment influences the accuracy about family kits storage and manipulation (e.g., amount stored in the warehouse, shipment requests).

- *Supplier Agreements*: represents investments in agreements with international suppliers. Theses investments guarantee immediate access to agreed amounts of family kits during response operations. Also, they affect their purchase price on orders made during response operations.

- *Regional Transportation Agreements*: corresponds to expenses made on agreements between the region's islands and transportation companies. These investments influence waiting times for accessing transportation vehicles. The game simulates two transportation modes: planes and ships. Planes are faster than ships but are more expensive.

- *Customs Clearance and Sharing Agreements*: corresponds to improvements on trade facilitation agreements and on customs systems to improve importation processes among the islands. It affects the time required to process family kits on border entry points.

Each investment option can be purchased at discrete levels (0-none, 1, 2,...), with costs increasing in a step-wise manner. These costs, as well as their selection criteria, are discussed in more detail in Section 4.4. To make an investment, the player uses money from the available preparedness budget, which is limited. As a result, investments must be carefully analyzed to find the best match between improvements and the islands' needs. The investment interface is shown in Figure 3.3.

Investments are further categorized based on their local or regional impacts. Local investments, such as *Distribution Capacity*, are applied and affect a single island, while regional investments, such as *Supplier Agreements*, are applied and impact all islands in the region. In the game, these investments are distinguished by an associated globe icon. These visual

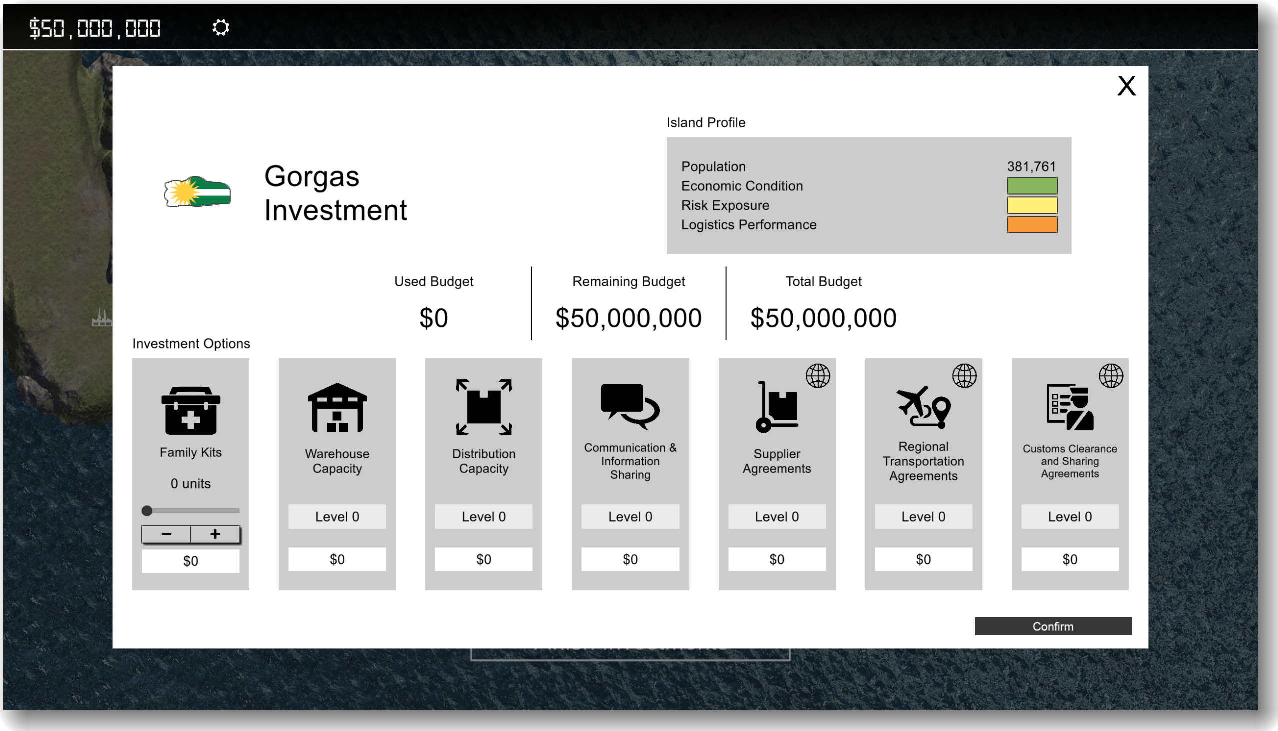


Figure 3.3 Investment options.

elements can be seen in Figure 3.3 in the last three investment options (i.e., *Supplier Agreements*, *Regional Transportation Agreements*, *Customs Clearance and Sharing Agreements*).

By considering the limited budget, the islands' characteristics and the investments' impacts, the player must decide which investments to purchase. The investments made during the preparedness phase have a direct impact on the dynamics of the response phase, allowing players to immediately see the impact of their investment decisions. For instance, investments in *regional transportation agreements* during the preparedness phase can reduce the *transport procurement* time in the response phase thereby resulting in faster transfers of family kits to the affected islands. Furthermore, the amount of preparedness investments made in an island before the hurricane season directly affects its ability to effectively respond to hurricane damages, potentially determining the player's success or failure in the game.

3.1.2 Response phase

Once the player complete their preparedness investments, they are directed to the start of the hurricane season, which marks the beginning of the response phase. At this moment, storms appear in the region of focus, moving throughout the region and menacing the islands. The storms can appear in different categories and may evolve through time. They are classified according to their patterns and wind characteristics, following the National Oceanic and Atmospheric Administration (NOAA) storm definition (`https://www.weather.gov/mob/tropical_definitions`). Once they reach a hurricane category, they follow the *Saffir-Simpson Hurricane Wind Scale* that further divides hurricanes into five categories based on their wind speed.

The player can monitor the movement and evolution of hurricanes in the game through illustrative forecasts, as shown in Figure 3.4. They display possible trajectories that the watched storms can take, as well as their predicted category evolution over time.

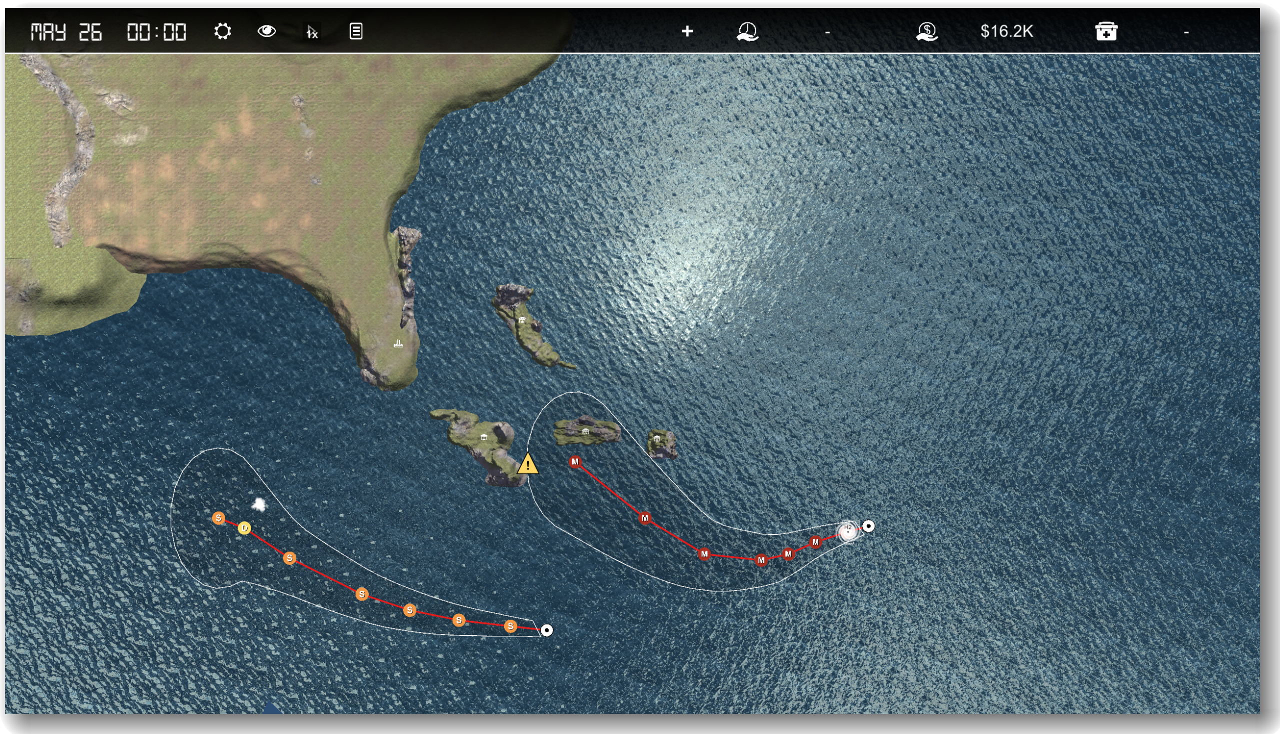


Figure 3.4 Depiction of the hurricanes and their associated forecasts.

Hurricane damage

When a hurricane hits an island, damages are recorded and simulated in the game through immediate demands from the impacted populations. Figure 3.5 illustrates a damage report that the players see once a hurricane strikes an island.

This report summarizes information about the damages and immediate needs caused by the hurricane. Section A presents information on the number of families in need of assistance, and on the number of families that will be served by the family kits already stored in the island's warehouse or by those currently in transit to the impacted island. The information

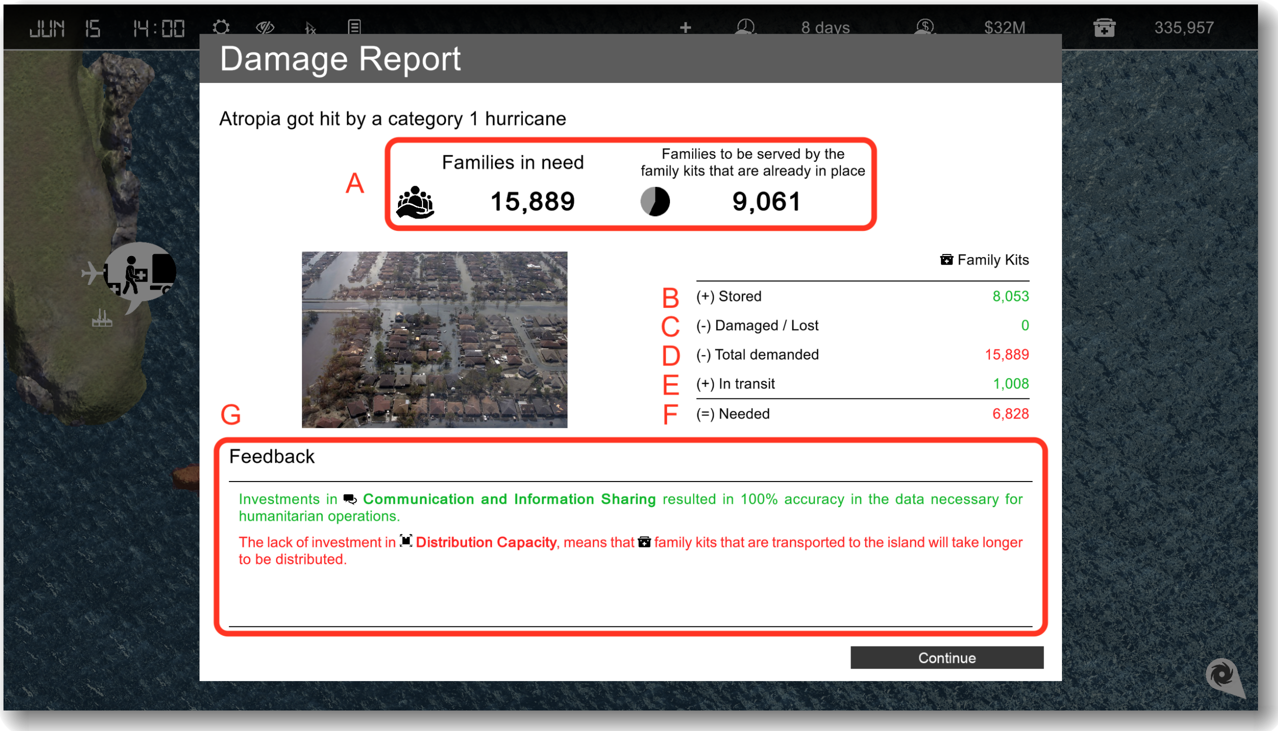


Figure 3.5 Example of damage report.

about family kits is further detailed into four parts: B displays the number of prepositioned kits, C shows the amount of family kits lost due to hurricane damages, D refers to the total demand of family kits, and E reports the number of kits in transit to the island. Finally, part F summarizes the demand information thereby determining if additional family kits are needed.

The damage report also includes a feedback section (G) that allows the player to assess its preparedness decisions. The feedback can be either positive, recognizing a wise investment, or negative, highlighting a lack of investment in a particular area. This section enables the player to gauge the impact of their preparedness choices on humanitarian operations and encourages the development of more effective strategies in future scenarios.

Transport of family kits

The player's objective in the response phase is to meet the generated demands as quickly as possible, while keeping operation costs as low as possible. These demands can be met by distributing family kits from three sources: local, regional, and international. Family kits in the local warehouse are immediately distributed to the demanding population. However, whenever the local demand exceeds the local warehouse's capacity, the player needs to transfer extra kits from neighbouring islands or purchase them from international suppliers. To illustrate, Figure 3.6 depicts a transfer window that appears once the player selects to transfer family kits between two islands – this window pops up after the player clicks on two islands of the game. Section A displays the selected origin and destination islands. In section B, the player can decide about the number of family kits to be transferred subject to constraints on the destination's warehouse capacity and to the origin's maximum possible offer. Section C provides the player with information about the number of family kits needed at the destination island. Section D displays the amount of family kits already in transit to the destination, which allows the player to consider these kits before making further transfers. Section E shows the inventory of family kits at the destination's warehouse (as a fraction of its capacity) after the transfer of the kits selected in B. Note that these family kits will be stocked in the destination's warehouse only if they are not used to meet the immediate demand indicated in C. In the figure, the destination warehouse capacity is 50,000 family kits. Its occupation displays 44% as result from 17,932 family kits in transit surpassing the number of demands plus 3,947 family kits selected by the player. Section F shows the time required to deliver the selected family kits in B, what is correlated to the number of family kits to be transferred and the selected transport type. Finally, section G displays the total shipment cost.

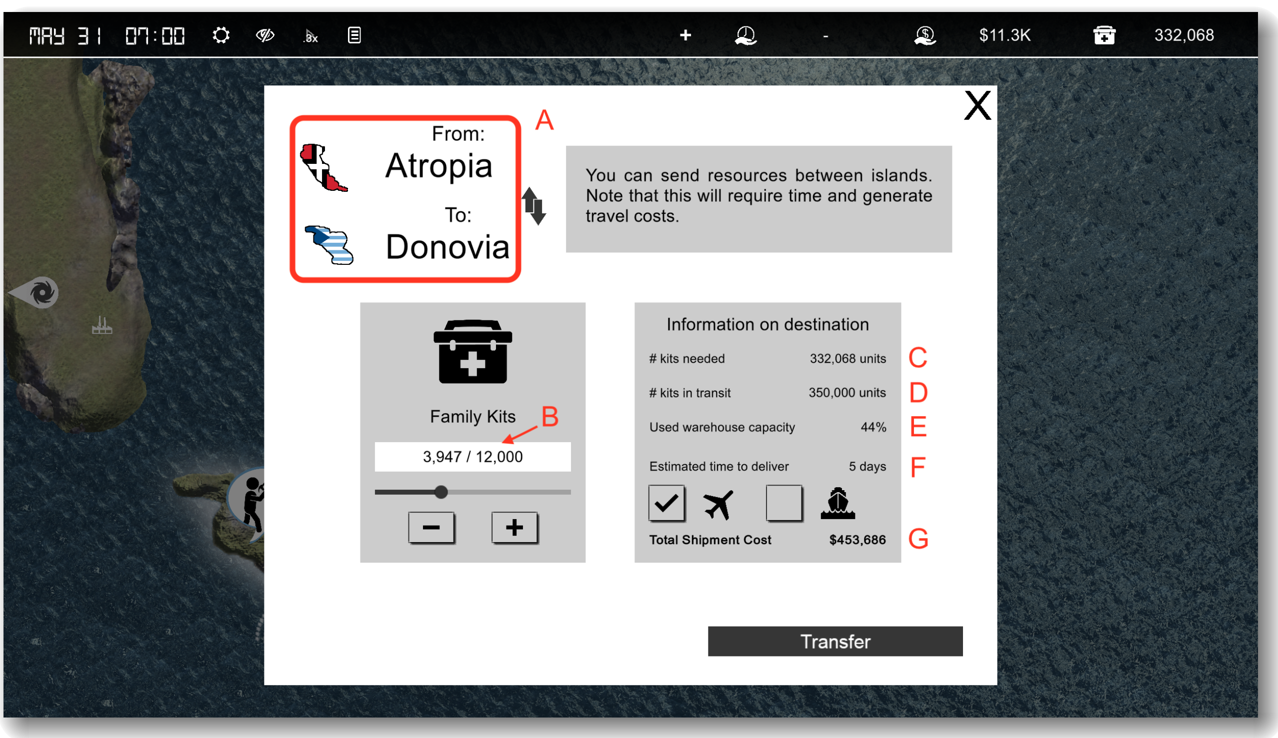


Figure 3.6 Example of transfer window.

When the player decides to perform a transfer between two islands, a series of processes are carried out as follows:

1. *Transport procurement*: is the process of finding a transportation vehicle (airplane or ship) to transport family kits.
2. *Transport preparation*: represents the preparation and loading of family kit inside the procured transportation vehicle.
3. *International transportation*: corresponds to the actual transportation of family kits between the origin and destination islands.
4. *Unloading shipment*: denotes the process of unloading the shipment at the destination island. It encompasses the unloading of the family kits from the plane or ship to the border customs.
5. *Customs clearance*: corresponds to the process performed at the destination border to ensure that all documents and products agree with the island regulation laws.
6. *Transport to warehouse*: represents the process of moving relief items from ports or airports to the warehouse.
7. *Inland distribution*: is the actual distribution of relief items to the people in need.

Purchasing family kits from international suppliers involves a different process. The international transfer follows the same order defined by the process steps 1-7 above, except for steps 1 and 2 that are replaced by a *family kit international preparation* process. This process takes into account the preparation of family kits by international suppliers. If the quantity of family kits requested is within the agreed amount established by preparedness investments on agreements with international suppliers, family kits are promptly dispatched without any preparation delay. However, if the quantity exceeds the previously agreed amount or if no agreement has been established, the preparation process takes longer to complete. Further information on the calculation of the preparation time from international suppliers can be found in Section 4.3.

Repair of infrastructures

The game also simulates the repair of ports and airports to restore regular operations after a hurricane hit. While this process is in execution, its corresponding island's ports and airports are not allowed to receive or send family kits from/to other islands. Incoming shipments are held in the *international transportation* process part until they can proceed to the *unloading* process. Conversely, outgoing shipments are held in the *transport procurement* process until they can proceed to the *transport preparation* phase.

Response strategy

Transfer decisions can be made at any time during the response operation. However, the moment they are taken is usually determined by the player's decision-making strategy. For example, if the player anticipates that a hurricane is likely to hit an island, they may immediately send relief items via ships to save on operational costs and guarantee that the items arrive at their destination on time. If the hurricane deviates from its forecasted trajectory, however, the player will have unnecessarily increased the total cost of the operation. In contrast, if the player waits until the hurricane is too close to the island before sending the items via plane, they will be more confident about their use although at a higher operational cost.

Performance indicators

In order to improve their strategy and decision-making skills, players can monitor a series of KPIs while playing the game. They are:

- *Average Response Time*: This indicator represents the average amount of time the player takes to fulfill the demand of one family kit. It is calculated as the total response time divided by the total number of delivered family kits.
- *Operation Cost*: This indicator represents the total amount of money spent by the player during the response phase.
- *Demand for family kits*: This indicator shows the current number of families that require family kits. It serves as a measure to assess the player's supply chain management.

By considering the KPIs together, players can evaluate their performance in terms of agility, cost and coverage. Nonetheless, it is crucial to monitor all three KPIs together to avoid false conclusions about the player's performance. For instance, if the player does not serve any family kit demand, the operational cost and average response time indicators are low, although the demand for family kits is maximum. Another example may appear when all demands are served by ships. Although the operation cost and the current demand may present low values, the average response time indicator might reveal that the response operations need to increase their efficiency – maybe attainable if planes are used instead. Finally, an operation where all shipments are made by planes may have low average response times and low current demand for family kits but at higher costs. In summary, monitoring all three KPIs is necessary to eliminate false impressions of good performance, and to identify operations aspects that must be improved.

The KPIs are readily accessible to the player during the game's response phase, as depicted in Figure 3.7. The part A of the figure provides a summary of the player's performance across all nations, displaying the average response time, the total number of demands for family kits, and the total operation cost. This summary provides the player with a macro view of their overall performance regarding the humanitarian operation as a whole. Part B of the figure presents specific KPI values for each island, which are based on the player's operations in each location. These metrics help the player to compare their performance regarding the operations performed in each nation, then identifying which islands require more attention and resources. For example, in the figure, for the impacted inhabitants of *Donovia* (i.e. the third island), the average response time is 11 days, the operation cost is 1.4 million, and the estimated range of demands for family kits is between 415,000 to 623,000.

Figure 3.7 Depiction of the KPIs.

Although the KPIs above are focused on the response phase, the amount of money spent in the preparedness phase should be also taken in consideration to determine the player's performance. As mentioned before, preparedness investments influence the game dynamics. Hence, as shown in the next section, the final report of the game splits the operation cost into two components: one related to preparedness and another related to response operations.

3.1.3 Final operation report

The response phase finishes when all storms have dissipated and all inland distribution processes have been completed. At this point, the player receives an operation report that outlines their performance metrics and how they evolved during the response phase. An example of the operation report is provided in Figure 3.8.

Figure 3.8 Depiction of the operation report.

Part A of the report displays the player's overall performance regarding both preparedness and response decisions. It provides the player with a comprehensive evaluation of their performance throughout the entire game, including how well they prepared for hurricanes and how effectively they responded to the events that occurred during the response phase. Moreover, it displays the player's rank in comparison to other players who have previously played the game.

Part B contains graphs that show the evolution of the player's KPIs over time. The graph presents in their x-axis the moment in time when the hurricanes occurred in the game, thus allowing the player to gain insight about the effectiveness of their preparedness and response decisions, as well as identify areas for improvement in future playthroughs.

Part C allows the player to access specific information about the whole operation with respect to each island. The island-specific information allows the player to gain a granular understanding of their performance in meeting the needs of each island's population during the response phase. By examining the breakdown of investments made and performance metrics, the player can identify areas for improvement in their resource allocation and response strategies.

3.2 Summary

Finally, a summary of the game flow explained in this chapter is illustrated in Figure 3.9. Additionally, the game includes a tutorial mode that focuses on introducing the game to new players. More details about the tutorial can be found in Appendix A.

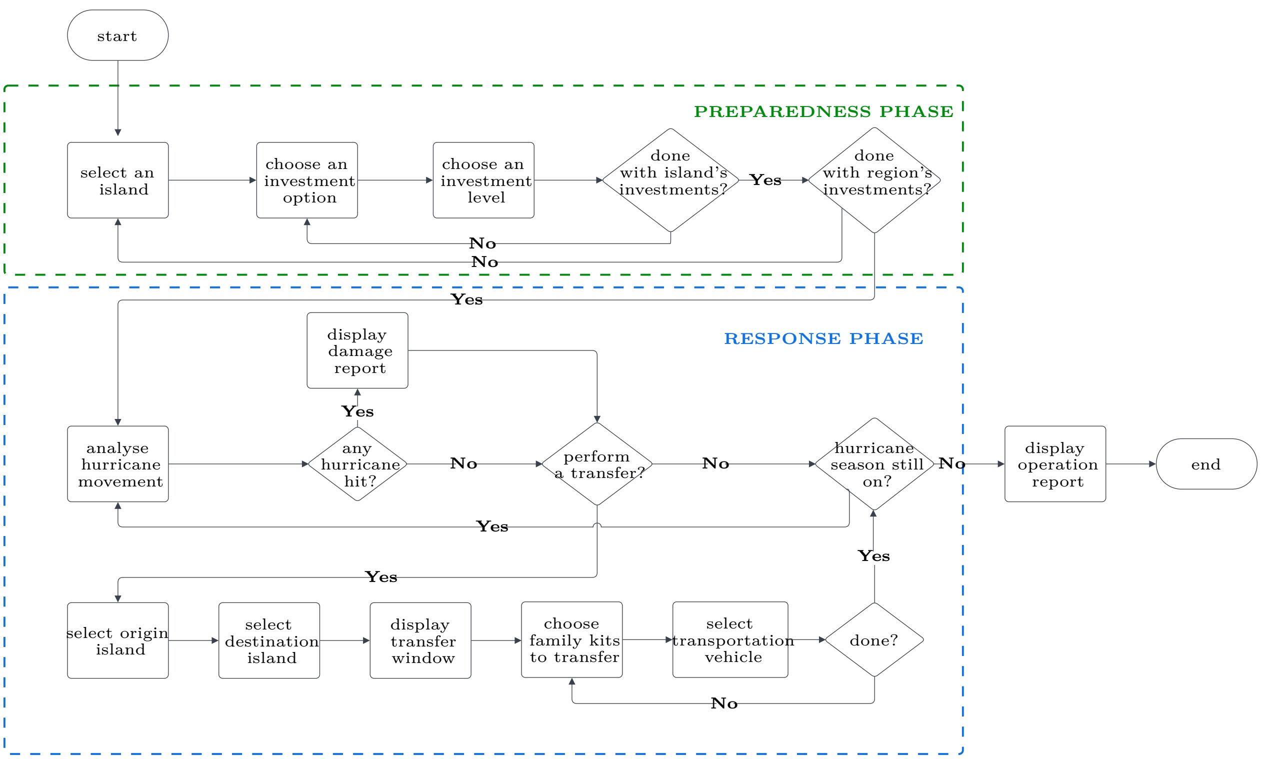


Figure 3.9 Diagram of the game flow.

3.3 Game design and iterative testing for enhanced player experience

The game development process is rarely a straightforward journey, most projects involve multiple iterations to achieve their desired objectives. In the case of the *HurricaneLog* game, our focus on the player experience was twofold: (i) providing an experience that authentically mirrors the challenges confronted by humanitarian logistics decision-makers during their operations and (ii) creating an enjoyable and engaging gaming experience. To accomplish this, the game underwent meticulous design refinement through numerous rounds of discussions and testing involving humanitarian agents and logistics professionals. This iterative approach ensured the inclusion of decision-making elements relevant to real-world operations. Furthermore, recognizing the importance of a user-friendly interface, we engaged the expertise of a user interface designer to enhance all game screens and elements. The goal was to build an intuitive and visually appealing interface that would facilitate user interaction with the game.

The game was also subjected to testing involving individuals not affiliated with game design or humanitarian logistics to ensure a fun and educational experience. These qualitative tests were conducted in two rounds, with four players selected for each round. All playtesting took place online through a video conferencing platform and followed the subsequent steps:

1. **Game Installation**: Players were instructed to install and launch *HurricaneLog* on their computers. This initial step aimed to identify any potential issues related to game installation.

2. **Context Description**: The playtesting moderator provided an overview of the game's context and explained the player's role within the game. Players were encouraged to share their screens, allowing the moderators to observe their interactions with the game. Players were informed that the playtesting process aimed to uncover gameplay flaws, such as bugs, non-intuitive elements, and unclear aspects. Therefore, while they were encouraged to ask questions, the moderators refrained from providing answers unless such information was critical to the players' progress in the game. This approach was adopted to allow players express their inquiries about some parts of the game, highlighting unclear points, and give them the opportunity to discover by themselves, validating the game interaction experience.

3. **Game Tutorial**: Players initiated their gaming sessions by completing the game tutorial. During this phase, moderators adopted the *think-aloud* protocol, requesting that players vocalize their thoughts and express their immediate reactions while interacting with the game. This approach served to elucidate players' reasoning behind their

actions, their perspectives on the game, and to pinpoint areas for potential improvement. At the conclusion of the tutorial, players were invited to provide feedback on any aspects of the tutorial and suggest possible enhancements.

4. **Main Game Play**: Players were tasked with playing the main game, adhering to the same protocol utilized during the tutorial.

5. **Survey**: Upon completing the game session, the playtesting moderator administered a brief survey designed to gain further insights into players' experiences and perceptions of the game. The survey questionnaire used can be found at Appendix B.

Throughout the entire play session, the moderator diligently recorded various opportunities for improvement, identified bugs, and noted questions raised concerning player actions. These observations and insights were valuable during the subsequent survey, where they served as a foundation for further discussions.

The first round of playtesting revealed numerous areas for potential enhancement, encompassing overall bugs, need for refinement of island profile element descriptions, need for improved tutorial clarity, investment impacts, and enhanced user interface elements.

In preparation for the second playtesting round, the identified improvement points were thoroughly discussed with the game design team. These discussions involved multiple rounds of deliberations aimed at devising effective solutions.

The second playtesting round involved four new players and followed the same procedural steps detailed earlier. This new round yielded additional insights and areas for improvement, which, once again, were addressed through extensive discussions with the game design team.

In summary, the development of *HurricaneLog* was a dynamic and iterative process, driven by a dual commitment to delivering a realistic, enjoyable, and educational gaming experience for all. By addressing gameplay flaws, refining elements, and improving the user interface, we aimed to create an engaging and accessible tool. The insights gained from these testing phases were invaluable, leading to improvements that shaped the game's final form.

CHAPTER 4 GAME DESIGN CHOICES

HurricaneLog aims to simulate an environment similar to what humanitarian logistics decision makers experience in their operations. Thus, in addition to mechanics that enable this experience, the content of the game also needs to be based on real data and on realistic scenarios. In this chapter, we present how data information was collected to project the game, and how this data was adapted and transformed to the game context.

4.1 Hurricanes

Hurricane simulations are the primary natural events replicated in the game. Thus, it is essential to provide accurate representations for the simulated hurricanes so that the players can experience a realistic simulation.

Hurricane movements are inherently unpredictable due to their stochastic nature. Predictive models for hurricane movements rely on various factors such as historical data and meteorological parameters [79, 80]. However, these models provide only rough estimates and may not match real-world movements [80, 81, 82]. Some models are also complex and time-consuming [83]. For these reasons, *HurricaneLog* collects hurricane trajectories from recognized online databases, eliminating the need for complex modeling while maintaining a realistic representation of hurricane movements.

4.1.1 Tracks

The trajectories and category information on hurricanes were obtained from the IBTrACS database, which contains information on tropical cyclones that have occurred since 1842. It serves as a centralized data repository from multiple organizations around the world, making it a valuable resource for hurricane research and analysis. The database provides information about more than 100 different hurricane-related characteristics, including wind speed, latitude, and longitude. For detailed information on the data available, please refer to [84].

The following hurricane attributes were collected from IBTrACS to model the hurricanes in the game:

- *usa_sshs*: *Saffir-Simpson Hurricane Scale* information based on the wind speed provided by the US agency.

- *latitude*: coordinate that specifies the north–south position of the hurricane on the surface of the Earth.
- *longitude*: coordinate that specifies the east–west position of the hurricane on the surface of the Earth.
- *iso_time*: ISO Time provided in Universal Time Coordinates (UTC).

Table 4.1 presents an example of 2017 hurricane *Maria* track obtained from the IBTrACS database.

Table 4.1 Example of the extracted hurricane track for 2017 hurricane *Maria*.

#	usa_sshs	latitude	longitude	iso_time
1	-1	12.2	-49.7	2017-09-16 12:00:00 UTC
2	0	12.1861	-50.7576	2017-09-16 15:00:00 UTC
3	0	12.2	-51.7	2017-09-16 18:00:00 UTC
4	0	12.274	-52.4383	2017-09-16 21:00:00 UTC
⋮	⋮	⋮	⋮	⋮
128	-4	47.8181	-24.2851	2017-10-02 03:00:00 UTC
129	-4	48.0	-22.0	2017-10-02 06:00:00 UTC
130	-4	48.0506	-19.5486	2017-10-02 09:00:00 UTC
131	-4	48.0	-17.0	2017-10-02 12:00:00 UTC

In addition to the *Saffir-Simpson Hurricane Scale* five categories, the attribute *usa_sshs* from the IBTrACS database also uses additional values to better specify the strength of a tropical storm event. Table 4.2 lists all possible values for this attribute and their respective category associations found in the IBTrACS database.

The data collection about the hurricane tracks was carried out in two steps. First, the names of the hurricanes were obtained from the National Hurricane Center's Tropical Cyclone Reports [71] based on the hurricane season year. Next, the hurricane information was retrieved using the Google BigQuery SQL [85] query and filtered using the names collected in the first step. After the data collection was completed, each hurricane tracking information was stored in a file, including its category evolution, and its position from formation to disappearance.

While most of the data from the IBTrACS database is tabular and well-organized, the frequency of recorded information varies among the stored storms. According to the IBTrACS documentation, the most common sampling frequency is six hours. However, New Delhi, an agency that contributes with tracking data to the database, also records information at higher frequencies, such as at every three hours. Additionally, during significant events like

Table 4.2 Storm category conversion table.

usa_sshs	category
-5	Unknown
-4	PostTropical
-3	Disturbances
-2	Subtropical
-1	Tropical depression
0	Tropical storm
1	Hurricane Cat. 1
2	Hurricane Cat. 2
3	Hurricane Cat. 3
4	Hurricane Cat. 4
5	Hurricane Cat. 5

storms landfalls, track information may be recorded at a higher frequency than the common sampling frequency of six hours. Since consistent sampling frequency is crucial for accurate modeling, all data points recorded at a frequency less than six hours were removed from the hurricane tracks of our game. For hurricane tracks recorded at a three-hour frequency, data points falling between one six-hour intervals were also removed.

The game leverages the collected hurricane track information to recreate the movement of hurricanes over time. This is accomplished by following the trajectory geographical points, as well as the specific time of occurrence for each point. The information from the *usa_sshs* column is also used to model the evolution of the storm, including six storm categories: tropical storm, and hurricane categories 1 to 5. These categories are illustrated in the game as in Figure 4.1. By incorporating this information, the game offers an accurate representation of the movement and development of each hurricane, allowing users to visualize the storm's path and progression. For values of the attribute *usa_sshs* lower than zero, the game represents the storm as a set of clouds.

4.1.2 Forecasts

Forecasts for hurricanes are critical in humanitarian logistics operations, where timely and accurate information is essential for decision-making and response planning. When a hurricane approaches, forecast models are used to predict the storm's path, intensity, and potential impact on communities and infrastructure [86]. These forecasts are then used by humanitarian organizations to prepare and mobilize resources, such as food, water, and medical supplies, and to coordinate emergency response efforts [86]. In the *HurricaneLog* game, re-

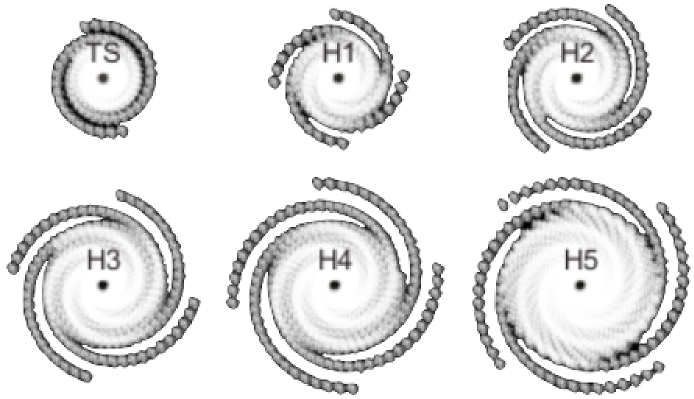


Figure 4.1 Depiction of the game storm categories.

producing these forecasts is a key feature that allows players to experience the challenges and complexities of disaster response.

Hurricane forecast information in the game is obtained from the NHC GIS Archive, which offers comprehensive advisories and generated forecasts for each of the Atlantic and East Pacific storms observed since 2008. The forecast files include hurricane predicted track and uncertainty cone data for each forecast observation, which is generated by taking into account the historical error rates of previous hurricane forecasts and the predicted range of the storm's potential tracks. The wider the cone, the greater the uncertainty surrounding the storm's potential path [86]. The advisory files are in a *.kmz* format, which can be easily viewed using the *Google Earth* software [87]. As an example, Figure 4.2 shows the predicted track and uncertainty cone for the 2017 hurricane *Maria*.

The NHC produces numerous forecasts during a hurricane's life-cycle, leading to the generation of a substantial number of tracks and cone files. For instance, in the case of Hurricane *Maria* in 2017, 59 forecasts were produced. To manage this large volume of data, all the information extracted from the archive was recorded in two *.csv* files: one for the hurricane predicted track information and another for the uncertainty cone.

Table 4.3 illustrates the forecast track .csv file for 2017 Hurricane *Maria*. It provides comprehensive information about the forecasted tracks of the hurricanes. The columns *longitude* and *latitude* specify the predicted positions of the forecasted points, while the *category* column represents the hurricane category forecasted for the respective date as recorded in the *date* column. The *category* feature is comprised of ten categories, including *initial*, which denotes the starting point of the forecasted track; *d* for tropical depression, which are storms with

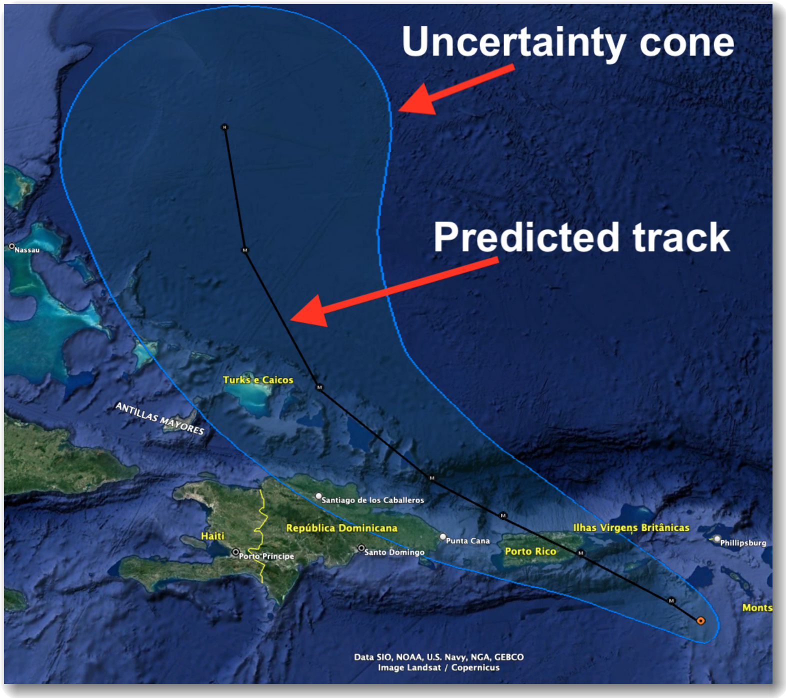


Figure 4.2 Forecast data for the 2017 hurricane *Maria*.

wind speeds less than 39 mph; *s* for tropical storm, with wind speeds ranging from 39 mph to 73 mph; *h* for hurricane, equivalent to hurricane categories 1 or 2 with wind speeds between 74 mph and 110 mph, according to the *Saffir-Simpson Hurricane Wind Scale*; *m* for major hurricane, equivalent to hurricane categories 3, 4, or 5, with wind speeds exceeding 110 mph; and *l* for remnant low, which is a post-tropical cyclone with maximum sustained winds less than 39 mph. Additionally, *xd*, *xs*, *xh*, and *xm* represent the extratropical versions of tropical storms, which are referred to as extratropical when they lose their tropical characteristics, but can still have winds of hurricane or tropical storm force as per the NHC [88].

Table 4.3 Example of the extracted forecasted track for the 2017 hurricane *Maria*

longitude	latitude	category	tau	date	maxWind	windGusts
-63.1	16.3	initial	3h	2017-09-19 12:00:00 UTC	140 knots	170 knots
-64.1	17.0	m	12h	2017-09-20 00:00:00 UTC	140 knots	170 knots
-65.7	18.0	m	24h	2017-09-20 12:00:00 UTC	135 knots	165 knots
-67.1	18.8	m	36h	2017-09-21 00:00:00 UTC	125 knots	150 knots
-68.4	19.6	m	48h	2017-09-21 12:00:00 UTC	125 knots	150 knots
-70.5	21.5	m	72h	2017-09-22 12:00:00 UTC	120 knots	145 knots
-72.0	24.5	m	96h	2017-09-23 12:00:00 UTC	105 knots	130 knots
-72.5	27.5	h	120h	2017-09-24 12:00:00 UTC	95 knots	115 knots

The *tau* column designates the forecast time in hours from the advisory issue time. The *maxWind* and *windGusts* columns show the predicted maximum wind speed sustained for at least a minute and the maximum wind speed during sudden increases, respectively.

Regarding the uncertainty cones, the files contain sets of points that form the cone shape. As an example, Table 4.4 showcases an uncertainty cone .csv file that was included in one of the 2017 hurricane *Maria* advisories. It contains the points that shape the cone presented on the Figure 4.2.

Table 4.4 Example of the extracted predicted uncertainty cone for 2017 hurricane *Maria*

#	longitude	latitude
1	-63.18616	15.97806
2	-63.17434	15.97578
3	-63.13472	15.97255
4	-63.10625	15.97255
⋮	⋮	⋮
1739	-63.25117	15.99986
1740	-63.24123	15.99502
1741	-63.209	15.98371
1742	-63.18616	15.97806

The information from Tables 4.3 and 4.4 is used to provide the player with insights about the evolution of the hurricane category, and to recreate the NHC advisories that are commonly used in humanitarian logistics operations. Similar to real-life, the game issues advisories that include the forecast information for active storms, which are updated every 6 hours. When a storm falls below the tropical depression category, no more advisories are released until the storm once again reaches a warning category.

Uncertainty cones resolution and data processing

Reproducing the forecasts in the game proved to be a challenging task, particularly in regard to the uncertainty cones. The NHC represents the cones through a series of connected points that create a cone shape, as shown in Table 4.4 and Figure 4.2. Each uncertainty cone is composed of several points. In the case of Figure 4.2, 1,742 points are used to draw the depicted uncertainty cone.

To render the cones in the game, the point files are read and loaded into memory during the preparedness phase to ensure that the player does not experience any game slowdowns caused by file readings. Once all the points are loaded, the game manages to render each forecast accurately. However, due to the high number of points required to generate every single cone, the game's performance was significantly impacted, particularly when multiple hurricanes and forecasts were generated simultaneously. Additionally, the large number of points resulted in a significant increase in memory usage, which undermined the game's accessibility and playability on less powerful computers. Therefore, to maintain the game's accessibility and improve performance, it was necessary to reduce the number of points required to generate each cone to a manageable level.

The reduction method process the cone files and produce new ones with a reduced number of points. It starts by selecting the first point in the cone file, adding it to a list of selected points. The process then proceeds by scanning each subsequent point in the file, calculating its Euclidean distance to the last selected point. If that distance is smaller than a predefined *min_distance* threshold, the scanned point is discarded. Otherwise, that point is selected for rendering. This process ends after scanning all points from the uncertainty cone file. Figure 4.3 illustrates the original cone file points compared to the output of the reduction method.

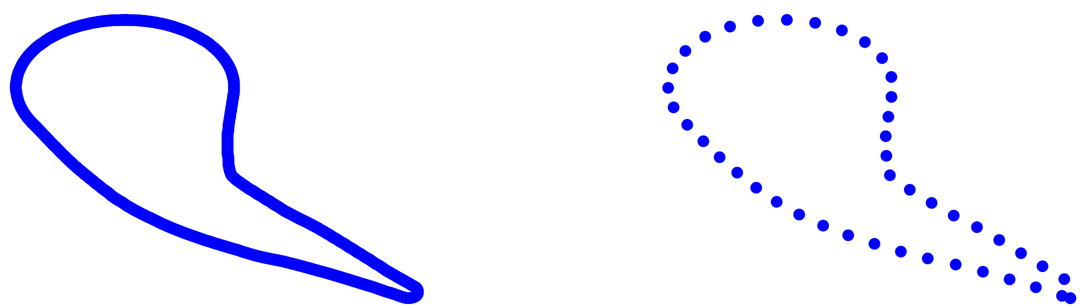


Figure 4.3 Illustration comparing the cone shapes of the original and reduced files for Hurricane *Maria*'s uncertainty cone in 2017

The *min_distance* threshold was determined through empirical analysis with the goal of reducing the number of points to improve the game's performance while still preserving the overall aspect of the original uncertainty cone. A value of $min\_distance = 1$ was judged as satisfactory leading to an average point reduction of 94%.

Combining IBTrACS data to NHC data

In the NHC advisory images, each forecasted track has a point that represents the hurricane location at the time of the advisory issue. This point is crucial for understanding the forecast, as the advisory does not display the actual hurricane on the map. In contrast, the *HurricaneLog* game presents both the forecast and the hurricane, thanks to the combination of information from different databases, which enables an accurate simulation of the forecasted movement and of the progression of each storm.

However, this combination of data sources sometimes leads to discrepancies. By combining the hurricane movement and category information with the NHC forecast advisory data, some inconsistencies were found. For example, the forecast initial point (orange point in Figure 4.2) might not align with the hurricane's actual position. At a given time t, the hurricane's location could be l_h according to the IBTrACS database, while the forecast initial point would be at location l_f. This mismatch is most noticeable when the forecast initial point is ahead of the actual hurricane position, which could cause confusion for the players.

Furthermore, inconsistencies were also found between the hurricane movement sampling time and the forecast advisory issue time. For example, the hurricane movement data might be issued every six hours starting at 6 a.m., while the first NHC forecast advisory might be issued at 8 a.m. and produced every six hours thereafter. This makes it difficult to verify that the data matches. This misalignment between the hurricane and the forecasted tracking points was perceived as an issue in the game and needed to be addressed.

To address all these issues, a data processing step was implemented. This step assumes that the IBTrACS data is correct, and modifies the NHC forecast advisory data accordingly. In cases where the advisory data and IBTrACS hurricane data issue time match, the forecast track and uncertainty cone positions were translated to the hurricane position. As such, the initial point of the forecast track was moved to the hurricane's position, and the following forecast track elements were adjusted accordingly. When the issue times differ, the process estimates the hurricane's position at the time of the forecast advisory and updates the forecast elements accordingly.

For example, a forecast advisory may be issued at 8 a.m., while the available hurricane position data was issued only at 6 a.m. and 12 p.m. at two different locations, l_{h1} and l_{h2}, respectively. To estimate the hurricane's position at the time of the forecast advisory, the data processing step calculates the hurricane's velocity between the two data points (l_{h1} and l_{h2}) and then multiplies that velocity by the time difference between the hurricane position data and the forecast advisory issue.

The velocity (v) between the two hurricane data points l_{h1} and l_{h2} can be calculated as $v = ||l_{h1} - l_{h2}|| \times (12 - 6)$, where $||l_{h1} - l_{h2}||$ represents the distance between the two hurricane position data points, which can be calculated using a distance formula. The factor $(12 - 6)$ represents the time difference between the two data points, which is six hours in this example.

Once the velocity (v) is calculated, the estimation the hurricane's position (l_{hf}) at the time of the forecast advisory is made by adding the velocity multiplied by the time difference to the location of the first hurricane position data point (l_{h1}). In our example, the estimated position l_{hf} would then be given by $l_{hf} = l_{h1} + v \times (8 - 6)$.

Selecting the simulated world area

The game simulates the occurrence of Atlantic hurricanes. However, due to the vast expanse of the world that experiences hurricanes and the game's focus on a limited number of nations, only a portion of the region could be included in the game. To ensure an entertaining and challenging experience for players, this selection process prioritized the region with the highest frequency of hurricanes.

Figure 4.4 displays the areas with the highest density of tropical storms in September over a 100-year period, as reported by the NHC [89]. The figure highlights that the region with the highest incidence of hurricanes (in red) is located near the Caribbean. *HurricaneLog* simulates this area and its extension to the east to offer players a better chance of witnessing storms approaching the game's nations.

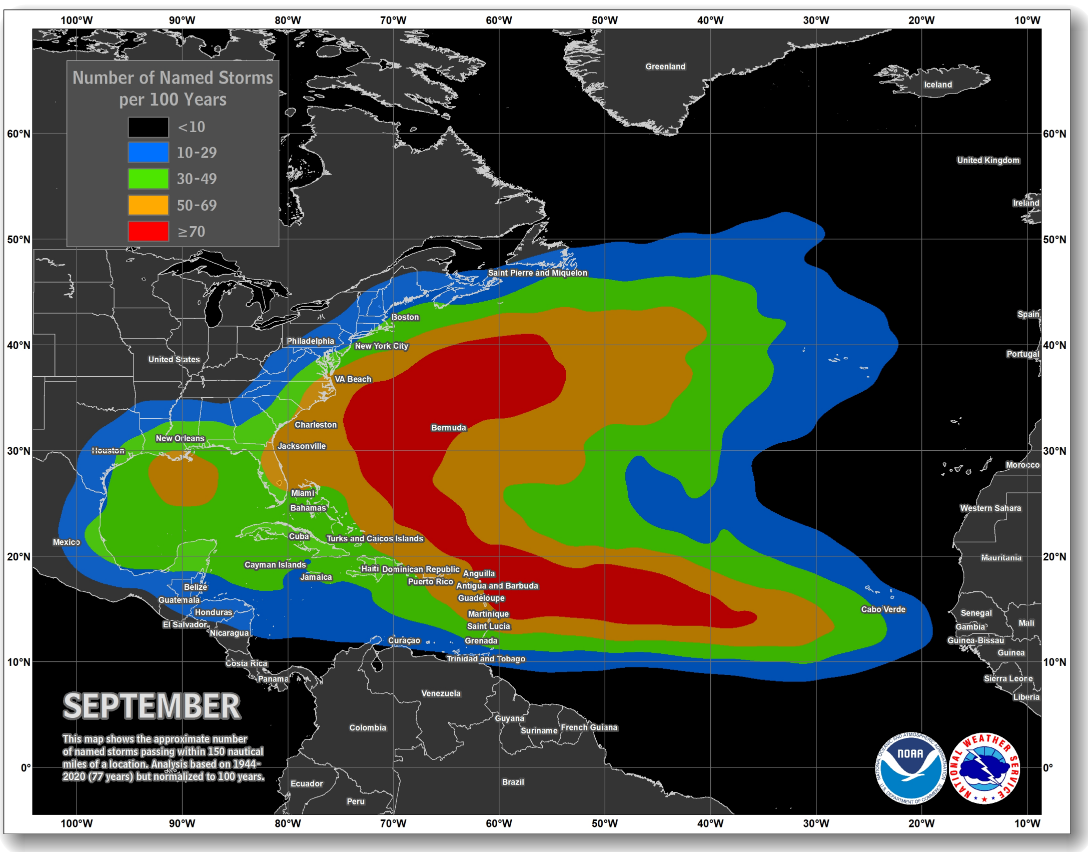


Figure 4.4 Area where tropical cyclones tend to occur during the most intense month of the hurricane season.

Converting world coordinates to Game coordinates

To incorporate data from both IBTrACS and NHC sources into the game, a final step was necessary - converting world coordinates (latitude, longitude) to corresponding game environment coordinates. This conversion step involved defining height and width ratios, represented as h_r and w_r, respectively, where $h_r = h_g/h_m$ and $w_r = w_g/w_m$. The height and width of the game area were denoted as h_g and w_g, while the height and width of the selected world map area were denoted as h_m and w_m. These ratios were used to translate the coordinates as follows: Given a point location (p_x^m, p_y^m) on the world map and the centre of the world map area (c_x^m, c_y^m), the corresponding point location (p_x^g, p_y^g) in the game map was obtained using the following equations:

$$
\begin{aligned}
p_x^g &= (p_x^m - c_x^m) * w_r \\
p_y^g &= (p_y^m - c_y^m) * h_r
\end{aligned}
\tag{4.1}
$$

Figure 4.5 demonstrates the outcome of a translation operation from real geographical data to *HurricaneLog* game coordinates. The left picture depicts the forecast in the real world map, while the right picture shows the forecast translated to the game.

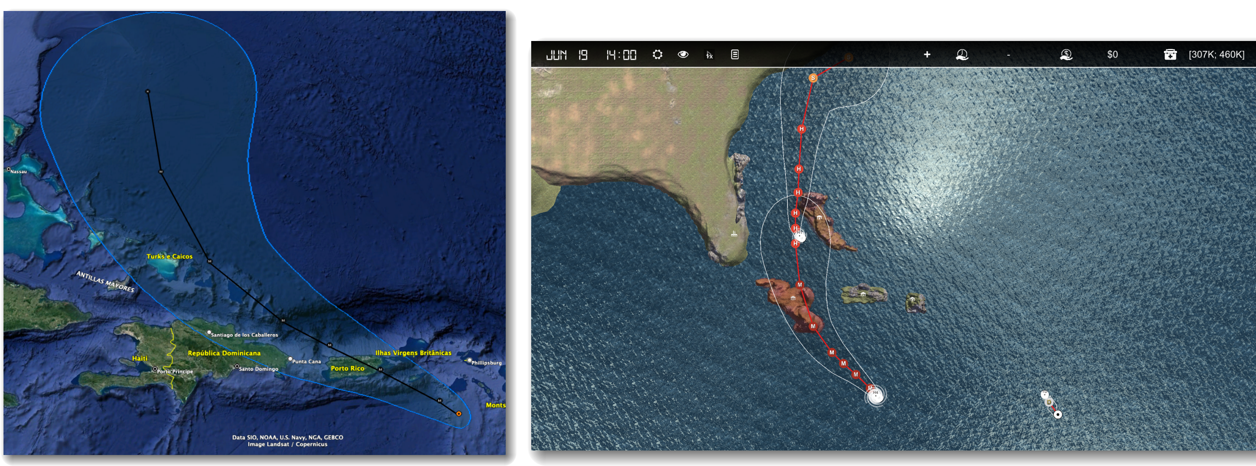


Figure 4.5 Portrayal of the forecast observation for the 2017 hurricane *Maria* in the world map and translated to the game map.

4.1.3 Damage

Natural disasters, such as hurricanes, can cause devastating damage to populated areas, leaving communities in a state of crisis. It is crucial for humanitarian operations to quickly and accurately determine the extent of damage caused by a hurricane to provide assistance to those in need. However, accurately assessing the damage caused by a hurricane can be incredibly challenging, particularly in a game or simulation.

The complex interaction between the destructive nature of a hurricane and the resilience of societies makes it difficult to predict the extent of damage that may be inflicted upon a populated area. The strength of the hurricane, the resilience of the infrastructure in the affected region, the preparedness of the local population and emergency services, besides other factors can all have a significant impact on the level of caused destruction.

Replicating this complexity in a game or simulation requires a great deal of skill and attention to detail thereby ensuring that the realism of the situation is maintained. This involves accurately modeling the various factors that influence hurricane damage, such as wind strength, storm surge, rainfall, and flooding, as well as the societal factors that impact the preparedness and resilience of the affected population. However, the complexity of accurately modeling these factors pose a significant challenge to the development of the game, requiring in-depth knowledge about hurricanes.

One possible approach to accurately simulating the effects of hurricanes in a game, while reducing the problem complexity, is to use data from previous hurricane damage events. By analyzing historical data on the impact of hurricanes on populated areas, game designers can identify patterns and trends that can inform the simulation of future events.

For example, if a given nation was hit by a category three hurricane in the past, and 30% of their population was affected, this data can be used to inform a simulation of damage caused by a similar hurricane in the future. By determining that 30% of the population will be affected by a category three hurricane in that nation, game designers can create a more realistic and accurate simulation that accurately reflects the damages caused by the hurricane.

Building on this concept, Balcik et al. [67] proposed a straightforward solution for determining hurricane damage to a studied area. Their damage simulation approach can be summarized as follows: Let P be the total population of the affected nation, L be the maximum percentage of that population affected by a hurricane in the past, and h be a random variable that depends on the hurricane category. The resulting damage d_f incurred to the region by a hurricane of category f is then calculated using Equation 4.2.

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

where:

$$h_f = \begin{cases} [0.5, 1.0], & \text{for } 4 \leq f \leq 5 \\ [0.2, 0.5], & \text{for } f = 3 \\ [0, 0.2], & \text{otherwise.} \end{cases} \tag{4.2}$$

This simulation approach provides a useful framework for estimating the potential damage caused by a hurricane based on the characteristics of the affected region and the severity of the hurricane. Moreover, it is consistent with the *Saffir-Simpson Hurricane Wind Scale* described by the NHC [90]. This scale defines as category 1, hurricanes that yield some damage, as category 2 those causing extensive damage, category 3 those causing devastating damage, and categories 4 and 5 extreme hurricane causing catastrophic damage. This damage simulation was hence adopted in the *HurricaneLog* game.

In the context of simulating the effects of hurricanes in the game, obtaining data on the impact of previous hurricane events is crucial for accurately estimating potential damage caused by future events. The EM-DAT is a valuable resource for collecting information on disaster events, including hurricanes, from 1900 to the present day. This database allows for vulnerability assessment and priority setting in humanitarian action at national and international levels. To collect data on the impact of hurricanes in the Caribbean region, the location filter feature in EM-DAT was used.

While the data collected from EM-DAT can provide information on the number of people affected by a hurricane event, further data on population size is necessary for accurately estimating the greatest percentage of the population affected by a tropical storm. This population size data was obtained from the World Bank Open Data database, which records statistical data on countries around the world. By combining the population size data with the number of people affected obtained from EM-DAT, the greatest percentage of population affected by a tropical storm can be determined, which is necessary for calculating hurricane damage using (4.2).

In addition to simulating the effects of a hurricane on a population, it is also important to simulate the effects on the humanitarian supply chain. The game simulates the loss of relief items in a warehouse on the occasion of a hurricane strike event using the model proposed by Rodríguez-Pereira et al. [74]. According to this model, the loss of relief items depends on the hurricane category, with half of the relief items being lost for hurricanes of categories 4 and 5, 20% lost for hurricanes of category 3, and 0% lost otherwise. This provides a realistic and accurate simulation of the impact of a hurricane on the humanitarian supply chain.

4.2 Islands

The accurate representation of islands is crucial to the success of the game, as it aims to provide players with a realistic and challenging gaming experience that reflects the particular characteristics of the different nations that compose the Caribbean region. That region is known for its vulnerability to recurrent Atlantic hurricanes, which can have devastating effects on the islands and their populations depending on factors such as their risk level and economic condition.

To determine each nation's risk level, we used the INFORM risk index [91], which considers various factors such as hazard exposure, vulnerability, and lack of coping capacity. Similarly, the GNI per capita was used to determine each nation's economic condition. The data used in this analysis was obtained from the World Bank Open Data database.

We aimed to create a comprehensive representation of the Caribbean nations by including islands with varying combinations of risk levels and economic conditions. This included islands with low risk levels and high economic conditions, low risk levels and medium economic conditions, medium risk levels and low economic conditions, and high risk levels and low economic conditions. The selection of these profiles was crucial in providing a realistic representation of the Caribbean region, where islands with high risk levels and low economic conditions are more vulnerable to the impact of natural disasters.

Figure 4.6 provides a visual plot of the Caribbean nations according to their 2017 GNI per capita and risk level. This graph helped us identify the islands that better fit into our desired profiles.

4.2.1 Selection according with the islands profiles

Players assess the nations in the *HurricaneLog* game by means of their population sizes, economic conditions, and levels of risk. In addition to this data, the logistic performance metric is also included as part of the nations' profiles, serving to benchmark their performance on trade logistics and identify areas for improvement. It is based on a survey of operators and combines qualitative and quantitative measures to create profiles of logistics friendliness for countries, offering both international and domestic perspectives [92]. By observing this index, players should decide if an island requires logistical investments.

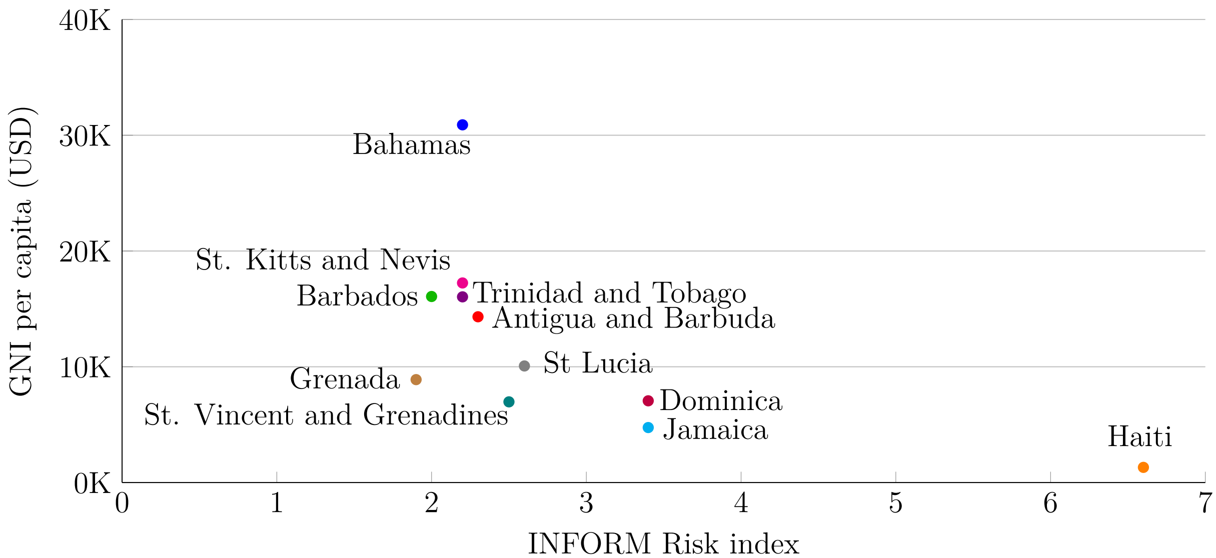


Figure 4.6 Plot of the GNI per capita and risk index of Caribbean islands (source: World Bank Open Data, 2017).

The data used for the logistic performance index was obtained from the World Bank Open Data database. However, this information is not available for all islands in the database. The nations whose data regarding the logistic performance index was not available were discarded from our analysis. Finally, we selected the following islands according to the desired profiles: the Bahamas (low risk, high economic condition), Trinidad and Tobago (low risk, medium economic condition), Jamaica (medium risk, low economic condition), and Haiti (high risk, low economic condition).

To ensure a realistic and challenging gaming experience that accurately reflects the complexities of the "real" Caribbean region, we also considered as much as possible the location of the selected islands. We took into account the consistent risk index and hurricane hit likelihood based on the game's hurricane trajectory. Figure 4.7 illustrates how we assigned the final profiles to the game islands. By carefully selecting and assigning diverse island profiles, we were able to create a gaming experience that realistically simulates the characteristics of the region as well as the challenges associated with humanitarian logistics operations during the Atlantic hurricane season.

It is important to note that the islands in the *HurricaneLog* game have fictional names and geography. This intentional deviation from real-world details is implemented to prevent players, particularly those with knowledge of the Caribbean region and its history of hurricanes, from making decisions based on actual events rather than the characteristics provided in the game. Our goal is for players to evaluate the different island profile indicators and make

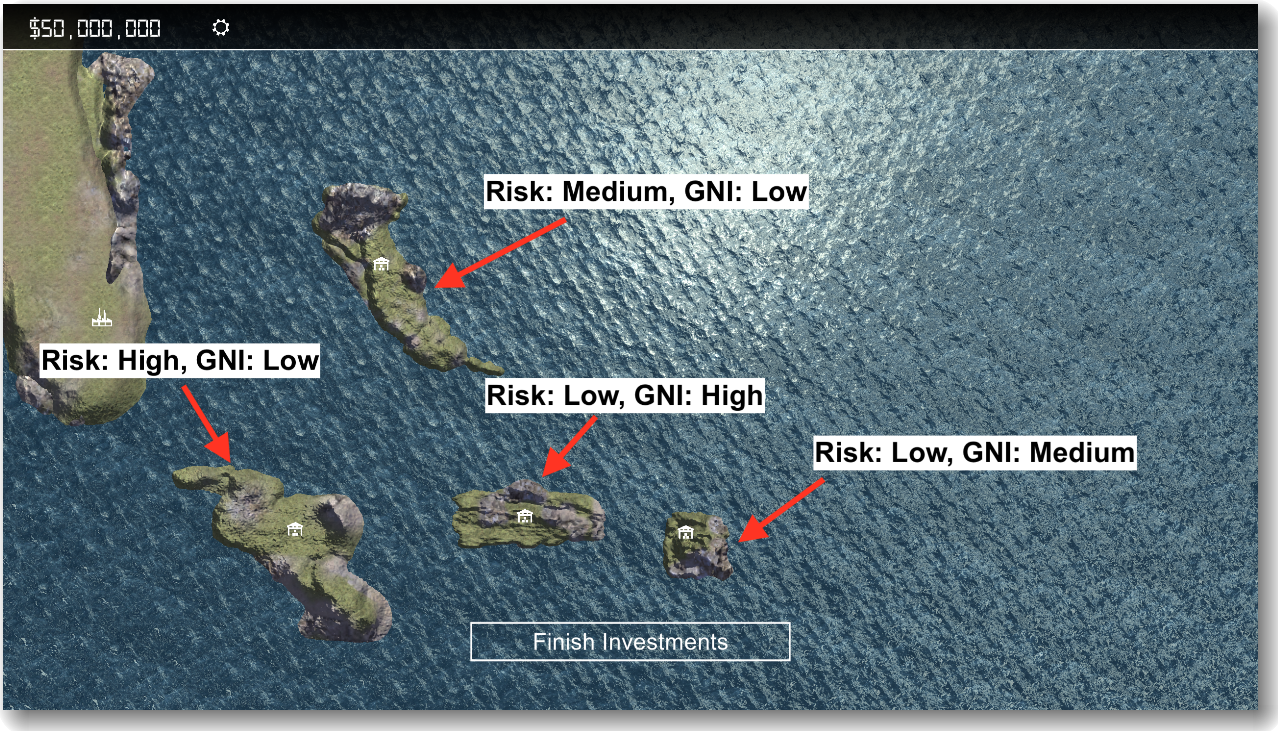


Figure 4.7 Illustration of the selected profiles assignment to the game islands.

preparedness decisions based on the simulated data within the game environment.

4.3 Response phase processes

The operations of a humanitarian supply chain are crucial for the success of the response phase. In the game, they are simulated as processes and, as such, given their importance, they must be simulated as best as possible. Their costs, time duration, limitations, and ordering were estimated through several discussions with humanitarian logistics professionals, and from specialized publications in the domain.

For the majority of these processes, the time duration and costs are linked to the amount of family kits handled per unit of time. Therefore, for the remaining of this section, capacities will be addressed together with time and cost.

4.3.1 Process times

The game processes reproduce the transfer of family kits between islands. Some processes are directly linked to family kit management activities, while others represent setbacks that occur during the transfer operation. All the existing processes in the game are listed below.

- *Inland distribution*: is the actual distribution of family kits to the people in need.
- *Transport procurement*: is the process of finding a transportation vehicle (airplane or ship) to transport family kits.
- *Transport preparation*: represents the preparation and loading of family kits inside the procured transportation vehicle.
- *International transportation*: corresponds to the actual transportation of family kits between the origin and destination islands.
- *Unloading shipment*: denotes the process of unloading the shipment at the destination island. It encompasses the unloading of the family kits from the plane or ship to the border customs.
- *Custom clearance*: corresponds to the process performed at the destination border to ensure that all documents and products agree with the island regulation laws.
- *Transport to warehouse*: represents the process of moving family kits from ports or airports to the warehouse.
- *Family kits international preparation*: is the preparation of family kits by international suppliers.
- *Repair of ports and airports*: is the actual repair of ports and airports after a hurricane hit.

Each of these processes has an execution time that must convey with their real counterparts. In the following sections, we will explain in detail the activities involved in the above processes and how we determine their duration.

Inland distribution 

The inland distribution process involves handling and transporting family kits to the affected families in the areas affected by the hurricanes. The handling activity involves the loading and unloading of family kits into trucks. According to Patrisina et al. [75], the trucks commonly used in relief operations are able to carry either 4 or 1.5 tons. Moreover, Wisetjindawat et al. [76] assumes that it takes 70 minutes to manually load or unload a 4-ton truck at a non-warehouse facility and 20 minutes at a warehouse with forklifts. The game assumes the use of 4-ton trucks in the distribution process, and the handling time is assumed to be 1 hour, which can be reduced through investments.

The transport activity assumes that the warehouses are 90km from the distribution location and that a truck travels at an average speed of 60km/h. Thus, we estimate the truck takes 1.5h to connect these two facilities. In addition, the game considers that the family kits distribution once at the destination takes 1h to complete. Finally, assuming the truck is busy until it returns to the warehouse, the total transport time is estimated in 4 hours.

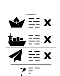
Initially, nations do not have trucks immediately at their disposal. When necessary, 8 trucks can be obtained after 48 hours. It is assumed that each truck can make 15 trips per week, carrying 200 family kits each. This capacity value is based on the assumption that the volume of family kits that fit into a container also fits in a four-ton truck. According to Balcik et al. [67], each 20-foot container can carry 200 family kits. Therefore, the basic distribution capacity assumes the value of 25,000 family kits per week.

The total inland distribution time t_d in hours, given a demand for family kits k_d and a distribution capacity c_d, is calculated as follows:

$$t_d = 168 \times \frac{k_d}{c_d}. \tag{4.3}$$

The result of the division is multiplied by 168 in the equation to convert its scale from weeks to hours.

Investments in trucks and handling equipment can reduce the inland distribution time and increase the distribution capacity. These investments will be discussed in Section 4.4.1.

Procurement 

The procurement process is responsible for finding vehicles for the international transport of family kits. This process has two possible durations of time depending on the player's investments. If the nation has already acquired its own fleet of transport vehicles through investments, the procurement process is not necessary, and its processing time is then zero. Otherwise, the processing time is sampled from a normal distribution with a mean of two days and a standard deviation of 0.5 days. The use of a normal distribution introduces a stochastic element to the game, making the process more realistic and reflecting the uncertainty that exists in humanitarian logistics operations. It is worth noting that the actual procurement time in real-world scenarios can vary widely depending on various factors, such as the availability of transport vehicles, bureaucratic procedures, and negotiation time with suppliers.

The game's procurement process aims to provide a simplified but realistic representation of the process.

Preparation

The preparation process involves preparing the family kits in the warehouse for shipment, transporting them to a shipping point (port or airport), and loading them onto the selected means of transport. The total process time corresponds to the sum of these activities.

The first part of the process (handling) is the same as in the inland distribution process, and takes 1 hour in the game. Next, transportation from the warehouse to the port or airport is assumed to be a round trip, and takes 1 hour.

Loading family kits into the chosen transport mode involves the use of containers, with each truck carrying one container. The loading time is based on the time required to load a container into the transport vehicle. After consulting with logistics professors at HEC Montréal, we initially set the loading time to 30 minutes for planes and 20 minutes for ships. However, after conducting stress tests, we found that loading times of 30 minutes were more appropriate for both ships and airplanes. This decision was made because in scenarios with high numbers of family kits, the ship transport became faster than the airplane, which was not in line with the game's goal of accurately simulating the relative speeds of the two modes of transport.

In the game, the preparation process for shipping is considered a form of distribution and uses the nation's distribution capacity to determine its processing time. However, the distribution capacity is based on a 5-hour calculation (1 hour for handling + 4 hours for inland transportation and distribution), while the preparation process only takes 2.5 hours (1 hour for handling, 1 hour for transportation, and 0.5 hours for loading). Therefore, an adaptation to the reduced processing time was necessary. This adaptation is calculated using four variables: t_h for warehouse handling time, t_i for inland transportation time, t_s for international shipment time, and t_l for container loading time. The formula for the capacity adaptation, denoted as c_p, is 4.4.

$$c_p = c_d \times \frac{t_h + t_i}{t_h + t_s + t_l} \tag{4.4}$$

Once the adapted distribution capacity c_p is obtained, the time t_p in hours to prepare the family kits n_{kits} selected by the player is calculated as:

$$t_p = 168 \times \frac{n_{kits}}{c_p} \tag{4.5}$$

Thus, *HurricaneLog* accurately simulates the time it takes to prepare family kits for shipment in a realistic manner.

International transportation

Once all family kits have been loaded onto the ship or plane, they are transported to the destination island. The duration of this process varies depending on the mode of transportation, the origin and the destination nations.

Experts interviewed in [56] suggested that implementing different travel times between regions could improve the game experience. To achieve this, *HurricaneLog* uses location information to determine varied and realistic travel times.

For plane travel times, values were obtained from [93], which provides estimated travel times between two airports based on the great circle distance and the average airspeed of a commercial airliner. The airports were determined using information from [94]. When there were multiple airports in a given nation, the busiest one in terms of passenger traffic per year was selected. The flight time for international suppliers was set to eight hours. The resulting travel times, presented in hours, are shown in Table 4.5.

Table 4.5 Plane travel times in hours between the game islands and the continental international supplier.

	Trinidad & Tobago	Bahamas	Haiti	Jamaica	Int. Supplier
Trinidad & Tobago	0	3.37	2.35	2.95	8
Bahamas	3.37	0	1.55	1.42	8
Haiti	2.35	1.55	0	1.22	8
Jamaica	2.95	1.42	1.22	0	8
Int. Supplier	8	8	8	8	0

The ship travel times were provided by Rodríguez-Pereira et al. [74]. To calculate these times, they determined the distance between all pairs of Caribbean countries and divided them by an assumed travel speed of 20 knots. The resulting travel times, presented in hours, are shown in Table 4.6.

The study conducted by Rodríguez-Pereira et al. [74] did not provide information on travel times for international suppliers using ships. As a result, it was necessary to estimate these times based on the travel times of international suppliers using planes. By calculating the

Table 4.6 Ship travel times in hours between the game islands and the continental international supplier.

	Trinidad & Tobago	Bahamas	Haiti	Jamaica	Int. Supplier
Trinidad & Tobago	0	67.20	52.80	50.40	159.52
Bahamas	67.20	0	28.80	33.60	159.52
Haiti	52.80	28.80	0	14.40	159.52
Jamaica	50.40	33.60	14.40	0	159.52
Int. Supplier	159.52	159.52	159.52	159.52	0

average difference between ship and plane travel times, it was found that ship times are, on average, 19.94 times greater than plane times. Consequently, that relation was used to set the ship travel time from the continental international supplier to the islands to 159.52 hours.

Unloading

Upon arrival at the destination, the shipments are unloaded from the transportation vehicle and passed through border customs. Since the game considers border customs to be located at the entry port, the unloading process is essentially the same as the loading process described before. Therefore, the game assumes the same execution time for unloading a container as for loading, i.e., 30 minutes for both planes and ships.

The procedure to determine the total unloading processing time follows the same principle as before too. The distribution capacity c_d of the destination island has to be adapted to the unloading reduced execution time. This adaptation is calculated using three variables: t_h for warehouse handling time, t_i for inland transportation time, and t_f for the container unloading time. The formula for the capacity adaptation for the unloading process, denoted as c_u, is given by:

$$c_u = c_d \times \frac{t_h + t_i}{t_f} \tag{4.6}$$

Once the adapted distribution capacity c_u is obtained, the time t_u in hours to unload n_{kits} family kits from the transportation vehicle is calculated as:

$$t_u = 168 \times \frac{n_{kits}}{c_u} \tag{4.7}$$

Customs clearance

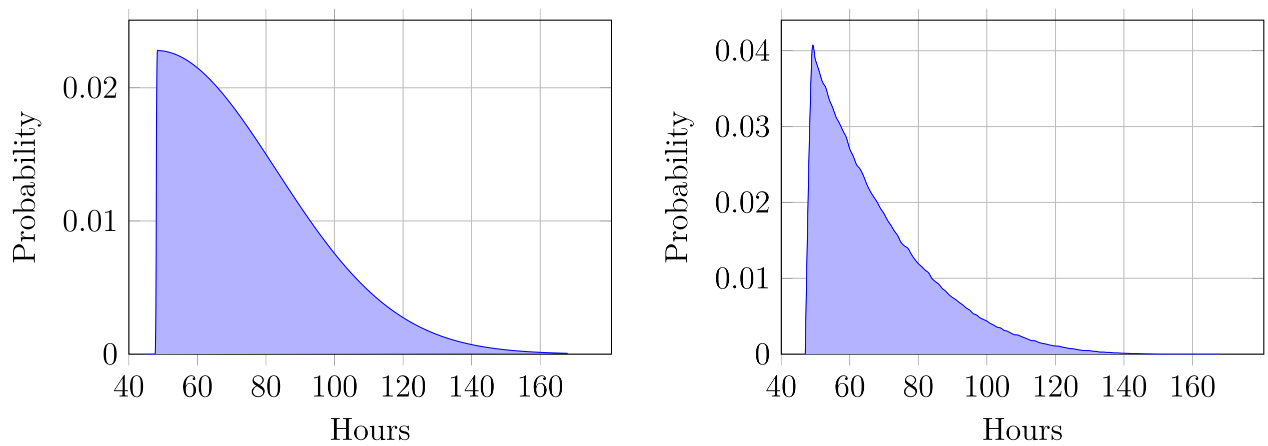
The customs administration is responsible for ensuring compliance with various laws and regulations. It prevents the importation of illegal and hazardous goods and prohibited transactions, as per the World Trade Organization's commitments [95, 96]. Processing times for customs clearance vary based on constraints such as regulations, procedures, resources, and capacity [97].

To determine the customs clearance processing times in the game, we considered data from previous humanitarian response operations. According to Braman [77], relief items for an earthquake in Lagos were processed in either 24 hours or three days. In survey interviews conducted by Gull [78] with humanitarian agencies and agents, waiting times were reported to vary between 24 and 168 hours, with some respondents reporting waiting times between 7 and 21 days.

The examples demonstrate that customs clearance processing times are unpredictable, and as such, the processing time for the game's customs clearance should be modelled as a random variable that simulates real-world process disruptions. To ensure realistic time variation, that random variable is designed to have values within a defined interval, denoted by $[a, b]$, such that the probability of the variable's value being between a and b is 1. Moreover, process disruptions represented by that random variable should occur at a realistic rate. Specifically, the random variable should assign higher probabilities for completing the custom clearance task early in the interval (two days) and lower probabilities for completing it at the end of the time interval (seven days), which represents significant delays due to missing documentation, for instance.

After considering several probability distributions that can describe this behavior, the Skewed Normal [98] and PERT-*Beta* [99] distributions were identified as promising candidates. These distributions can be parameterized to have higher probabilities for values closer to the beginning of the interval and lower probabilities for values closer to the end of the interval, as shown in Figure 4.8.

The Skewed Normal distribution function features a gradually decreasing probability curve when approaching the right end of the interval. The curvature was determined through empirical tests on the shape, location, and scale parameters, resulting in specific values of 300, 48, and 35, respectively. This distribution is interesting to model the custom clearance processing times as it allows for a greater probability of completing the task closer to the beginning of the interval, indicating minor errors in the process. However, having the random variable described by this distribution yields values outside the desired interval $[a, b]$,



(a) Skewed normal distribution

(b) PERT-*Beta* distribution

Figure 4.8 Skewed Normal and PERT-*Beta* distributions adapted to the interval of 2 to 7 days.

particularly close to b. Additionally, the highest probability of the curve is not at the start of the interval, as desired. Finally, determining the best parameter values to describe the desired random variable is challenging. Therefore, we decided to not use this distribution in the game.

The PERT-*Beta* distribution curve simplifies the parameterization through three variables: the minimum value a, the mode m, and the maximum value b. This ensures that the random variable does not assume values outside the interval. However, its drawback is that the minimum value of the interval, parameterized by a, becomes impossible to achieve, which may not be desirable for some applications. For example, in the game, the starting value of the interval must have a non-zero probability. To address this, the parameters of the distribution had to be adjusted to ensure that the minimum value of the interval has non-zero probability to occur while still maintaining zero probability for values outside the interval. Figure 4.8b depicts an example of the PERT-*Beta* distribution using adjusted values of $a = 47.9$, $m = 48$, and $b = 168$.

Although the PERT-*Beta* distribution has a simplified parameterization, its decay is more abrupt, resulting in a decreased susceptibility to delays in the process. In this case, such behaviour is considered a disadvantage.

To take advantage of the benefits of both distributions, an adaptation was created that has a decay similar to the Skewed Normal distribution and allows for an exact definition of the interval as in the PERT-*Beta* distribution. Figure 4.9 provides an example of this distribution for the processing time interval from 2 to 7 days.

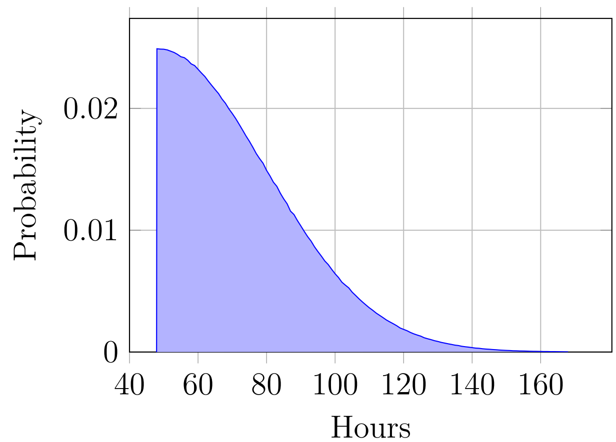


Figure 4.9 Distribution adapted to the game.

Finally, the initial custom clearance processing time interval was set to 2 to 7 days. The game allows to reduce this processing time through investments.

Transport to warehouse

Once the family kits are approved by customs administration, they are transported to the nation's warehouse. In the game, this step is referred to as "transportation to the warehouse". Unlike the preparation process, it does not involve any loading activities. The transportation time for this step is defined as one hour for handling the kits, in addition to another hour for the round trip by the transport vehicle.

As in the previous processes, its total duration is dependent on the number of family kits being transported and on the island's distribution capacity. To calculate the process duration, the distribution capacity c_d of the destination island has to be adapted to the new reduced execution time. This adaptation is calculated using three variables: t_h for warehouse handling time, t_i for inland transportation time, and t_q for the transport vehicle round trip time. The formula for the capacity adaptation for the transport to warehouse process, denoted as c_w, is given by:

$$c_w = c_d \times \frac{t_h + t_i}{t_h + t_q} \tag{4.8}$$

Once the adapted distribution capacity c_w is obtained, the time t_w in hours to transport n_{kits} family kits to the warehouse is calculated as:

$$t_w = 168 \times \frac{n_{kits}}{c_w} \tag{4.9}$$

This process finalizes the transfer activities between two nations. However, as previously mentioned, players can request family kits from international suppliers.

Family kits international preparation 

When a request for family kits is made from international suppliers, the total time of the shipping process depend on the level of investment made during the preparedness phase. If a player has invested in agreements with international suppliers, the family kits, up to the agreed number, are immediately shipped. However, if the number of family kits exceeds the agreed amount, the preparation time is determined by sampling from a Normal distribution with a mean of 17.5 days and a standard deviation of 1.

To ensure timely delivery of family kits, it is important for players to carefully consider their investment levels and agreement terms with international suppliers. A higher level of investment may result in faster shipping times and fewer delays in receiving family kits. Additionally, players should consider the potential impact of delays on their overall strategy and adjust their investment levels accordingly.

Fixing ports and airports 

The last process is the fixing of ports and airports, which occurs after a hurricane hits a nation then damaging its infrastructure. To determine the execution time of this process, we consulted the work of Balcik et al. [67], which indicates that in the first three days after a hurricane, affected warehouses are unable to send shipments by air to other nations. Additionally, Verschuur et al. [100] found that ports typically take about two days to recover after a hurricane. Based on this information, we have set the duration of the port and airport fixing process in the game to two days.

4.3.2 Process costs

The realistic simulation of the supply chain in the game requires the definition of costs based on actual logistics activities. This section outlines the costs associated with the game processes. Note that many of these costs are included in the preparedness phase investments. Therefore, only the costs directly associated with the response phase processes will be presented hereafter. Besides, processes not controlled by the player, such as the repairs of ports and airports, are not part of the player's performance indicators, and hence, are not described in this section as well. Indeed, considering how costs are computed is critical as they impact the final response operation cost and influence the player's decision-making.

International transportation

In the game, the transportation cost regarding international shippings is calculated based on the work of [67]. The authors used data provided by the IFRC, freight, and flight companies to estimate costs.

Table 4.7 shows the costs per family kit for air travel between pairs of nations represented in the game. The forward and backward costs are not necessarily equal (see [74]). They are determined based on average travel times discounted by the number of flights between the origin and destination islands. Besides, handling costs are added based on the origin island. They refer to expenses associated with warehouse handling, loading and unloading of family kits, and preparing customs documents. Thus, nations with higher labor costs present higher departure costs.

Table 4.7 Plane travel costs per family kit between the game selected nations.

	Trinidad and Tobago	Bahamas	Haiti	Jamaica
Trinidad and Tobago	0	93.31	114.85	88.56
Bahamas	81.53	0	112.15	87.72
Haiti	79.88	93.75	0	90.22
Jamaica	107.83	100.12	114.85	0

For maritime shippings, transportation costs are calculated based on freight costs obtained from [101]. Balcik et al. [67] estimated the cost of transporting containers of beauty and personal care commodities between each nation and added a fixed cost of $275 per container provided by IFRC. Table 4.8 reports these shipping costs for one family kit, including handling fees calculated based on origin labor costs.

It is worth noting that international suppliers have no associated shipping costs. They are included in the family kit price purchased from international suppliers through agreements.

Table 4.8 Ship travel costs per family kit between the game selected nations.

	Trinidad and Tobago	Bahamas	Haiti	Jamaica
Trinidad and Tobago	0	15.53	6.76	5.32
Bahamas	15.75	0	15.37	13.13
Haiti	6.61	15.01	0	5.25
Jamaica	5.26	12.85	5.32	0

Family kit international preparation

The family kit preparation process cost is embedded into the family kit price acquired from international suppliers. It includes handling and production costs. This cost is added as a penalty of 35% increase for family kits bought from international suppliers out of agreement amounts.

The Appendix C presents a summary of all capacities, costs and processing times used to simulate humanitarian operations within *HurricaneLog*.

4.4 Investments

Investments are one of the most important parts of the game. They link the preparedness phase to the response phase through their impacts on the operations. Therefore, their types, levels, impacts and costs were carefully selected through discussion with disaster risk management and humanitarian logistic professionals to provide an engaging, realistic and strategic experience to players.

All investments types in the game are listed below:

- *Preposition*: allows the pre-purchase of family kits, which can be stored in the local warehouse up to its capacity limit. These kits can be used to assist local populations or be transferred to another island in the region.
- *Warehouse Capacity*: corresponds to improvements on the local warehouse building infrastructure and inventory management. This investment increases the warehouse capacity and may reduce the loss of family kits in case of a hurricane damage. It also reduces the time required to prepare family kits for distribution.
- *Distribution Capacity*: stands for investments on the local distribution resources (e.g., volunteers, equipment for handling materials, trucks). It increases the capacity to distribute family kits items, resulting in lower distribution and transportation times.

- *Communication and Information Sharing*: refers to improvements in the communications between the operation's stakeholders. This investment influences the information accuracy regarding family kits storage and manipulation (e.g., amount stored in the warehouse, shipment requests).

- *Supplier Agreements*: represent investments in agreements with international suppliers. Theses investments guarantee immediate access to agreed amounts of family kits during response operations. Also, they affect their purchase price on orders made in the course of response operations.

- *Regional Transportation Agreements*: correspond to expenses made on agreements between the region's islands and transportation companies. These investments affect the waiting times to access transportation vehicles. The game simulates two transportation modes: planes and ships. Planes are faster than ships but are more expensive.

- *Customs Clearance and Sharing Agreements*: corresponds to improvements on trade facilitation agreements and on customs systems to improve importation processes among the islands. It affects the times required to process family kits on border entry points.

The following sections will discuss how each impact and costs associated to the investments were defined and how they were designed to create a dynamic link between the two game phases, i.e., preparedness and response.

4.4.1 Impacts and costs

Investments made in the preparedness phase of *HurricaneLog* influence the time performance of different processes in the game, ultimately leading to a reduction in the overall cost of the response operation.

However, achieving a balance between investing in the right areas and avoiding over-investing in unnecessary ones, or under-investing which leads to higher response phase costs, is crucial. Cost considerations should be an integral part of every investment decision. This necessitates strategic thinking and resource optimization by players to ensure effective investment decisions are made.

Preposition 

The preposition investment option allows players to purchase family kits in advance, thus indirectly reducing response times and operation costs in the game. While it does not directly impact any process in the response phase, having family kits readily available in the affected nation's warehouse speeds up the distribution process to affected populations.

In the game, each family kit costs $148, based on data from [67]. This cost does not include inventory holding expenses such as insurance, handling costs, and opportunity capital costs, which are estimated at 6% of the family kit's price.

Warehouse Capacity

The Warehouse Capacity investment option enables players to increase the storage capacity of family kits in the affected nation's warehouse. This investment has four levels that also affect the amount of lost family kits due to hurricane damages, as well as the warehouse processing times.

The first level[1] is the basic level that players have access without any sort of investment. It sets the warehouse's capacity at 12,000 family kits, which is the warehouse capacity used in the work of [67].

The second level provides a small improvement. It reduces the loss of family kits by 10%, handling times by 5%, and increases inventory capacity to 50,000 family kits. The associated cost is calculated based on the one-year rental cost of a 12,000 family kits capacity warehouse, which is obtained from [67]. Adjusting this cost to account for the increased capacity in the game yields a final cost of $600,000.

The third level reduces the loss of family kits by 20%, handling times by 10%, and increases inventory capacity to 100,000 family kits. The cost calculation uses the same method as the second level, which results in a cost of $1,200,000.

The fourth and last level offers the greatest improvement. It reduces the loss of family kits by 30%, handling times by 15%, and increases inventory capacity to 200,000 family kits. The associated cost, after calculating and rounding to the next thousand, is $2,600,000.

Distribution Capacity

Similarly to warehouse capacity, distribution capacity has four investment levels that promote faster and larger distribution of family kits. They regard all activities that involve inland vehicles, such as inland distribution, transport to the warehouse, and family kit preparation.

Its most basic level requires no additional preparedness budget and provides a distribution

[1] Hereafter, we will use levels 1, 2, 3 and 4 to denote the investment levels instead of 0, 1, 2 and 3. Please note that the first level means that no investments have been made.

capacity of 25,000 family kits per week. This level guarantees that 48 hours after a demand appears in the nation, the player will have enough trucks to deliver 25,000 family kits per week. No distribution time reduction is offered at this level.

The second level offers a 10% reduction in distribution times and an increase in distribution capacity to 50,000 family kits per week. Each truck used for distribution can make 15 distribution runs in a week and has a capacity of transporting 200 family kits in each run. Therefore, the cost associated with this level includes the cost of buying 16 trucks with a 10-year amortized cost of \$10,000 each, as well as a maintenance cost (including drivers, maintenance, and fuel) provided by the WFP Haiti of \$25,000, resulting in a total cost of \$600,000.

The third level provides even greater improvement by offering a 12.5% reduction in distribution time and doubling the distribution capacity to 100,000 family kits per week. The same principles of truck costs are used to calculate the cost of this investment level, but now for 33 trucks, resulting in a total cost of \$1,200,000.

The fourth and final level offers the greatest improvement by reducing distribution times by 15% and increasing the distribution capacity to 400,000 family kits per week. This requires 133 trucks to guarantee the distribution capacity. Consequently, the cost of this investment level is \$4,000,000.

Communication and Information Sharing

Effective communication and information sharing are essential for the success of any humanitarian operation [102]. Clear communication channels facilitate coordination, prevent both overlapping initiatives, and slow relief efforts [103]. Furthermore, sharing information among stakeholders enhances collaboration and promotes efficient allocation of resources [104].

In the game, the impact of this investment is simulated by improving the accuracy of the information that players have regarding the inventory levels of warehouses, the active demands for family kits, and the actual amount of family kits shipped between islands. Inaccuracies are represented in the game by intervals of possible values. For example, considering 20% of inaccuracy, the game displays the amount of family kits in the warehouse as $[80, 120]$ if the amount of family kits in a warehouse is 100. Similarly, when a player makes a transfer request, the shipment may contain $\pm 20\%$ of the selected number of family kits.

This investment type has four levels, each offering a higher level of information accuracy. The basic level provides 20% inaccuracy, while levels two, three and four offer 15%, 10%, and perfect information, respectively.

The costs of these levels were determined using information from investments made by the Caribbean Disaster Emergency Management Agency (CDEMA) on Information and Communications Technology (ICT) [105], and the cost of implementing Enterprise Resource Planning (ERP) systems in mid-size businesses [106]. The costs for levels two, three, and four are $\$500,000$, $\$700,000$, and $\$1,000,000$, respectively.

Supplier Agreements

In any humanitarian operation, securing necessary supplies is critical for timely and effective disaster response. One of the benefits of establishing agreements with suppliers is the guarantee that supplies will be immediately available when demanded. Moreover, they allow to fix the price of commodities in advance, generally at a lower price than at the time of need. To address this challenge in *HurricaneLog*, players have the option to establish agreements with international suppliers for the procurement of family kits. This enables players to ensure the timely delivery of supplies during disaster response thereby improving the overall effectiveness of the operation.

This investment has four levels where the first implies the absence of an agreement. In that case, the players have no immediate access to family kits from international suppliers, being subject to a preparation time of at least 14 days. Additionally, family kits cost 35% more than their regular price.

The second level secures family kit prices and guarantees the player immediate access and shipping to $50,000$ family kits. Any additional family kit (i.e., exceeding the agreed amount) are subject to the same penalties as the basic level. The cost of this level is calculated using a pre-purchasing contract model presented in [107]. The model requires the purchaser to pay a unit premium price o for all family kits ordered in advance. Once a disaster strikes, the purchaser will trigger the option contract and pay the supplier an exercise price e per unit for the family kits actually transferred. The authors affirm in [107] that the price of this contract model is usually higher than the relief items' wholesale price W to attract suppliers, but cheaper than the retail price P to attract purchasers. For simplicity, we have adopted $W = o+e$ and $P = W \times 1.35$. Therefore, players who make agreements will pay the wholesale price, where W is the same as the prepositioning price of \$148 per family kit, $o = W \times 50\%$, and $e = W \times 50\%$. Any family kit exceeding the agreed amount will be subject to the retail price P. The cost of this level is set at 50% of the wholesale price for $50,000$ family kits, resulting in a cost of $\$3,700,000$.

The third and fourth investment levels offer agreements for $100,000$ and $200,000$ family kits, respectively, while maintaining the cost penalty of 35% for family kits exceeding the agreed contract. The cost calculation for these levels follows the same principles used in the second level, yielding costs of \$7,400,000 and \$14,800,000, respectively.

Regional Transportation Agreements

The regional transportation agreements investment option allows players to negotiate with transportation companies to secure vehicles for the immediate delivery of family kits. This investment has two levels. The basic level has no associated cost, but it does not provide any transportation vehicle guarantees. As a result, players may have to wait up to two days to access transportation services. The level one option ensures immediate access to transportation, reducing the procurement time to zero.

To determine the cost associated with level one, we calculated the average transportation route unit cost between all island pairs, and multiplied it by the expected number of family kits to be transported, which is 400,000. The resulting cost for level one is then set to \$1,000,000.

This investment is crucial for ensuring the timely delivery of relief items. By securing transportation vehicles in advance, players can reduce the time it takes to deliver family kits to affected areas. Furthermore, the cost of transportation is often a major expense in relief operations, making this investment a critical component of any disaster response strategy.

Customs Clearance and Sharing Agreements

The customs clearance and sharing agreements investment option aims to improve the processing time for border administration. It offers four investment levels, with the basic level having no costs or improvements, resulting in a processing time between two and seven days.

The second level of investment implements agreements to simplify international trading procedures across all islands, reducing processing times to [1.5,5] days. We obtained the associated cost for this level from [108], which states that the initial capital expenditure for introducing trade facilitation measures plus their annual operating cost in developing countries is \$5,000,000.

The third and fourth investment levels improve customs clearance processes even further, reducing processing times to between 1 to 3 days, and between 12 to 36 hours, respectively. The fourth level assumes the implementation of an integrated customs management system for international trade and transport operations called Automated System for Customs Data

(ASYCUDA). Its implementation cost is reported in [109] as $\$8,000,000$, and we have added $\$2,000,000$ for equipment and infrastructure, resulting in a total cost of $\$10,000,000$. We have considered the third investment level as a midpoint between the second and fourth levels, with a cost of $\$7,500,000$.

4.4.2 Preparedness budget

The preparedness budget plays a crucial role in *HurricaneLog*'s gameplay by restricting the player's investment capacity. This limitation prompts the player to carefully evaluate which investments are the most rewarding while also considering the diverse nation profiles and potential hurricane damages. It creates a more challenging and engaging gameplay experience, as the player must balance their goal of preparing the nations as thoroughly as possible with the need of saving budget for future response actions.

The initial budget was set to $50M so as to provide players with access to most of the investment options. We analyzed this budget considering four investment strategies. The first one assumed that, for each investment option, the players never invest in level 1 and have an equal probability of investing in one of the other levels (Level 1 = 0% | Level 2 = 33% | Level 3 = 33% | Level 4 = 33%). The second strategy assumed that players again have zero probability of investing in level 1 regarding an investment option, but have 25% probability of investing in level 2, 50% probability of investing in level 3, and 25% probability of investing in level 4 (0% | 25% | 50% | 25%). In the third investment strategy, players have an equal probability of investing in any level regarding an option (25% | 25% | 25% | 25%). Finally, in the fourth investment strategy, the players favour level 1 with a 50% likelihood, level 2 with 25%, and levels 3 and 4 with 12.5% probability each (50% | 25% | 12.5% | 12.5%). Table 4.9 summarizes the total budget allocated to preparedness investments using each investment strategy for a total $1,000$ game simulations.

Table 4.9 Used budget by the different investment strategies in 1,000 simulation games.

Investment strategy	Used budget Min.	Avg.	Max.
(0% | 33% | 33% | 33%)	$10,825,000	$19,757,650	$31,100,000
(0% | 25% | 50% | 25%)	$10,825,000	$19,390,500	$31,100,000
(25% | 25% | 25% | 25%)	$0	$14,747,600	$30,600,000
(50% | 25% | 12.5% | 12.5%)	$0	$9,028,050	$29,100,000

The budget not used to invest in preparedness investment options can be either carried out to the response phase, or used in purchasing family kits to be prepositioned in the islands before the hurricane season begins. Table 4.10 shows the number of kits that can be purchased with the remaining budget for each investment strategy based on the performed $1,000$ game simulations.

The *HurricaneLog* game simulates the 2017 Atlantic hurricane season, which was particularly active, incurring significant damages to the Caribbean islands. This intense activity and damages are translated to the game in a total simulated demand of 600,000 family kits throughout the season. As we can observe in Table 4.10, none of the evaluated strategies allow players to meet that demand with a budget of $50M based solely on family kits prepositioning; the maximum that can be prepositioned is $400,000$. This result played a key role in selecting the budget limit, as it allows for the possibility of meeting more than half of the simulated demand even in an active hurricane season. Additionally, it encourages an hybrid strategy approach, as players cannot fulfill the entire demand only by means of prepositioned family kits. Consequently, they should invest in agreements with international suppliers to handle high-demand scenarios.

Table 4.10 Number of family kits that can be purchased with the remaining of the budget for each investment strategy.

	Family kits		
Investment strategy	Max.	Avg.	Min.
(0% | 33% | 33% | 33%)	313,400	241,938	151,200
(0% | 25% | 50% | 25%)	313,400	244,876	151,200
(25% | 25% | 25% | 25%)	400,000	282,019	155,200
(50% | 25% | 12.5% | 12.5%)	400,000	327,775	167,200

Finally, our simulations revealed that the fourth strategy is the most effective for meeting the family kits demand, entailing a considerable amount of preparedness investments while also prepositioning over 50% of the total demand. We anticipate this strategy to be the preferred approach for players, as it promotes targeted investments in accordance with each island's specific needs, and reserves budget for prepositioning or reducing the overall operational cost.

CHAPTER 5 DATA COLLECTION

The data collection process in *HurricaneLog* serves as the backbone of this research project. By capturing players' interactions with the game, the data collection infrastructure enables the analysis of diverse decision-making strategies employed by humanitarian agents in a simulated environment. This chapter outlines the data collection methodology employed by *HurricaneLog*, which records events generated during players' interaction with the game without disrupting their gaming experience.

The data collection flow, as depicted in Figure 5.1, involves the systematic capture, transfer, and storage of player-generated events. Once collected, these events are then sent to remote servers for further processing. Subsequently, the information is transferred to a local database for in-depth analysis.

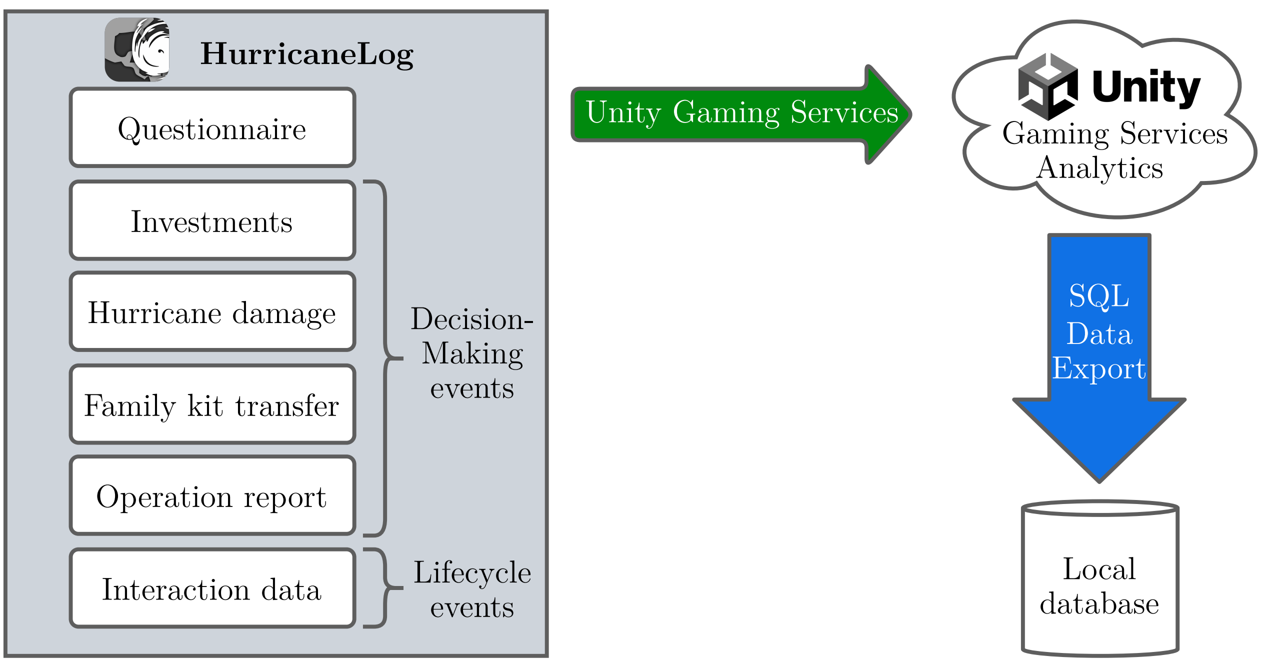


Figure 5.1 Diagram of the data collection flow.

HurricaneLog was developed in *Unity*, leveraging this solution allowed us to incorporate the *Unity Gaming Services Analytics*, a powerful data collection solution. This service automatically generates unique identifiers for new players and play sessions while efficiently handling caching and sending all recorded data events to *Unity* servers for initial processing. The robustness of this approach ensures its viability for supporting a large number of active players. Notably, the game *Among Us* [110], that also uses the *Unity Gaming Services*, has reached a staggering 60 million daily active users at its peak [111]. By utilizing *Unity Gaming Services Analytics*, we address common challenges related to server connections that may arise when scaling up serious games in educational settings [56].

Additionally, this solution provides valuable insights into the collected data, such as the number of active users, new users, and average play session durations. Moreover, it allows for exporting all collected data in an unprocessed format for further detailed analysis, supporting a comprehensive evaluation of the game's performance and player interactions.

To provide a practical example of how events are produced and the order in which they are sent, Figure 5.2 illustrates the events produced by a player who opened the game for the first time, decided to participate in the experiment, answered the questionnaire, proceeded through the tutorial following all the steps, and then decided to quit the game.

Despite the robustness and ease of using the *Unity Gaming Services Analytics* solution, it is free for games with less than 50,000 Monthly Active Users (MAU), which refers to the number of players who actively engage with the game within a single month. This limitation is well-suited for the experiment's needs and ensures cost-effectiveness by avoiding the necessity of maintaining a dedicated server for the game. Additionally, adopting this solution adds security layers around game data collection and the initial storage of that data, providing more effective measures than manual implementation.

5.1 Collected information

Before participating in the study and having their data collected, players are presented with a consent form outlining the specific data that will be collected, the storage process, the intended use of the data, and the duration of storage. All data collection practices adhere to the guidelines set by the *Polytechnique's Ethics Committee*, ensuring that players' privacy and autonomy are respected.

As part of the data collection process, the game includes a questionnaire that gathers additional information about the player's field of work, educational level, level of expertise, familiarity with humanitarian logistics, and gaming experience. This questionnaire is presented to players once during the game experience, and its data provides valuable contextual information that can be correlated with players' decision-making patterns and strategies. For further details on the questionnaire, refer to Appendix D. It is important to say that this is the only moment during the game experience when players are explicitly asked to provide data for collection, and subsequent analysis.

HurricaneLog ensures data anonymity by generating non-identifying identification numbers

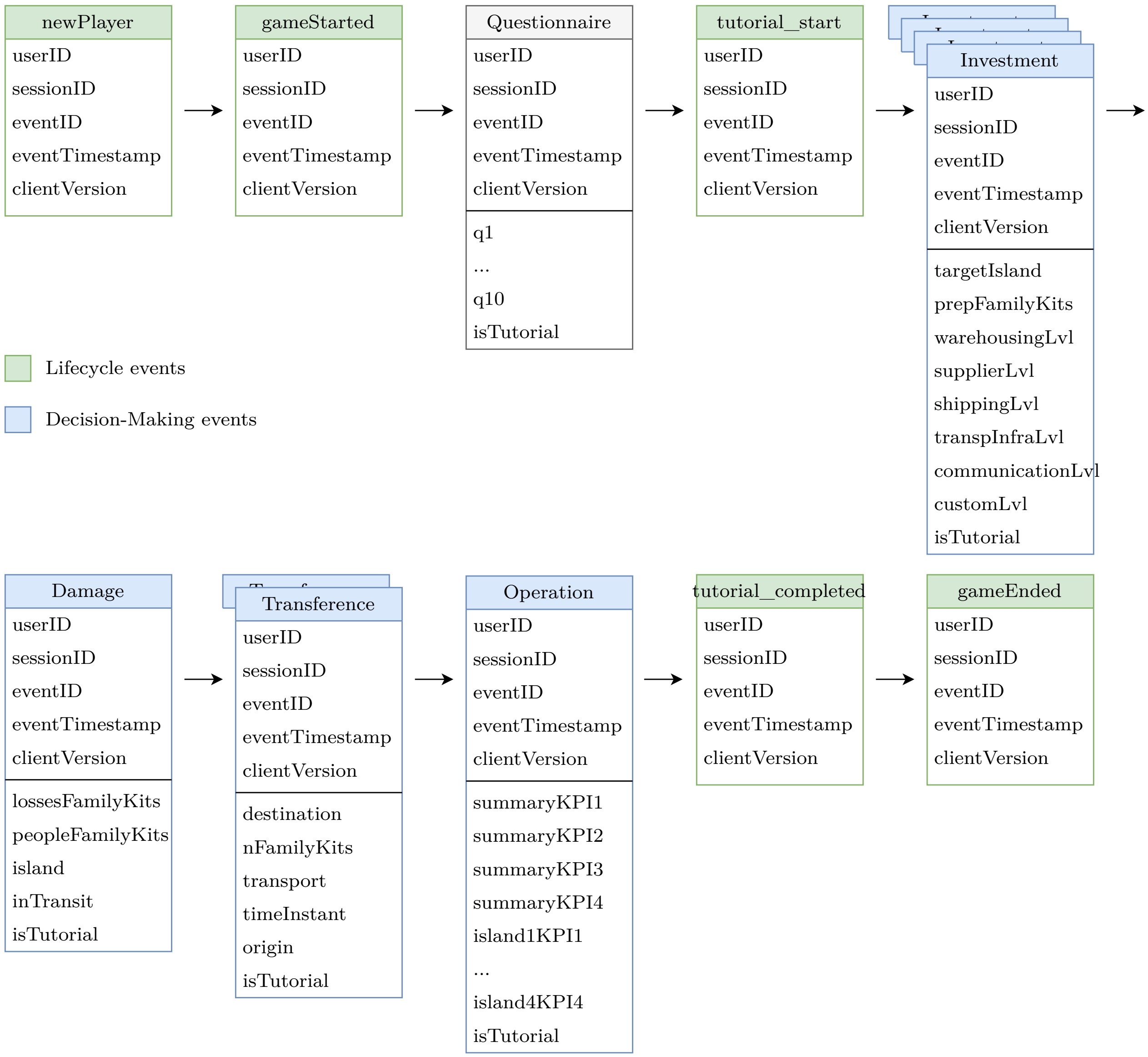


Figure 5.2 Set of events produced in the player example.

for each player. Furthermore, each play session receives an exclusive session ID. These identification details are combined with all collected data, differentiating data points between players and play sessions. As a result, all collected data is secure and anonymized, making it impossible to identify individual users based on the collected data.

In summary, the data collection process includes two categories of game events:

(i) **Decision-Making Events:** These events encompass all player strategy decisions and their consequences during the game's preparedness and response phases. They are:

   (a) **Investments events:** Describe the investments made by players in all nations.

This data include the number of prepositioned family kits and the chosen investment level for each option.

(b) **Damage events:** Capture the affected nation's name, the number of families affected, the number of family kits lost during the damage event, and the number of family kits in transit to the affected nation.

(c) **Transference events:** Record the place of origin and destination, including purchases from international suppliers. Additionally, record the number of family kits selected, the transportation mode (planes or ships) used, and the time of the transfer.

(d) **Operation events:** Detail the consequences of player actions and translate them into KPIs that can be either region-wise or nation-wise.

(ii) **Lifecycle Events:** These events encapsulate the various stages of a player with the game, from their initial engagement and progress through different phases (preparedness and response) and modes (main game - representing the core gameplay experience, and tutorial - providing initial guidance) to their ongoing interaction with the game and, eventually, their potential disengagement or attrition. Lifecycle events are divided into four types:

(a) **Phase events:** Describe a player's progress through the two game phases: i.e., preparedness and response. There are three types of phase events:

- Phase Start: Generated when a player begins the preparedness or response phases, marking the initiation of their engagement with the respective game phase.
- Phase Quit: Produced when a player chooses to exit the preparedness or response phase prematurely, providing insight into player disengagement.
- Phase Complete: Generated when a player successfully finishes either the preparedness or response phase, indicating their progress and achievement in the game.

(b) **Tutorial Events:** Describe a player's progress through the game tutorial. Similarly to the phase events, there are three types of tutorial events:

- Tutorial Start: Generated when a player begins the tutorial.
- Tutorial Skip: Produced when a player chooses to prematurely exit the tutorial.
- Tutorial Complete: Generated when a player successfully finishes the tutorial.

(c) **New Player Events:** Generated when a player opens the game for the first time.

(d) **Game engagement events:** Describe a player's engagement with the *HurricaneLog* game. There are two types of game engagement events:

- Game Started: Produced when a player opens the *HurricaneLog* game.
- Game Ended: Generated when the player closes the game application.

5.2 Data upload and internet connection

HurricaneLog operates as a standalone game, meaning that an internet connection is not mandatory to play and utilize the game's functionalities. Nevertheless, having an internet connection while running the game is advised as it plays a crucial role in data collection. Once an event is recorded, it is cached within the game and sent to *Unity*'s servers at regular intervals. In the absence of an internet connection, the data is cached in local files by the solution and transmitted once an internet connection becomes available.

5.3 Data privacy

To ensure data privacy, all information collected from the game is kept secure and anonymized, making it impossible to identify individual users based on the collected data. Additionally, questionnaire data is coded to further safeguard participants' responses. In the unlikely event of a data breach in *Unity* servers, none of the data collected can be linked back to individual players and their answers.

The experiment meticulously minimizes data collection to include only strictly necessary information, mitigating any potential privacy concerns. Moreover, the game grants players the ability to withdraw their consent at any time during the experiment. If players choose not to provide their consent initially, no data is collected. Conversely, if they do grant consent, data collection proceeds until the consent is withdrawn. In such cases, data collection ceases immediately, and a "forget me" event is sent to *Unity* servers to have all associated data entries promptly deleted.

All collected data is stored on *Unity* servers, accessible only by authorized personnel. Once the data is exported to a local database, it is password-protected and accessible solely to relevant members of the research team.

5.3.1 Drawbacks

While *Unity Gaming Services Analytics* offers outstanding features at no cost, it lacks flexibility in precisely selecting the data required for the experiment. It collects players' IP addresses to determine if they are in regions protected by regulations like General Data Protection Regulation (GDPR) European Economic Area (EEA), China's Personal Information Protection Law (PILP), or California Consumer Privacy Act (CCPA). Though it does not share players' IP addresses with developers, it includes their country of access in the collected events. While this aspect of data collection cannot be customized or removed, it remains unused in any analysis and is expunged during the processing phase before storage.

Another observation pertains to two data elements (age group and gender) that are part of the events sent through the *Unity Gaming Services Analytics* service and might be considered sensitive and personal. However, it is important to note that the game never solicits such information from the player. As a result, these fields are not collected during the data collection process, ensuring that no sensitive personal data is involved.

5.4 Data storage

Exported data events are consolidated and stored in a single local database, serving as a centralized repository for all the collected information. This approach streamlines the data mining and analysis process, facilitating the extraction of valuable insights, patterns, and trends from the extensive gameplay data.

Storing the data in a local database offers several advantages, primarily in terms of data organization and accessibility. Researchers can easily retrieve specific data points or groups of data based on customized queries, enabling in-depth analysis of gameplay mechanics, user interactions, in-game decisions, and other important metrics. This capability simplifies the selection and extraction of relevant subsets of data for detailed examination, ensuring a more efficient analysis process. Moreover, maintaining a centralized offline database is important to minimize costs since the *Unity Gaming Services Analytics*' free tier imposes limitations on the total query time used per month (0.05 query seconds / MAU).

Furthermore, the centralized storage allows seamless integration of multiple data sources and formats into a cohesive structure. Alongside the exported data events, supplementary data, such as player profiles and user demographics, can be incorporated into the same database. This holistic approach ensures a comprehensive view of players' gaming experiences, facilitating deeper insights and more accurate conclusions.

Another advantage of storing the exported data events in a single database is the potential for data standardization and normalization. Standardization involves establishing consistent formats, units, and naming conventions across different data types, facilitating comparisons and correlations. Normalization, on the other hand, involves transforming data into a common scale or range, eliminating biases that may arise from disparate data sources. By applying these techniques, we can effectively eliminate inconsistencies and enhance the quality and reliability of the collected data.

5.4.1 Database

To ensure efficient query execution, especially with large datasets, a well-designed database structure is crucial. As part of the data preprocessing process before storage in the local database, events undergo filtering to retain only relevant information and eliminate any redundant data. The stored data includes essential fields to differentiate between different game events, record the order of events, distinguish events between users and player sessions, and store event-related data.

The chosen data storage solution for *HurricaneLog* was MongoDB, a non-relational database that stores data in the form of documents and allows dividing these documents into collections (similar to tables in relational databases). Unlike SQL databases, MongoDB collections do not have a fixed structure, offering flexibility to accommodate the evolution of events and data collection. This feature is particularly beneficial as it allows us to incorporate new data fields without breaking the collection structure.

In summary, the database contains the following collections: *Damage*, *Investment*, *Operation*, *Questionnaire*, *Transference*, *gameStarted*, *gameEnded*, *phase_start*, *phase_quit*, *phase_complete*, *newPlayer*, *tutorial_start*, *tutorial_skip*, *tutorial_complete*. Although there is no enforced referential integrity, all collections are linked by the user generated ID and session generated ID associated with each event, establishing relationships as depicted in Figure 5.3.

To provide a clear understanding of the events and their sequence within a player's game session, it is essential to define the pairing criteria based on the occurrence of events in time. A *gameStarted* event is considered to be paired with a *gameEnded* event if they share the same userID and sessionID, with the *gameEnded* event occuring next to the associated *gameStarted* event. Keeping this pairing definition in mind, Figure 5.3 illustrates the sequence of events produced within a player's game session when they choose to participate in the experiment.

The player's game session begins with a *newPlayer* and *gameStarted* event being generated when they first open the game in the experiment. Following this, when the player responds to the questionnaire, a *Questionnaire* event is produced. At the end of the game session,

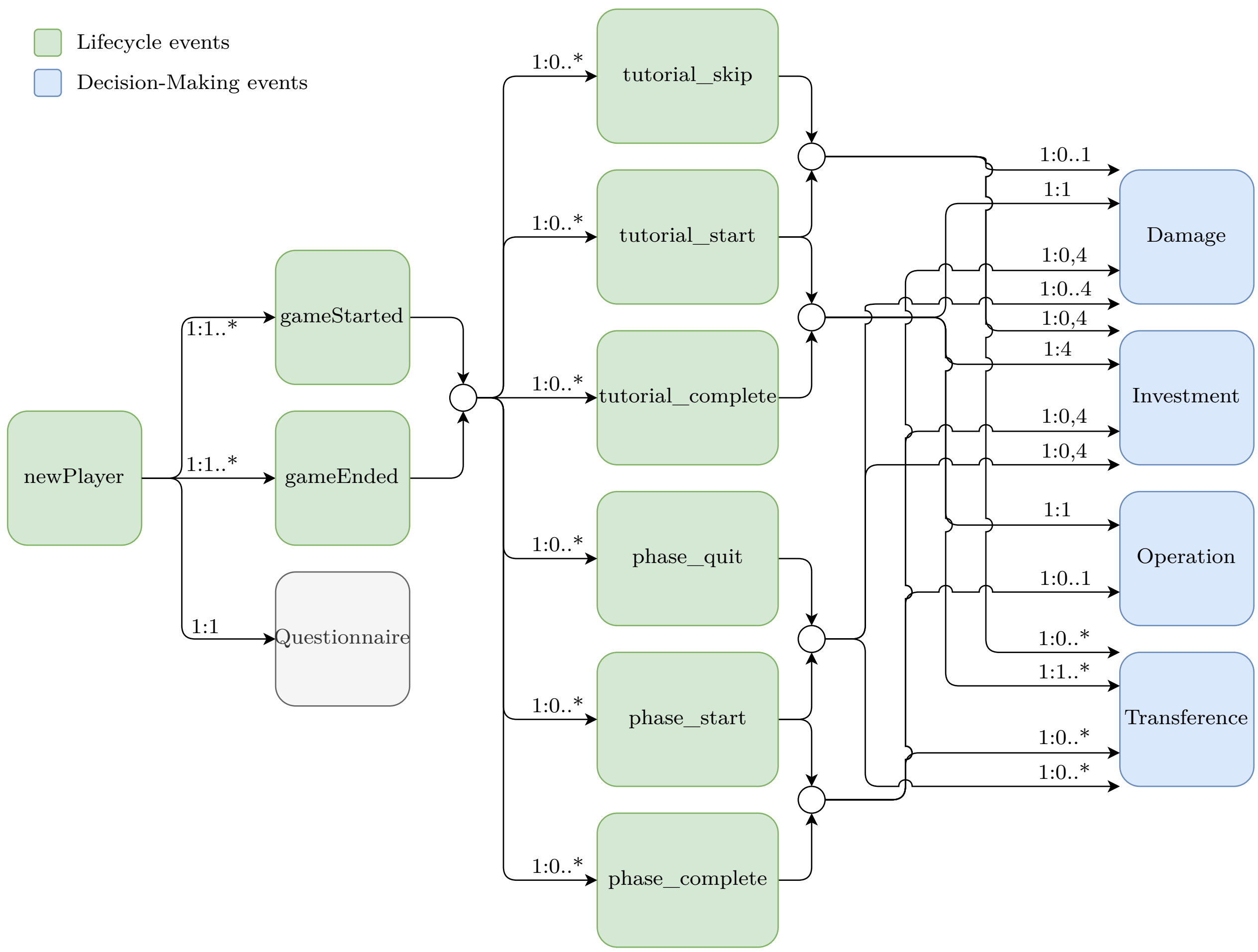


Figure 5.3 Diagram of the relationship between game events.

when the player decides to close the game, a *gameEnded* event is generated. Between the *gameStarted* and *gameEnded* pair, multiple *tutorial* and *phase* events may occur, forming a sequence of events that describes the player's interactions with the game. The relationships between these events are depicted with labels in the links connecting them.

For instance, the link between the *newPlayer* event and the *gameStarted* event has a label of 1:1..*, indicating that for one *newPlayer* event, at least one *gameStarted* event is produced, and there is no limit on the number of events of this type that can be created, as represented by "*".

Furthermore, each *tutorial* pair (e.g., *start→skip* or *start→complete*) is associated with a limited number of Decision-Making events, except for *Transference* events, which are unlimited and depend on the player's decisions. Similarly, the same pair definition applies to *phase* events, which can be further divided into *preparedness* and *response* phases.

For each pair of *preparedness* start and quit or complete phase events, only four *Investment* events can occur. They refer to the series of investments options made in each island. In contrast, for *response* phase event pairs, there can be at most four *Damage* events, one *Operation* event, and an unlimited number of *Transference* events.

This presented event relationship, summarized in Figure 5.3, streamlines query procedures, enabling efficient retrieval of specific events associated with a particular player and their session. By linking events through user ID and session ID, querying all events produced by a specific player during a given session becomes straightforward. This approach minimizes the need for complex joins or lookups, thereby enhancing overall query performance.

For example, to find all events produced by a player in a particular main mode play session, researchers can simply query the *Investment*, *Transference*, *Damage*, and *Operation* events from the database for the given *userID* and *sessionID* within the time interval defined by the *phase_start* and *phase_complete* pairs of events. This approach simplifies the querying process and enhances the efficiency of data retrieval.

5.5 Ethical considerations and approval

The data collection process carried out by *HurricaneLog* underwent a thorough ethical review and evaluation by *Polytechnique's Ethics Committee*. The evaluation aimed to ensure that the study, involving human participants, adheres to specific legal and ethical imperatives, while respecting participants' rights and privacy and complying with all relevant regulations and guidelines.

To achieve this, *Polytechnique's Ethics Committee* evaluated all aspects of the experiment, including its objectives, financing, experimental procedures, forms of recruitment and participation, potential risks, and how the collected information would be handled and protected.

Upon careful evaluation, the research project received approval from the Ethics Committee, affirming its commitment to ethical research practices and ensuring the highest care and confidentiality in handling participants' data.

CHAPTER 6 PRELIMINARY ANALYSIS

This chapter is a primer on data analysis carried out with the aid of the framework using *HurricaneLog*. Here, we provide essential context and first insights obtained from a small experiment with the game. The primary objective of this chapter is to lay the foundation for subsequent data analyses and interpretations that can contribute to the humanitarian logistics field by revealing nuanced decision-making patterns and their impact on operational outcomes.

6.1 Description of the experiment

The data collection was conducted using a well-defined quantitative experimental design aiming at gathering valuable insights into players' decision-making and responses during (simulated) hurricane relief operations.

Participants were recruited through three approaches. The first approach involved visiting classes of two courses at Polytechnique Montreal to invite students to participate in pre-scheduled online group sessions. For each course, three sessions of one-hour duration were created, and participants were only required to attend one of them. The second approach consisted of spreading the invitation to the entire university through an email sent by the student association of Polytechnique Montreal. Additionally, the invitation was extended to a broader community through social media channels. The third and last approach involved a workshop online session during the EURO Humanitarian Operations Summer School in Humanitarian Logistics, from June 26th to 28th, 2023.

To facilitate the game installation and accommodate participants from different backgrounds and expertise, we created a website with information about the game, including links to download and installation guides[1]. The experiment information and consent form were made available on the website so participants could familiarize themselves with the experiment before downloading the game or attending any session. Furthermore, a contact email was provided to address any questions related to the game or the experiment.

In summary, the participation in the experiment occurred in two types:

(1) **Group Facilitated Sessions (GFS):** This refers to the group where participants attended pre-scheduled online sessions facilitated by the researcher, watched the tutorial

[1] `https://thiagocorreiap.github.io/hurricane-game/`

explanation, and had the opportunity to ask questions before playing the main game.

(2) **Individual Self-Guided Sessions (ISGS):** This refers to the group where participants played the game individually, following the tutorial video or playing the game tutorial without attending any facilitated sessions.

The game was designed to be self-sufficient in terms of providing a controlled experimental environment. A tutorial was developed to explain and familiarize the players with the game mechanics before playing the game. However, as we wanted participants to play the game with as much knowledge about it as possible, we decided to present the tutorial step by step and answer possible questions. For the ISGS case, we created a video that went through the same instructions presented in the GFS.

As mentioned earlier in Chapter 5, participants were presented with an information and consent form when running the game for the first time. Thus, it was ensured that all participants had access to the information and consent form before playing the game. In the GFS sessions, participants had five minutes to read and decide on the consent. No difference was made between participants who gave consent and those who did not. The game was able to collect data based on the consent given, and participants were free to leave the session at any time.

After the first five minutes of the GFS, the session moderators used 20 minutes to present a guided step-by-step game tutorial and answer questions. The remaining 35 minutes were then dedicated to allowing participants to play the game. Although the sessions had a scheduled one-hour duration, moderators remained available to answer any questions until the last participant left the online room.

Regarding the GFS held at the humanitarian operations summer school, the entire activity spanned three days and was divided into four sessions. The first session, lasting for 30 minutes, entailed the moderators providing the game and activity context, guiding participants through the tutorial step by step, and answering questions. The second session occurred the following day and had a two-hour duration. During the first hour, participants played the game individually, and in the second hour, they were grouped into teams of three members for collaborative play. Throughout the entire session, moderators were available to answer questions and visited all groups to check if participants were succeeding in communicating with their group members. On the third day, the third session unfolded, dedicating two hours to group discussions and presentation preparation. Drawing from the group formations established in the previous session, participants collaboratively engaged in comprehensive discussions. These discussions were geared towards synthesizing their individual and collective experiences within the game, aiming to identify overarching patterns and strategies that emerged. The concluding session of the activity dedicated two hours to encompass participants' presentations, punctuating the learning experience. During this session, each group elucidated their unique strategies, objectives, and the insights gained from the game. Moderators played a crucial role, orchestrating and guiding these discussions to facilitate a collective understanding of the diverse approaches and decision strategies employed by participants.

6.1.1 Control of external variables

External variables, such as participants' prior gaming experience and familiarity with humanitarian logistics, could potentially influence the gameplay outcomes. To address these factors, we gathered demographic information from the initial questionnaire and incorporated relevant variables as covariates in the data analysis to control for their effects.

6.2 Data cleaning and preprocessing

Besides the preprocessing done for data storage presented in Chapter 5, a second preprocessing and data cleaning is done to ensure all data used in the analysis is free of noise and unwanted entries.

The cleaning and preprocessing performed involved three steps:

1. **Remove test instances events**: During the game development, multiple tests had to be performed to ensure the game and data collection service were working as expected. Additionally, we had test-users that played the game to give feedback on missing features, confuse parts and to look for eventual unexpected behaviours/bugs. Naturally, these tests generated events that were collected and stored as part of the data collection framework. Therefore, the first processing step was created to remove any event generated within the test time interval. A query looked for all events produced within a date window and all resulting events were removed from their respective collections in the database.

   After the game release and start of the experiments, some minor updates had to be done. For example, improving the wording in the *Information and Consent* form and creation of a button to control the game sound. Before releasing these minor updates, new tests had to be performed. However, in this case, simply deleting all events produced within the test time interval was not possible as it would risk deleting events from people playing the game at the same time tests were being performed. It this case, the tests were performed in a smaller scenario, basically by just the developer. Therefore, the solution for this case was to exclude all events produced by the developer's *userID*.

2. **Remove tutorial decision-making events**: The game tutorial was designed as an instructional platform for players, offering them a controlled environment to familiarize themselves with game mechanics. Consequently, the decision-making events recorded during the tutorial phase were not integrated into the analysis. This exclusion was made based on the rationale that these events were meant for educational purposes rather than contributing to the primary data analysis. It's worth noting, however, that although not considered for the analysis presented here, these tutorial-related decision-making events could be worthy for alternative uses or insights. For instance, they might serve as a basis for understanding players' initial learning curves, identifying common misconceptions, or assessing the effectiveness of the tutorial in conveying essential gameplay strategies. In order to delete these events, the second processing step involved querying and subsequently removing all events generated within the time intervals defined by event pairs such as *tutorial_start→tutorial_skip* or *tutorial_start→tutorial_complete*.

3. **Remove events from uncompleted operations**: The third and last step is responsible to remove all *Decision-Making* events that happened in uncompleted operations. We call an operation as uncompleted when the player prematurely ends a game phase (preparedness or response) producing a *phase_quit* event. To delete these *Decision-Making* events, this processing step queries and remove all events produced within *phase_start→phase_quit* pairs of events.

In data collection, cleaning, and processing, it is common to encounter missing or inconsistent data. However, in the *HurricaneLog* data collection framework, missing data within the events' parameters does not exist. This is because data production and collection are entirely controlled, ensuring that all necessary parameters of the events are included without any missing values. Nevertheless, there can be instances of missing events due to internet connection issues when sending data to *Unity*'s servers. In such cases, we handle the missing events appropriately. For *Decision-Making* events, we disregard the associated *phase_start→phase_complete* events pair and all other *Decision-Making* events produced within the time window defined by this pair. As for *Lifecycle* events, we make efforts to preserve the events associated with the main game mode. If a *gameStarted* or *gameEnded* event is missing, we try to define their time window frontier using the next or previous pair of *gameStarted→gameEnded* events and maintain the events associated with this interval.

Similarly, we apply the same approach for missing *phase_start* or *phase_complete* events to retain as much data as possible.

It is important to note that during our experiment and data collection, no instances of missing data events occurred. We maintain a robust data collection process to minimize the possibility of missing events and ensure the reliability of the data gathered.

6.3 Descriptive statistics

The *HurricaneLog* experiment involved 29 players from diverse backgrounds. Among them, 18 were students, a trend that can attributed to the university context of the experiment. Additionally, 6 participants were from Science, Technology, Engineering, and Mathematics fields, 2 were from Education and Training, and 1 each from Health Science, Law, Public Safety, Corrections and Security, and Transportation, Distribution and Logistics backgrounds.

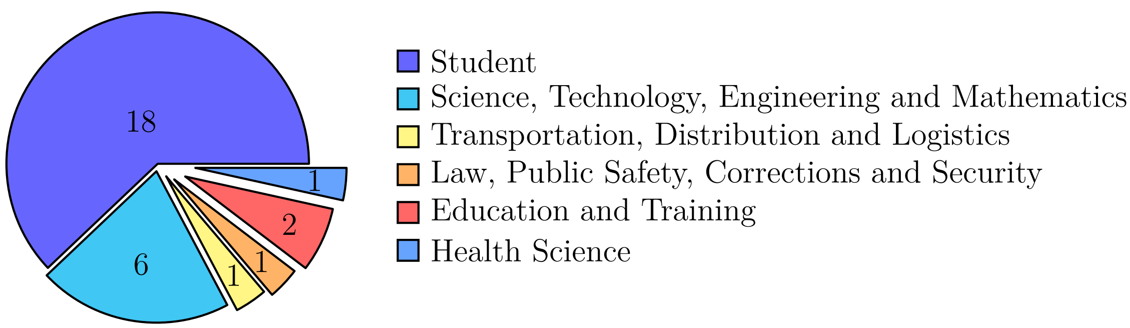


Figure 6.1 Players' field of work.

However, while these findings provide valuable insights, there are limitations to consider. One potential limitation is the relatively small sample size of 29 players. The specific population recruited for the study, including a significant number of students due to the university context, may also limit the broader applicability of the findings. These limitations should be taken into account when interpreting the results.

Among the student participants, their distribution of fields of study was as presented in Figure 6.2.

6.3.1 Professional experience

Participants' professional experience varied from none to over 10 years: five players had no prior professional experience, six had between 3 to 6 years of experience, six had between 3 months to 1 year of experience, and six others between 1 to 3 years of experience. The

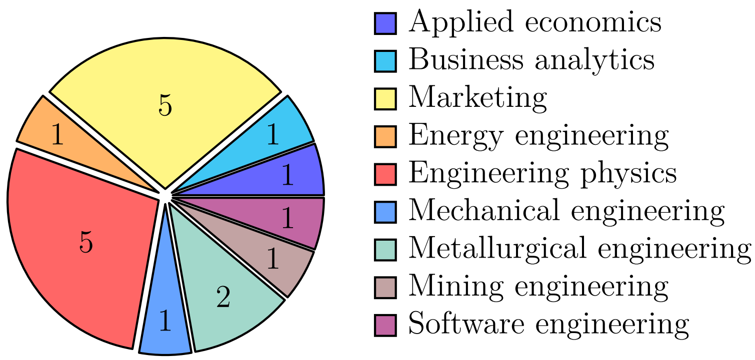


Figure 6.2 Players' fields of study.

remaining participants' professional experience fall into different ranges, including less than 1 month, at least 1 month but less than 3 months, at least 6 years but less than 10 years, and 10 years or more.

Out of the participants, 15 had prior experience studying logistics, while 14 did not. In terms of their experience in logistics and operations management, it was quite diverse. Notably, 13 participants had no prior experience in this field. On the other hand, a considerable portion of the participants (7) had accumulated at least 3 years but less than 6 years of experience. The remaining participants showed varying levels of experience, ranging from under a month to over 10 years.

In terms of experience in the humanitarian sector, 18 participants had no experience, while 11 had some experience, with 1 participant having 10 years or more of experience in the field.

6.3.2 Gaming experience

Among the players, 11 declared themselves as not being gamers. Of the remaining 18, 7 considered themselves casual players, 7 as mid-core players, and 4 as hardcore players. From this subset, 5 participants were console players (Xbox, PlayStation, Nintendo Switch docked with TV), while the remaining 13 preferred PC/Mac (desktop, laptop) gaming.

6.3.3 Key Performance Indicators scores

Players' game performance was systematically assessed through the utilization of the game's essential KPIs. In particular, we focused on the KPIs scores related to the first playthroughs of every player. This choice aimed to analyze players' initial strategies without the influence of past gameplay experience.

To assess the performance of players, it is essential to consider the game's objectives. In *HurricaneLog*, the primary player objective is to meet the generated demands as quickly as possible while keeping operational costs as low as possible. An ideal solution within the game would, therefore, exhibit a combination of low average response time, a minimal number of unsatisfied demands, and cost-efficiency. It's important to recognize the dynamic relationship among these KPIs. For instance, achieving low operational cost at the expense of a high number of unsatisfied demands is not considered an optimal result. In this context, the interactions between these KPIs reveal the complex nature of players' decisions and the challenges they face when aiming for efficient disaster relief. These aspects will be explored further in the subsequent sections.

The following sections investigate the characteristics of the captured data in more detail, providing an initial exploration of players' strategic choices, decision diversity, and overall performance within the game's dynamic framework.

Average response time

The population's average response time KPI, as presented in Figure 6.3, offers several key insights into the players' performance. The median response time of 16.75 days provides a central reference point, indicating that half of the players responded to demands within this time frame. In particular, the minimum value obtained was inferior to 1 day, which suggests that certain players demonstrated exceptional efficiency in responding immediately to generated demands.

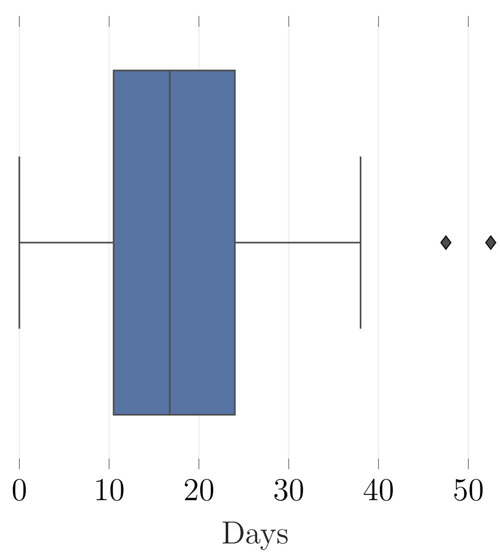


Figure 6.3 Players' average response time.

However, as mentioned earlier in Section 3.1.2, to gain a more comprehensive understanding of player performance, it is essential to analyze all game KPIs together. Otherwise, a single KPI might suggest exceptionally positive performance, indicating a promising strategy. Yet, when considered alongside other KPIs, this strategy may reveal major flaws, such as very low average response time and operation cost coupled with a high number of unsatisfied demands. This could be the case for players who achieved an average response time of less than 1 day.

Achieving null response time is not realistic in the game because of inherent logistical constraints. This leads us to infer that such players either focused solely on distributing a small number of prepositioned family kits or did not completely satisfy the generated demand for family kits. These strategies highlight the trade-off between speed and completeness in addressing disaster scenarios – players with very low response times very likely address only a limited portion of the demands, emphasizing quick reactions over comprehensive coverage.

Examining the interquartile range (IQR) between the first quartile (Q1) and the third quartile (Q3) – namely, from 10.5 to 24 days – captures the performance of the middle (50%) of players. The fact that this range spans more than two weeks indicates relatively diverse response times among this group. However, some players recorded an extended response time of 38 days, revealing a subset of players who faced challenges in prompt disaster relief. These players may have encountered delays due to factors like family kit allocation, distribution capacity, or strategic decision-making.

The outliers, represented by the values 47.5 and 52.5 days, denote extreme subjects where response times significantly exceeded the norm. These outliers reveal potential inefficiencies or sub-optimal strategies that led to delayed responses. It is essential to consider these outliers within the context of other KPIs to form a comprehensive understanding of individual players' overall performance.

Demand of family kits

This KPI reports the number of families that require assistance during the response operation. Once the hurricane season concludes, players receive an operation report that provides a more comprehensive version of this KPI. Instead of solely indicating the amount of demanded family kits (i.e., families in need), it also highlights the *percentage of unsatisfied demands* at the end of the game, which represents the proportion of families that remain in need out of the total number of affected families (i.e., families in need + families served). This metric plays a essential role in evaluating the player strategy performance, reflecting the coverage achieved by their operations. A large percentage of unsatisfied demands indicates low coverage, implying that a small fraction of families received assistance during the operation. Conversely, a small ratio indicates high coverage, suggesting that a substantial fraction of families were assisted. Figure 6.4 presents the distribution of the players' percentage of unsatisfied demands for our sample population, offering a visual representation of their performance in addressing the needs of affected families.

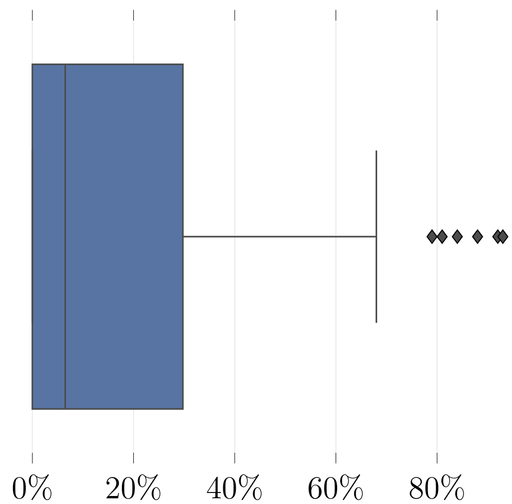


Figure 6.4 Boxplot of players' percentage of unsatisfied demands

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For the studied population, the median value for this KPI was 6.5%. This positive result implies that, on average, half of the player's population managed to satisfy almost all of the generated demands.

However, it is noteworthy that some players struggle to satisfy the demand, leading to scores as high as 68%. The presence of outliers at 79%, 81%, 84%, 88%, 92%, and 93% emphasizes the challenges faced by a subset of players in effectively managing their resources and strategic decisions. These high percentages could potentially result from several factors. Players scoring at the upper end of this metric might have adopted budget-saving strategies, sacrificing demand satisfaction to optimize their financial resources. Alternatively, delayed initiation of relief operations could have contributed to the accumulation of unmet needs as the hurricane season progressed.

Operation cost

The operation cost is an important KPI that players deal during both phases of the game: preparedness and response. Throughout the game, the players are exposed to the respective operation costs of each phase. Then, at the conclusion of the hurricane season, they gain a comprehensive overview of the operation cost in the final operation report, which breaks down the preparedness and response costs, offering a deeper understanding of resource allocation across the distinct phases.

Figure 6.5 presents a boxplot representing the distribution of the players' total operation costs. It provides insights into the players' performance in resource management to effectively address disaster scenarios.

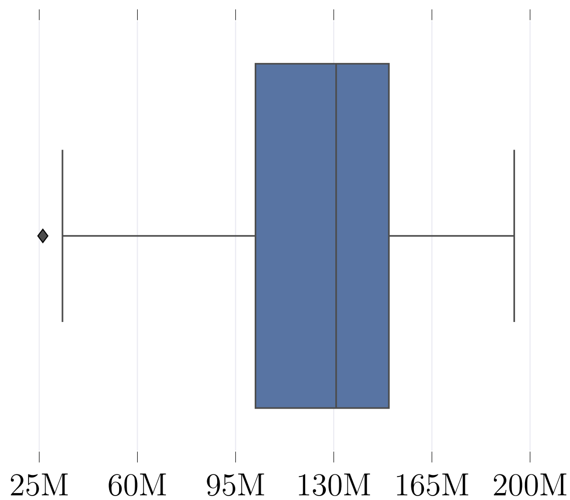


Figure 6.5 Players' total operation cost.

We can observe from the figure that the median cost is equal to \$130.85M, with interquartile range spanning \$47.53M between the first and third quartiles (Q1 and Q3). This variability in player strategies is further highlighted by the presence of extreme points. While some players achieved a minimum operational cost of \$33.28M, potentially indicating resource-efficient strategies, others attained a maximum of \$194.35M, possibly signalling a primary focus on other KPIs or a lack of emphasis on preparedness efforts. Yet, it is noteworthy that despite similar operational cost values, players' strategies can significantly differ, prioritizing preparedness, response operations, or a balanced approach.

Examining these cost distributions not only provides insights into resource allocation strategies but also complements our understanding of earlier-discussed KPIs. For example, certain strategies may manifest in both operational costs and response times. This comprehensive analysis aids in better comprehending the nuanced decision-making processes employed by players.

While the total operation cost offers a broad perspective on players' performance, a closer examination of phase-specific costs reveals finer insights. This scrutiny is particularly valuable as it delineates players' resource allocation strategies regarding the prioritization of specific phases.

Preparedness cost The distribution of preparedness investments costs, as depicted in Figure 6.6, showcases a leftward skew, indicating a prevalent trend among players to allocate their investments towards the higher end of the budget spectrum, often near the maximum limit of $50,000,000. This observation reflects the strategic significance players attribute to preparedness within the game. Further, remark that none of the players chose to invest nothing in all of the available investments. The absence of zero investments signifies a consensus among players that neglecting preparedness could lead to sub-optimal game performance, emphasizing the key role of strategic planning in effectively mitigating the impact of disasters.

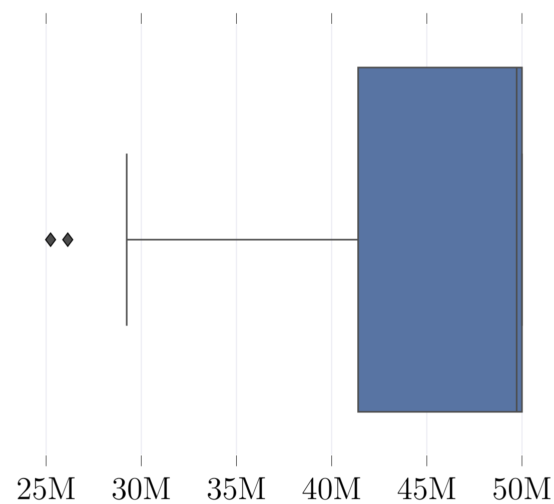


Figure 6.6 Players' preparedness investments cost.

Two notable outliers at $25.23M and $26.13M stand apart from the rest of the data in Figure 6.6. These instances reveal that some players opted for significantly lower investment amounts compared to the majority. While the rationale behind these outlier choices can be multifaceted, they highlight distinct strategies that prioritize specific aspects of disaster response over extensive preparedness investment. These outliers offer valuable insights into the diverse strategies employed by players and demonstrate the versatility of the game, accommodating various gameplay approaches.

Response cost The distribution of response operation costs was more spread, as illustrated in Figure 6.7, with costs spanning from $149K to $144M. This large cost range reveals the multifaceted strategies embraced by participants when allocating resources for response operations.

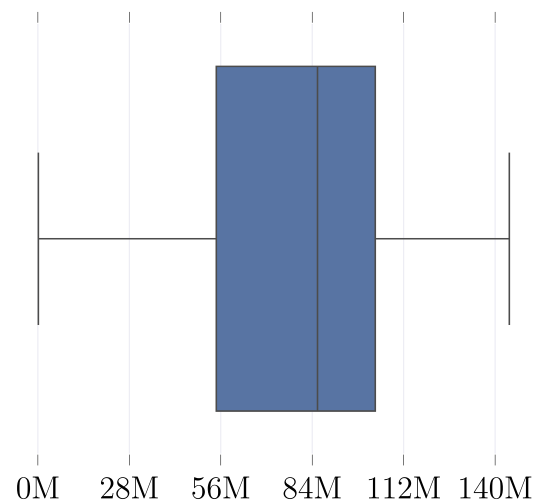


Figure 6.7 Players' response operation cost.

The median response cost of $85.61M provides insight about the typical expenditure used in response operations. However, it's essential to explore the quartiles for a comprehensive understanding. The first quartile ($54.63M) indicates that a significant portion of players managed to operate at relatively lower costs, while the third quartile ($103.30M) highlights the point at which higher spending patterns began to emerge. This quartile-based analysis reinforces the notion that players were not confined to a singular approach but rather chose diverse paths to tackle the challenges posed by the hurricane scenarios.

The smallest and biggest cost values also provide interesting insights. Notably, the smallest response cost $149K reveals that players may adopt an exceptionally frugal response strategy, opting for a more resource-conservative response, possibly relying heavily on prepositioned family kits. On the other extreme, the maximum cost of $144M refers to a player who spent significantly more in response operations, possibly driven by an elaborate plan involving extensive resource mobilization or rapid intervention.

Table 6.1 further analyzes the seven players who spent the least amount of money on response operations. We observe in the table that this strategy resulted in a high proportion of unsatisfied demands. Additionally, it led to low average response times compared to the population average, suggesting that these players primarily met their demands with prepositioned family kits.

However, even though Table 6.1 displays significant expenditures on preparedness invest-

Table 6.1 Performance of players with lowest spending on the response phase.

Response cost	Avg. response time (days)	% unsatisfied demand	Preparedness cost
$149.36K	2	93	$26.13M
$312.13K	0	92	$49.99M
$1.43M	8	84	$49.86M
$3.95M	8	79	$29.32M
$4.18M	15.5	88	$29.23M
$5.88M	10	81	$49.99M
$9.03M	19	68	$41.92M

ments, it is reasonable to hypothesize that these players either did not optimize their investments in the game islands, including prepositioning, or invested in options from which they were unable to fully benefit. For example, players might have prepositioned only a limited number of family kits, primarily relying on international suppliers, and subsequently completed the season without making any demands from them.

Non-dominated KPI solutions

Before concluding this section, it is important to highlight the set of non-dominated solutions achieved by players in *HurricaneLog*. In a multi-objective decision-making problem like disaster relief operations, where players must balance various KPIs, the concept of non-dominated solutions plays an important role.

Non-dominated solutions are those strategies or outcomes in which no single KPI can be improved without negatively affecting another KPI. In other words, these solutions are those that are better or at least equal to other solutions in some criteria without being worse in any of the criteria. They represent the best trade-offs where players have optimized their performance considering multiple objectives simultaneously.

Table 6.2 presents a collection of non-dominated solutions from our analysis. Each solution presents a unique combination of performance across the game three critical KPIs: average response time, percentage of unsatisfied demands, and operational cost. This table illustrates that while some players outperform in specific areas, they face challenges in others, and vice versa.

For instance, Solution 3 achieves a low average response time of 6.5 days, meeting all generated demands quickly, but it comes at the highest operational cost of $194.35M. In contrast, Solution 2 achieves the lowest operational cost of $26.28M and a very low average response time of 2 days but at the expense of the highest percentage of unsatisfied demands (93%).

Table 6.2 Set of non-dominated solutions achieved by players in *HurricaneLog*.

#	Avg. response time (days)	% unsatisfied demands	Operation cost
1	0.0	92	$50.31M
2	2.0	93	$26.28M
3	6.5	0	$194.35M
4	7.5	0	$180.67M
5	8.0	79	$33.28M
6	8.5	0	$143.86M
7	12.0	8	$128.70M
8	19.0	68	$50.95M
9	19.5	23	$103.69M
10	20.0	32	$101.57M
11	21.5	5	$118.87M
12	30.5	0	$132.70M

Solution 4 also manages to meet all generated demands but with a lower operational cost ($180.67M) compared to Solution 3, although with a higher average response time (7.5 days).

These examples illustrate the trade-offs players face when trying to optimize different aspects of their strategy. They show the complex decision-making processes involved in achieving the game's objectives, where players must balance factors like response time, cost-efficiency, and demand satisfaction. As this analysis suggests, there is no one-size-fits-all strategy in *HurricaneLog*, and players' decisions should be tailored to their specific objectives and priorities.

6.4 Exploratory insights and future avenues

In the preceding sections of this chapter, we have reviewed the experimental procedures employed, the data cleaning and preprocessing undertaken, and provided a preliminary overview of descriptive statistics from the *HurricaneLog* game dataset. While these initial analyses have provided valuable insights into players' behaviours and decision-making within the dynamic game environment, they merely scratch the surface of the wealth of information this dataset holds. Due to time constraints, an in-depth exploration of the data has been deferred, but the potential for uncovering intricate nuances remains. In this section, we offer a glimpse into the exciting possibilities that the *HurricaneLog* framework offers for unravelling players' decision-making strategies in the context of humanitarian logistics operations. In the following sections, we identify a series of research questions that can drive future investigations, and suggest methodologies that can be employed to answer these questions effectively. This insight into unexplored potential aims to inspire further research and shed light on the type of knowledge that can be extracted from the developed game-based platform.

6.4.1 Correlation between island's profile indicators and player's investment decisions

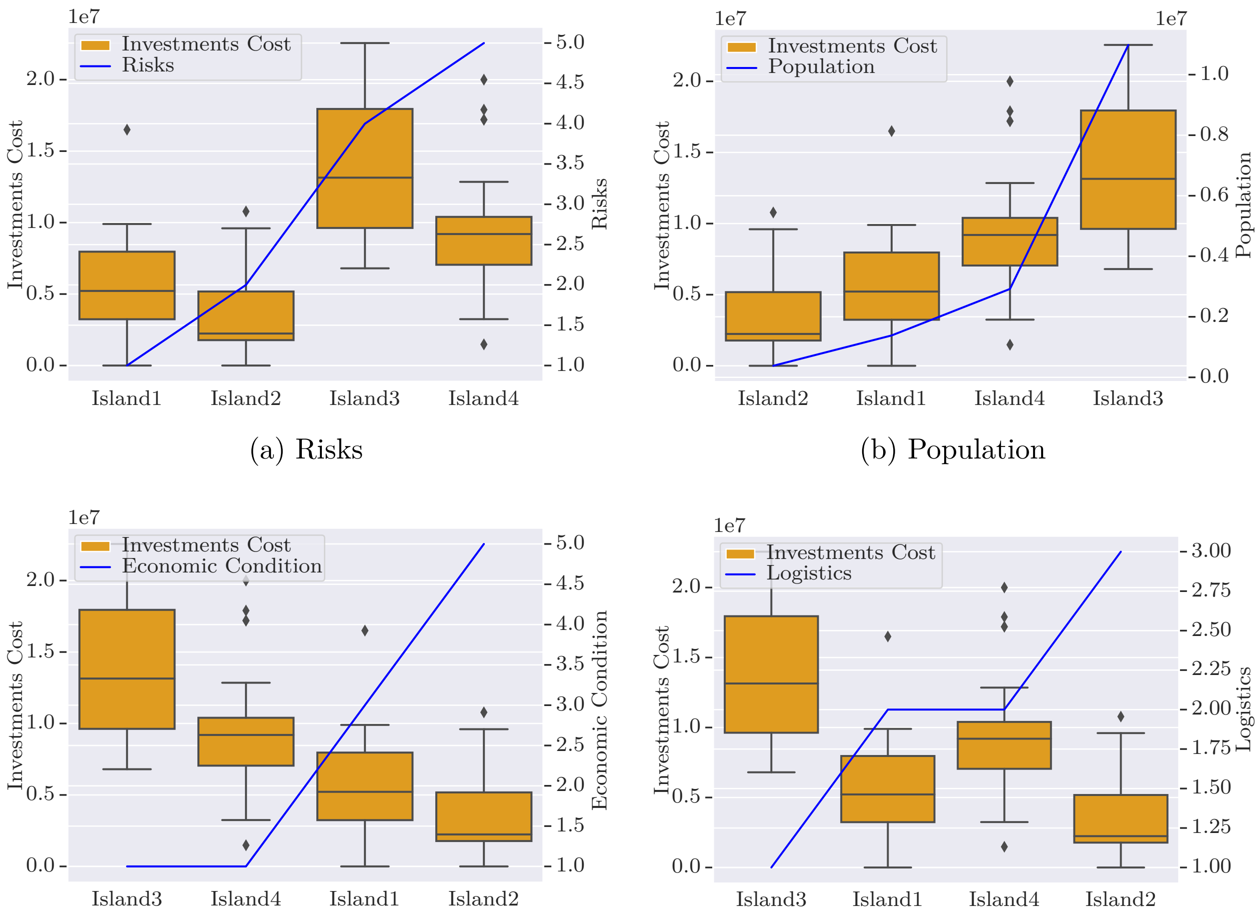
One area of investigation involves exploring potential correlations between the island profile indicators and the investment decisions made by players in the game. As described in Chapter 3, these profile indicators include the island's population size, economic condition, risk level, and logistic performance index, which together wield significant influence over disaster management strategies. Consequently, gaining insights into how players respond to these diverse island characteristics can yield invaluable understanding about their strategic decision-making.

To address this question, we conducted a correlation analysis using the Pearson correlation statistical test between the island profile indicators and the cost of investments made by the players during the preparedness phase of the game. The findings are summarized below:

- As illustrated in Figure 6.8a, the risk indicator exhibits a correlation coefficient of 0.50 (p–value < 0.001) with the investment cost. While this correlation is not perfect, its significance cannot be understated. In practical terms, this means that as the risk indicator for an island increases, players tend to allocate more resources, resulting in higher investment costs.

- The population size indicator appears strongly correlated with the investment cost, with a coefficient of 0.67 (p–value < 0.001) as shown in Figure 6.8b. This high correlation suggests that as the population of an island increases, players allocate more resources there. A possible explanation for this high correlation is that players might consider the population size when determining the number of family kits to preposition on the island. As the population rises, more families can be affected in case of a hurricane strike, requiring more family kits. This increased allocation of family kits can significantly raise the investment cost, as additional investments like increasing warehouse capacity may be necessary. This also explains the behaviour seen in Figure 6.8a; although island 4 has a higher risk level than island 3, the latter received more investments due to its larger population size.

- The economic condition and logistics performance indicators also presented interesting patterns (Figures 6.8cand 6.8d). The economic condition indicator exhibited a negative correlation of -0.62 (p–value < 0.001) with the investment costs, whereas the logistics performance indicator showed a negative correlation of -0.65 (p–value < 0.001). These negative correlations suggest that, as the economic condition of an island improves or its logistics performance becomes more efficient, players tend to allocate fewer resources to that island. This observation indicates that players might adopt different investment strategies in economically stable and logistically efficient regions, possibly focusing more on other aspects of disaster management, such as optimizing response operations.



(c) Economic Condition (d) Logistics

Figure 6.8 Investment cost distribution by island profile indicators. The islands are sorted regarding each indicator so as to maintain an increasing trend in the analyzed dimension.

These findings highlight the complexity of player decision-making within the dynamic game environment. Players adapt their investment strategies not only based on risk levels and population but also in response to the economic condition and logistics performance of the islands. Understanding these nuanced responses can inform disaster management strategies and contribute to more effective resource allocation in humanitarian logistics operations.

6.4.2 Impact of varied preparedness investment strategies on KPIs

Another aspect of investigation concerns exploring how different preparedness investment strategies influence the KPIs observed in the *HurricaneLog* game. The central question is whether distinct investment strategies, as clustered from player's investment decisions, significantly correlate with the player's results. This investigation examines the role of these strategies in achieving more effective disaster management outcomes.

To answer this question, we clustered the players with respect to their preparedness investment decisions. Each resulting cluster should represent a distinct investment strategy, thereby providing a comprehensive view of how players approach preparedness in the context of the game. This method allows us to explore emergent patterns and provide valuable insights into disaster management strategies.

To perform clustering, the investment decisions of each player are organized into an *investment matrix*, as illustrated in Table 6.3. In this table, the first column stores the number of family kits prepositioned by the player on each island, whereas the remaining columns correspond to the level of preparedness purchased by them regarding each one the six investment options available in the game. Note that regional investments are also represented in the last row of the investment matrix.

Table 6.3 Example of a player investment matrix.

	Preposition	Warehouse Capacity	Dist. Capacity	Comm.	Supplier Ag.	Regional Transp.	Customs Cl.
Island 1	0	0	0	2	0	0	0
Island 2	500	1	0	1	0	0	0
Island 3	10,000	2	1	0	0	0	0
Island 4	2,000	0	3	2	0	0	0
Regional	0	0	0	0	1	1	2

In clustering analysis, a fundamental ingredient involves establishing a dissimilarity between the entities to be clustered. This measure helps in keeping similar objects within the same cluster while separating different ones into distinct clusters. In our specific case, this dissimilarity measure between objects is determined by the Frobenius distance calculated between investment matrices. Thus, the dissimilarity between the investments matrices A^x and A^y

associated to two players x and y is calculated as:

$$d(A^x, A^y) = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{m}(a_{ij}^x - a_{ij}^y)^2}, \tag{6.1}$$

where n and m are the number of rows and columns of the players' investment matrices. Before computing the dissimilarity by means of the Frobenius distance, investment matrices are normalized by z-score scaling. This prevents variables with larger value ranges (here the number of prepositioned family kits) from dominating the clustering process.

In our analysis, the players' investment matrices were clustered with k-means into four groups, a choice made through empirical analysis considering the unique attributes of each cluster. In order to ease interpretation the resulting clustering was projected into two dimensions with t-Distributed Stochastic Neighbour Embedding (t-SNE) [112]. The projection is visually presented in Figure 6.9.

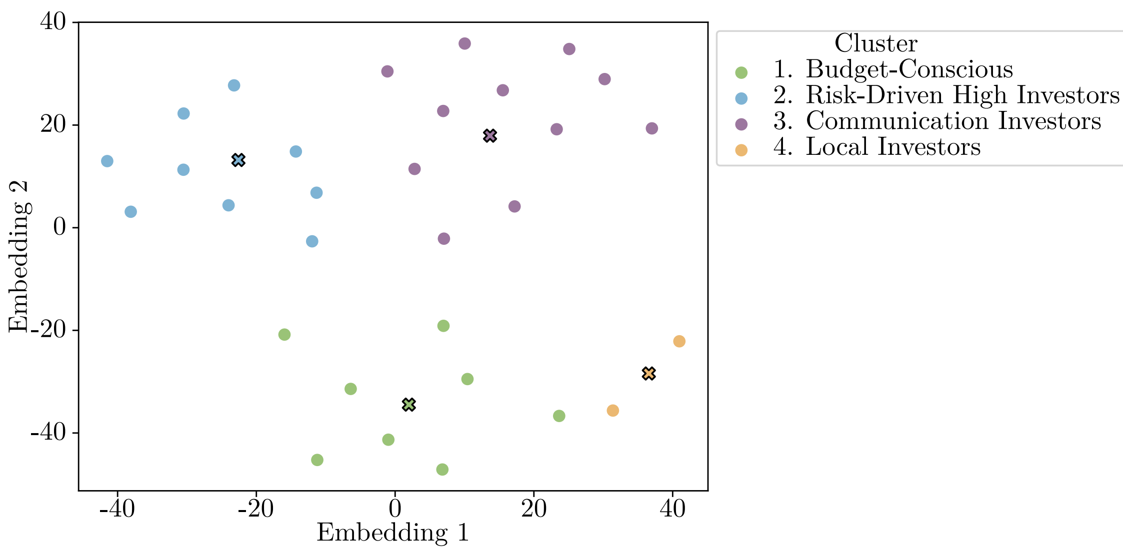


Figure 6.9 t-SNE visualization for the clustering of investment decisions obtained by k-means in our study. Each plotted point is associated to a distinct player.

In this visualization, we can observe well-separated clusters. Specifically, Clusters 1, 2, and 3 are relatively similar in size, comprising 8, 9, and 11 players, respectively. In contrast, Cluster 4 stands out with only two players. This discrepancy in cluster sizes suggests that the strategies represented by Clusters 1, 2, and 3 are more commonly adopted by players, while the strategy summarized by Cluster 4 is less often used.

Table 6.4 report the mean values of investment matrices found within each cluster. These values correspond to the clusters' centroids, hence representing the central tendencies found in each obtained cluster.

Table 6.4 Average investment matrices for the four clusters represented by color-coded rows.

	Preposition	Warehouse Capacity	Dist. Capacity	Comm.	Supplier Ag.	Regional Transp.	Customs Cl.
Island 1	34,312.25	1.00	0.38	0.25	0.00	0.00	0.00
Island 2	11,666.25	0.50	0.25	0.12	0.00	0.00	0.00
Island 3	72,256.00	1.75	1.50	0.75	0.00	0.00	0.00
Island 4	47,986.88	1.38	0.88	0.25	0.00	0.00	0.00
Regional	0.00	0.00	0.00	0.00	0.75	0.75	0.88
Island 1	16,523.78	1.11	1.00	0.89	0.00	0.00	0.00
Island 2	10,145.22	1.22	1.11	0.78	0.00	0.00	0.00
Island 3	51,531.00	2.44	2.44	2.33	0.00	0.00	0.00
Island 4	28,966.89	2.33	2.11	2.00	0.00	0.00	0.00
Regional	0.00	0.00	0.00	0.00	2.33	1.00	2.56
Island 1	33,231.82	0.91	0.64	2.45	0.00	0.00	0.00
Island 2	22,211.00	0.55	0.18	2.09	0.00	0.00	0.00
Island 3	71,450.55	1.82	1.64	2.55	0.00	0.00	0.00
Island 4	47,642.64	1.18	1.45	2.36	0.00	0.00	0.00
Regional	0.00	0.00	0.00	0.00	1.73	0.91	1.91
Island 1	18,749.00	1.50	1.00	1.50	0.00	0.00	0.00
Island 2	15,610.50	1.50	1.00	1.50	0.00	0.00	0.00
Island 3	119,569.00	3.00	2.00	1.50	0.00	0.00	0.00
Island 4	70,000.00	2.00	2.50	1.50	0.00	0.00	0.00
Regional	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Together, the strategies represented by the four clusters primarily revolved around the prepositioning of family kits in areas of high risk and large population density. Cluster 1 comprises budget-conscious players who made modest investments with an intermediate focus on prepositioning family kits. Cluster 3, labeled as "communication and information sharing investors", shares characteristics with Cluster 1 but emphasizes investments in *Communication and Information Sharing*. Cluster 2 prioritizes higher investments in riskier and more populous islands but with a reduced amount of prepositioned family kits in comparison with the other strategies. Cluster 4, named "local investors", abstains from regional investment options, channeling their budgets into family kit prepositioning, resulting in the highest average prepositioning of kits among all clusters.

To assess the influence of these investment strategies on KPIs, we calculated the average KPI values for each player in the cluster to represent *cluster-level* KPIs. They are are presented in Table 6.5. We remark from the table that:

- None of the investment strategies achieved a zero percentage of unsatisfied demands, implying that none of them fully met all demands.
- There exists a correlation between family kit prepositioning and response costs. Clusters with higher family kit prepositioning, such as Cluster 4, exhibit lower response costs, while those with lower prepositioning, such as Cluster 2, face higher response costs.
- Cluster 1, which is characterized by minimal investments, records the highest average response time due to limited investments.
- Cluster 4, despite prepositioning the most family kits, records the highest percentage of unsatisfied demands, possibly due to insufficient investments in international supplier agreements.
- Cluster 2, with an extensive investment strategy, experiences the lowest average response time, likely attributed to increased investments and the higher response cost incurred for expedited family kit transfers using planes.

Table 6.5 Mean KPIs for the players associated to the clustered investments matrices.

	Avg. response time	% unsatisfied demands	Preparedness cost	Response cost
Cluster 1	23.56	29	36,944,510	67,203,070
Cluster 2	11.05	21	47,027,370	82,979,700
Cluster 3	21.81	21	48,376,780	75,825,250
Cluster 4	21.75	41	45,741,420	41,359,370

In conclusion, our analysis reveals that the varied preparedness investment strategies adopted by players in the *HurricaneLog* game have a significant impact on KPIs. This finding highlights the importance of the players' investment choices in molding disaster management outcomes within the game.

6.4.3 Performance Evaluation of Response Strategies

Further study can be conducted to evaluate the different response strategies adopted by players and how they impact KPIs within the game. Analyzing these variations allows us to gain insights into the influence of these strategies on game outcomes and, consequently, on decision-making during the response phase.

We performed a clustering analysis to group players based on their response strategies within the game. This analysis was done using the players' transfer decisions, represented by a *transfers matrix* where each row corresponds to a player, and each column to a feature related to the player's transfer decisions, namely:

- Frequency: The total number of transfer decisions made by the player.
- Days between transfers: The average number of days between transfer decisions.
- Mean transfer by plane (#Family kits): The average number of family kits transferred by plane.
- SD transfer by plane (#Family kits): The standard deviation of family kits transferred by plane.
- Mean transfer by ship (#Family kits): The average number of family kits transferred by ship.
- SD transfer by ship (#Family kits): The standard deviation of family kits transferred by ship.
- Recency (days): The number of days between the most recent transfer and the end of the hurricane season.
- Preventive transfers: The number of transfers made to the affected island before the hurricane hit.
- Reactive transfers: The number of transfers made to the affected island after the hurricane hit.

To ensure that each feature contributed equally to the clustering analysis and to eliminate potential biases introduced by varying feature scales, we applied z-score scaling to standardize the transfer matrix data.

The first seven features are directly adapted from the cluster analysis of financial transactions presented in [113]. These features can be straightforwardly extracted from the transfer decisions data collected by the game. However, the two last features, i.e. *preventive transfers* and *reactive transfers*, require additional data processing. These features were purposefully designed to encapsulate players' actions during response operations, taking into account the behaviour of hurricanes.

Defining the criteria for categorizing transfers as preventive or reactive demands consideration of the time window before and after a hurricane's impact. The initial presumption is that all transfers executed before an island is hit by a hurricane can be deemed as preventive.

Yet, pinpointing the boundary between preventive and reactive transfers becomes crucial, particularly when a transfer decision is made just prior to a hurricane's arrival. To address this challenge, a comprehensive assessment of potential player-triggering scenarios across the islands was performed.

Three distinct types of scenarios were identified: (i) the emergence of a forecast uncertainty cone over the island, implying a potential but uncertain hurricane impact with lower probability; (ii) the appearance of a forecasted hurricane track over the island, indicating a higher likelihood of a direct hit; and (iii) the actual occurrence of the hurricane striking the island. An illustrative depiction of such scenarios is portrayed in Figure 6.10.

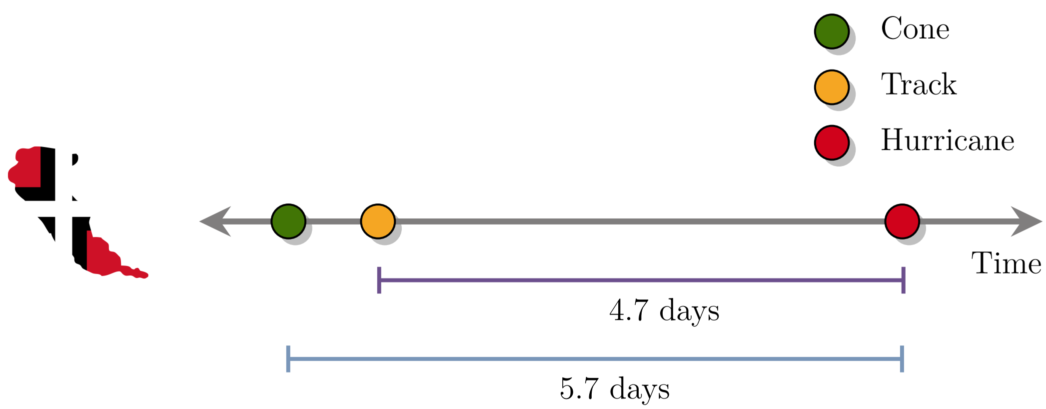


Figure 6.10 Example of scenarios that can trigger a player reaction.

The time intervals between scenarios (i)-(iii) were measured (e.g., in Figure 6.10 (i) occurs 5.7 days before the hurricane strikes the island, and (ii) 4.7 days before that) and averaged, to establish a standardized time window of reactivity prior to hurricane impact. This calculated period was found to be 5.5 days for all hurricane events in the simulated hurricane season. This same time definition was symmetrically applied for characterizing transfers as preventive post-hurricane impact. With these parameters established and informed by the collected damage events, the process of assigning values to the preventive and reactive transfers fields becomes straightforward. Following this definition, any transfer decision made within the range of 5.5 days prior to and after a hurricane's impact is categorized as reactive, while transfers occurring outside this range are designated as preventive.

The application of k-means, with $k = 5$, for clustering the rows of the transfers matrix allowed to identify well-separated clusters representing unique response strategies adopted by segmented groups of players.

Table 6.6 displays the mean values of response strategies within each cluster, representing their central tendencies. It also displays in the last row the number of players belonging to each of the clusters found.

Table 6.6 Mean response strategies for each identified cluster.

Cluster	**1**	**2**	**3**	**4**	**5**
Frequency	5.00	11.22	3.78	2.00	5.50
Days between transfers	2.36	0.60	2.72	20.94	1.65
Mean transfers by plane	31,011.53	55,391.17	146,710.99	165,979.17	110,473.67
SD transfer by plane	23,545.57	54,494.18	117,220.72	14,839.17	37,521.69
Mean transfers by ship	5,859.01	29,364.97	1,277.78	806.33	76,281.40
SD transfer by ship	4,678.78	9,041.78	0.00	0.00	54,180.30
Recency	36.29	20.58	36.10	39.29	27.94
Preventive transfers	0.50	4.22	1.00	0.67	1.00
Reactive transfers	4.50	7.00	2.78	1.33	4.50
# of players	6	9	9	3	2

All identified strategies displayed a higher number of reactive transfers compared to their respective number of preventive transfers. Additionally, each strategy included at least one transfer by ship. Most strategies showed a relatively low average number of days between transfers, except for Cluster 4, where the average was 20.94 days between transfers. Here's a closer look at each cluster's characteristics:

- Cluster 1 is characterized by "reactive low spenders" which presented low average number of family kits transferred compared to the other clusters. It is also characterized by its reactive behaviour, having about 90% of its transfers classified as reactive.

- Cluster 2 named "frequent senders" had the lowest average number of days between transfers compared to the other clusters. They also had the highest number of transfers made, indicated by the frequency feature. This behaviour, along with indicators suggesting that a portion of these transfers fell into the "preventive" category, while others were considered "reactive", implies that players adopting this strategy likely executed multiple transfers in close proximity to the borderline between the 'preventive' and 'reactive' definitions (i.e. the hurricane occurrence). Some of these transfers may have been initiated just before the 5.5-day window, classifying them as preventive transfers, while others were likely carried out immediately after the beginning of the 5.5-day window, placing them in the reactive category.

- Cluster 3 and 5 exhibited comparable strategies, characterized by substantial numbers of transferred family kits. Notably, Cluster 5 presented a higher average number of family kits transported via ships and conducted transfers at shorter intervals compared to Cluster 3.

- Cluster 4 describes the "wait and observe" strategy. Players in this cluster made transfers with a significant time interval between them. They likely initiated some transfers in the region and waited until hurricanes posed a danger to the islands or even waited until after the hurricane hit, resulting in a high number of family kits transferred.

To gain further insights, we assessed how these strategies influenced the game's KPIs. To determine the *cluster-level* KPIs, we calculated the average KPI values for each player within each cluster. The resulting *cluster-level* KPIs are presented in Table 6.7.

Table 6.7 Mean KPIs of the clustered response strategies.

	Avg. response time	% unsatisfied demands	Preparedness cost	Response cost
Cluster 1	12.25	62	42,627,836.00	24,733,552.83
Cluster 2	21.67	14	44,992,981.33	85,803,526.56
Cluster 3	21.00	03	48,930,844.00	101,901,240.00
Cluster 4	17.17	31	33,783,324.00	70,104,686.67
Cluster 5	31.25	19	44,999,240.00	76,433,985.00

We remark from the table that:

- None of the investment strategies achieved a zero percent of unsatisfied demands, indicating that none of them was able to meet the demands for familiy kits raised in the game. However, Cluster 3's strategy was clearly the best, achieving a percentage of unsatisfied demands close to zero.

- There is a correlation between response costs and percentage of unsatisfied demands among these identified strategies. Clusters with lower percentage of unsatisfied demands, such as Cluster 3, are associated with higher response costs, while those with higher percentage of unsatisfied demands, such as Cluster 1, relates to lower response costs.

- Cluster 1, identified as "reactive low spenders", records the highest percentage of unsatisfied demands due to a limited number of family kits transferred, also suggesting an absence or limited use of international suppliers. In particular, our observations indicate a recurring pattern: low average response times often coincide with high percentage of unsatisfied demands (see section 6.3.3). Through this empirical investigation, we have discerned that prepositioned family kits are promptly utilized to address initial demands. Moreover, when players exhibit both characteristics – low average response time and a high percentage of unsatisfied demands – it implies that they tend to stop the transfer of additional family kits to the affected region, then maintaining a shorter average response time.

- Cluster 2 presents the second lowest percentage of unsatisfied demands, with 14% of the demands remaining unfulfilled at the end of the game. Surprisingly, despite the rapid, sequential transfer pattern exhibited by players who adopted this strategy, it proves ineffective, as it leads to increased response cost without yielding a significant reduction in the average response time. In fact, the average response time associated with this strategy surpasses the overall average response time of all strategies. This reveals the learning potential of *HurricaneLog* on helping humanitarian agents to devise more effective response strategies during critical operations.

- Cluster 3, referred to as "demand fulfillers", achieves the lowest percentage of unsatisfied demands among all clusters. However, it also has the highest associated response cost, likely due to the focus on meeting all unsatisfied demands, leading to the purchase of family kits from international suppliers.

- Cluster 5 presents the highest average response time among all other strategies. This higher score is partially explained by the large number of transfers using ships, which are slower than planes. Although 81% of the demands were met, the response cost associated with this strategy is not significantly higher than that of Cluster 4, which is also explained by the use of ships instead of planes.

Following clustering, we conducted a one-way ANOVA to evaluate the impact of the identified response strategies on KPIs. The results, as shown in Table 6.8, indicate a statistically significant difference among clusters in terms of percentage of unsatisfied demands (F-score = 5.29, p-value = 0) and the response cost (F-score = 5.25, p-value = 0). In ANOVA, the F-score, also known as the F-statistic, measures the ratio of variance between groups to the variance within groups. A high F-score suggests that there exist significant differences between the group means, indicating that the response strategies have a notable impact on the percentage of unsatisfied demands and response cost. In this case, the low p-values (p-value = 0) indicate strong evidence against the null hypothesis, further confirming the statistical significance of these differences. However, the KPIs average response time and preparedness cost did not exhibit significant differences across clusters (p-values > 0.05). This result was expected for the preparedness cost KPI, as none of the features used in the clustering presented in this section are related to this performance index.

Additionally, we performed a Tukey's test to identify which specific clusters present significant differences in the percentage of unsatisfied demands. The results revealed that Cluster 1

Table 6.8 ANOVA for clusters KPIs centroids.

	F-score	p-value
Avg. response time	1.17	0.35
% unsatisfied demands	5.29	0
Preparedness cost	2.45	0.07
Response cost	5.25	0

("reactive low spenders") and Cluster 2 ("frequent senders") had statistically significant differences in their means. Similarly, significant differences were observed between Cluster 1 and Cluster 3 ("demand fulfillers") (see Table 6.9 for details). The test was not made regarding Clusters 4 and 5 due to their very reduced size, 3 and 2 respectively.

Table 6.9 Multiple Comparison of *% unsatisfied demands* KPI Means - Tukey HSD, FWER=0.05

group1	group2	meandiff	p-adj	lower	upper	reject
1	2	-0.48	0.01	-0.87	-0.08	True
1	3	-0.59	0.00	-0.99	-0.19	True
2	3	-0.11	0.87	-0.46	0.24	False

We also conducted a Tukey's test for the response cost KPI, and like the previous test for the percentage of unsatisfied demands, it revealed significant differences in means, specifically between Cluster 1 and Cluster 2 and between Cluster 1 and Cluster 3 (details in Table 6.10).

Table 6.10 Multiple Comparison of *response cost* KPI Means - Tukey HSD, FWER=0.05

group1	group2	meandiff	p-adj	lower	upper	reject
1	2	61,069,973.72	0.01	9,911,523.61	112,228,423.83	True
1	3	77,167,687.16	0.00	26,009,237.05	128,326,137.27	True
2	3	16,097,713.44	0.83	-29,659,795.38	61,855,222.27	False

These results align with the differences presented in Table 6.7. Clusters 2 and 3 exibit similar average scores for the percentage of unsatisfied demands, both with low values and for response cost, both with high costs. In contrast, Cluster 1 stands out by having higher percentage of unsatisfied demands and lower response cost.

In summary, our analysis reveals that various response strategies exert differing impacts on the game's KPIs, with a notable influence on the percentage of unsatisfied demands and response cost. These findings highlight the important role of the chosen response strategy in shaping the effectiveness of disaster management operations within the game.

CHAPTER 7 CONCLUSION

Humanitarian logistics serves as the pillar of any successful humanitarian operation, ensuring essential resources reach those in need. It constitutes a significant portion, approximately 80%, of the overall operational costs [114]. For this reason, the logistics decisions made by humanitarian agents are crucial in determining the outcome of these operations, dictating whether they achieve success or face failure. The implications of these decisions extend beyond mere budget allocations; they directly impact the lives of millions of individuals worldwide who depend on timely and effective assistance.

The success of responses to humanitarian emergencies relies on the utilization of data to inform evidence-based planning and decision-making [18]. Building upon this understanding, this research developed a comprehensive data collection framework to support data analysis. Leveraging the dynamic environment of the *HurricaneLog* game, this framework collects critical data on players' decision-making in two important phases of humanitarian operations, namely preparedness and response. In the preparedness phase, players are tasked with preparing the region for eventual hurricane disasters. These preparation activities involve various investments, including family kit prepositioning and dimensioning of distribution capacity. During the response phase, players face one hurricane season and are challenged with coordinating relief efforts, as well as managing the logistical challenges of delivering aid to affected islands. This research seeks to address an existing gap in the literature, where previous humanitarian serious games have not fully explored both preparedness and response actions and their implications within a region comprising multiple countries or islands. Moreover, none of these games have proposed a decision-making data collection solution that has the potential to reveal effective strategies and potential shortcomings through facilitated analysis.

The fundamental goal was to design a game that effectively collects data about the decision-making process of humanitarian logistics operations. Through the *HurricaneLog* game, we demonstrated how a carefully crafted simulation can capture the strategic decisions, resource allocations, and tactical choices of players as they interact with the complex domain of disaster preparedness and response. Moreover, *HurricaneLog* offers players insight into the challenges faced by logistics managers in humanitarian operations. This is achieved by aligning our design and mechanics with real-world data and information from literature. All these, while working the challenge of balancing the game level of abstraction to guarantee realism while still providing an entertaining experience.

As we explore the insights obtained from our research, it is essential to acknowledge that the act of data collection, particularly in the context of humanitarian logistics, plays an important role in seeking improvements. The information we have accumulated serves as an example, showcasing the potential of the game on pointing toward better decision-making, more effective planning, and ultimately, enhanced outcomes in the challenges of disaster management.

Looking ahead, it's crucial to address the limitations of our research, which may provide guidance for future research in this domain.

7.1 Limitations

The *HurricaneLog* game has inherent design limitations. One notable constraint is the level of abstraction within the game. While the game aims to replicate elements from humanitarian operations in pursuit of realism, some real-life operations had to be abstracted to enhance the game's entertainment value. Abstraction is a crucial aspect of game design, influencing how rules and narrative elements interact within the game environment. It delineates the range of actions available to players and what can be perceived within the game world [115].

In a typical humanitarian supply chain logistics scenario, the process of shipping relief supplies encompasses multiple stages. These include procuring supplies and determining their destination, arranging transportation, preparing the necessary international transport documents, deciding on the mode of transport, communicating with various stakeholders at different points in the process, planning the routes to reach the destination, and strategizing the distribution of supplies to the affected population. The game could choose to replicate these stages in detail or represent the supply chain process more abstractly by adjusting the quantities of relief items between nations. Achieving the right level of abstraction was a critical design decision that needed to align with the game's objectives. Too much detail could overwhelm players, while too much abstraction could lead to an oversimplified experience.

To mitigate this issue, the supply chain aspect of the game was simplified. It involves fewer decision actions on the player's part while retaining the critical elements of humanitarian supply chain logistics. This simplification was achieved by grouping logistics process stages into seven categories: transportation procurement, preparation for transportation, actual transportation, unloading, customs clearance, transport to the warehouse, and distribution. After relief items are transported between two nations, these seven processes automatically execute in sequence without requiring player intervention. The success of each process is contingent upon the investments made by the player during the preparedness phase. This approach strikes a careful balance, making concessions on certain aspects of a realistic representation of humanitarian logistics to ensure an engaging and enjoyable gaming experience.

Furthermore, the game's single-level design is another design limitation, that it, the game offers a fixed set of scenarios and challenges within a single level. While this design choice was intentional to maintain simplicity and accessibility, it may limit the depth of decision-making and the variety of scenarios players can experience. In real-world humanitarian logistics, operations vary significantly in terms of complexity and scale. Therefore, its single-level structure may not fully capture the diversity of challenges encountered in different humanitarian settings.

Although it is straightforward to simulate diverse hurricane seasons in the game, some reasoning and design choices must be made regarding the storms featured in each season. The analysis of the trajectories of these storms is crucial to avoid extended periods during the game where no storms or hurricanes appear in the region of interest. Hurricanes can follow various paths throughout the Atlantic, and some storms might spend their entire existence outside the game's area, potentially leading to player's disengagement.

Building on the discussion of limitations, the relatively small sample size also presents a constraint. Data were collected from 29 participants who engaged in the *HurricaneLog* game. Although this sample provided valuable insights into decision-making strategies, it may not comprehensively capture the full spectrum of potential participants or conditions relevant to real-world operations. A larger and more diverse sample size could offer better statistical results and a more comprehensive understanding of decision patterns.

It is worthy noting that this discussion about the limitations of the developed game is not supposed to be exhaustive. Indeed, additional limitations may become apparent as the game is further tested and experimented.

7.2 Future Research

While this research has made significant progress in understanding decision-making processes within the context of humanitarian logistics, it also provides a broader spectrum of possibilities for future studies. The framework produced in this research serves as a solid foundation for further exploration and analysis, with several promising avenues for future research.

7.2.1 *HurricaneLog* as a pedagogical tool

One area of exploration is the use of *HurricaneLog* in learning contexts. First, in supply chain management classes as a complementary teaching tool to the concepts of humanitarian supply chain. The game mechanics favours learning on:

- The importance of **situations awareness** by limiting the investment budget in the preparedness phase, mimicking the scenario faced by humanitarian logistics managers before a natural disaster. Thus, players are compelled to better understand investment options before choosing them.
- Players are given the opportunity to learn about the **importance of preparedness** by having access to the game's varied preparedness investment options, which were extracted from the literature and meetings with disaster risk management professionals. The game also highlights outcomes of preparedness investments by simulating real impacts in the game response operation, providing feedback through damage reports regarding the player's investment decisions.
- *HurricaneLog* provides learning of **tailored decisions** by exposing players to islands with different characteristics and needs. This profile diversification, coupled with the limited budget, compels players to thoughtfully consider the unique attributes of each island. Thus, they must elaborate strategies to make informed investments that address the specific needs of each island.
- Players are required to perform **quick-actions** during response operations, as the game intentionally does not allow pausing during response phase. This creates a continuous operation feeling that fosters a sense of urgency, mirroring the real-life decision-making context experienced by humanitarian agents.

The potential for using *HurricaneLog* as an educational tool has already shown promise, as we conducted a successful pilot test during the EURO Humanitarian Operations Summer School in Humanitarian Logistics. This experience led to engaging discussions regarding strategies and the role of international suppliers and family kit prepositioning in operation outcomes. We are currently preparing a pedagogical note that explains how to integrate *HurricaneLog* into an educational setting, offering guidance for educators interested in incorporating the game into their courses or training programs.

Additionally, the game holds potential as a training tool for humanitarian logistics agents, providing a platform to simulate a wide range of preparedness and response strategies, while enabling the evaluation of decision impacts via the game's KPIs.

Lastly, *HurricaneLog* can be employed as an informational tool to educate the general public about the challenges faced by humanitarian organizations in preparing and delivering assistance.

7.2.2 Performance improvement upon subsequent playthroughs

An important research question that future studies may address is whether players can enhance their performance after playing the game for a second time. This question is essential for assessing the game's effectiveness as a learning tool and its ability to facilitate skill development in humanitarian logistics.

To address it, one can measure and compare players' KPIs between their initial playthrough and their second encounter with the game. KPIs, including response time, percentage of unsatisfied demands, preparedness cost, and response cost, can be recorded during two or more play sessions, serving as quantifiable metrics to assess the player's performance variation over time.

In case players exhibit improvements in their KPIs upon their second playthrough, we can determine whether these improvements are statistically significant by means of statistical tests that compare the KPIs of players between their first and second game experiences. The findings from this investigation should provide insights into the learning curve of the game and offer valuable information on the effectiveness of the game as a tool for enhancing decision-making skills in disaster management.

7.3 Improvements on the game

As the *HurricaneLog* game continues to evolve, multiple possibilities emerge to enhance the player's experience and unveil new avenues for research and exploration.

7.3.1 Randomized hurricane seasons and island characteristics

One promising direction for improving *HurricaneLog* is to introduce randomness into the game's core elements. By implementing randomized hurricane seasons and varying island characteristics, the game can provide players with an ever-changing and unpredictable environment. This not only increases replayability but also mirrors the real-world unpredictability of natural disasters. Research opportunities emerge in exploring how players adapt their strategies in response to such randomized scenarios, analyzing the decision-making dynamics in uncertain humanitarian contexts.

7.3.2 Support for other types of disasters

Expanding the game's focus to include other types of disasters beyond hurricanes expands the relevance and educational value of *HurricaneLog*. By incorporating scenarios involving different disasters, such as earthquakes, floods, or pandemics, players can gain insights into a broader range of humanitarian challenges. This expansion offers an intriguing avenue for research into the comparative decision-making processes and strategies across various disaster scenarios.

7.3.3 Introduction of scarce items

To make gameplay more interesting and realistic, the introduction of specific scarce items, such as excavation machines, can add complexity and strategic depth to the game. These items could be crucial for addressing e.g. road blockages, thus requiring the players to allocate resources efficiently to transport and utilize them. Research possibilities arise in examining how players adapt to the introduction of such scarce resources and the implications for decision-making in resource-constrained environments.

7.3.4 Multiplayer cooperation and coordination

Coordination is a critical aspect of humanitarian operations [116, 117]. In disaster situations, where hundreds of organizations mobilize, operations often lead to redundant resources and efforts [118, 116, 117]. Initiatives like the UN's Logistics Cluster were established to enhance the coordination of efforts and ensure they effectively meet the needs of affected people while remaining reliable, inclusive, and in line with humanitarian principles [119, 120].

HurricaneLog promotes regional collaboration by providing a platform where islands in a region can coordinate their efforts to better prepare for and respond to hurricane emergencies. However, the game has potential to extend the collaboration to players by fostering cooperation and coordination among them. One approach is to develop a multiplayer version where each player controls a different aspect of the humanitarian operation, such as distribution, shipments, customs, or procurement. This cooperative gameplay encourages teamwork and strategy, simulating the collaborative efforts of humanitarian organizations. Research in this area can explore the dynamics of teamwork, communication, and coordination in multiplayer settings, providing insights into humanitarian logistics collaboration.

7.4 Enhancing player performance with AI decision support

The application of artificial intelligence (AI) and machine learning techniques to model and predict the decision-making behaviour of humanitarian agents is another exciting field for future research. Developing predictive models that can anticipate the choices and strategies of humanitarian logistics professionals under various circumstances could offer invaluable tools for decision support in real-world disaster management. By incorporating AI into the *HurricaneLog* game, players could receive tailored, data-driven recommendations at critical decision points. This AI-enhanced decision support system would analyze in-game situations, player preferences, and available resources to suggest the most effective actions for a given scenario. Through this integration, players could benefit from AI-generated insights, allowing them to refine their strategies, enhance their performance, and learn from AI-generated recommendations to make more informed decisions. This research could explore AI's impact on player performance, the effectiveness of AI-driven decision support, and how such an approach might translate to real-world decision-making in humanitarian logistics operations.

7.5 Contributions of this thesis

In conclusion, this thesis offers significant contributions to the field of humanitarian logistics and decision-making. It introduces an innovative and comprehensive data collection framework, featuring a serious game that strikes a delicate balance between realism and abstraction, effectively simulating the challenges faced by decision-makers in humanitarian logistic operations. Additionally, it presents a unique and robust data collection infrastructure. This integrated framework not only provides a controlled environment for assessing decision-making strategies but also facilitates valuable training and learning enhancements through data-driven insights. Furthermore, it offers educational value by allowing players to experiment with the impacts of their choices, while data analysis helps identify areas for improvement and reveals operational challenges, thus providing practical insights. These contributions not only advance the field but also showcase how serious games can drive innovative solutions and enhance disaster relief and humanitarian logistics operations.

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APPENDIX A TUTORIAL DESIGN

The main objective of the game is data collection. However, as the game is substantially complex and has only one level, players need to acquire knowledge about how the game works before the data collection process is performed. Otherwise, it can be difficult to identify whether one player's performance was inferior to the other due to a lack of knowledge or not knowing how to play the game. Thus, the game was built to teach its use through a tutorial in a special level.

The tutorial begins in a separate level from the main one. Here, the player is guided through the different interactions available in the game. This tutorial covers both phases of the game, demonstrating concepts such as making investments, types of investments, evaluation of the player, transferring family kits, etc. The information is presented through text balloons that explain each step, and to draw the player's attention to the relevant object, indicative arrows are used. An example of one of these balloons with its associated arrow can be seen in Figure A.1. To simplify the learning process, the information is divided into blocks (i.e., player roles, islands in the region, game phases, investments, budget, hurricanes, damages, transfers, KPIs). Additionally, each step is given a pause or a considerable amount of time to allow the player to read the information presented carefully. Experienced players who can comprehend the information more quickly can skip ahead without having to wait for the allotted time to pass.

In addition to teaching the player how to interact with the game, the tutorial was designed with two other objectives in mind: (i)engagement and (ii)non-interference. The first objective was to ensure that the player was unlikely to abandon the tutorial. Beginners usually have a harder time than experts in picking up a new game, so it is necessary to create a balanced experience that gradually introduces the game's complexity, allowing beginners to learn without being overwhelmed and experts to remain engaged [121]. To achieve this, we drew inspiration from modern game tutorials, where the player learns through exploration and interaction with the game. We introduce each game function intrusively, meaning that the player is temporarily limited to what is being presented. However, once the player has been taught about an action or content, they are free to interact with the game and use what they have learned without interruption. For example, once the investment concept is presented, they are free to invest in any of the islands without any tutorial interruptions. This allows the player to explore different possibilities without it affecting their performance in the main level.

Figure A.1 Depiction of the tutorial.

The second objective is to use the tutorial to teach the player about the game's functions, but without influencing their decision-making. For instance, it should not teach the player that the only way to play is to invest in a specific investment option, or that their operation will be better if they transfer family kits before a hurricane hits an island. To avoid this, the tutorial only presents general information about important points, leaving the player to decide what is best for them. Regarding investments, all options are presented in general and the player is encouraged to read each one carefully, in order to understand the differences between them and how each one affects their operation. When transferring resources, the tutorial explains how it is done, but does not indicate whether it should be done beforehand or after the hurricane has hit. It also presents the different vehicle options and their associated characteristics (e.g., airplanes are faster, but have a higher cost). Therefore, it is expected that players, considering their KPIs, can choose the options that best suit their game strategy.

APPENDIX B PLAYTESTING QUESTIONNAIRE

Rules / Explanation

Q1 - What could have been explained better or earlier when I was teaching the game?

Q2 - What do you wish you knew when you first started playing?

Q3 - Is there anything you feel like you still don't understand, even after finishing the game?

Play / agency

Q4 - What did you want to do, but couldn't or was unable to do?

Q5 - Were you decisions meaningful, or did they feel like they didn't matter?

Q6 - What were you asked to memorize / internalize / recall ? Was this too much for a game like this?

Strategy / tactics

Q7 - How would you describe your strategy?

Q8 - What other strategies did you think of?

Q9 - Would you say you knew how your decisions affected the outcome of the game?

Q10 - Would you think you would be able to play better next time?

Emotions / feelings

Q11 - What kind of emotions or feelings did you feel / notice as you played?

Q12 - Which elements helped you feel immersed in the theme of the game?

Q13 - Which elements took you out of the game's theme?

Q14 - What moments were the most fun? What moments felt like work, or were boring?

Q15 - What felt balanced or unbalanced? (Remember we're focusing on feelings here, not the raw math of things.)

Overall

Q16 - How long did the game feel (too short, too long, just right) ?

Q17 - Did the mechanics work well with the theme?

Q18 - Comments / Remarks

APPENDIX C GAME PARAMETERS

Table C.1 Summary of the game parameters.

Parameter	Value
Truck capacity	1 container
Handling time	1 hour/container
Procurement time	$X \sim \mathcal{N}(\mu = 2, \sigma^2 = 0.25)$
Transport to port/airport time	1 hour/container
Container capacity	200 kits
Loading/unloading time	30 minutes
International transportation time	Tables 4.5 and 4.6
Customs clearance time	$X \sim$ Modified Skewed-Normal distribution with interval of 2 to 7 days
Transport to warehouse time	2 hours/container
Family kit international preparation time	$X \sim \mathcal{N}(\mu = 17.5, \sigma^2 = 1)$
Port/airports fixing time	48 hours
International transportation cost	Tables 4.7 and 4.8
Family kit international preparation cost	\$51.80/family kit

APPENDIX D GAME QUESTIONNAIRE

Questionnaire

Q1 - What is your current field of work?

- Student
- Agriculture, Food and Natural Resources
- Architecture and Construction
- Education and Training
- Business Management and Administration
- Arts, Audio/Video Technology and Communications
- Finance
- Government and Public Administration
- Health Science
- Hospitality and Tourism
- Human Services
- Information Technology
- Law, Public Safety, Corrections and Security
- Manufacturing
- Marketing, Sales and Service
- Science, Technology, Engineering and Mathematics
- Transportation, Distribution and Logistics

Q2 - What type of course are you enrolled in?

- Applied Economics

- Business Analysis - Information Technologies
- Business Analytics
- Business Intelligence
- Applied Economics, Finance and Mathematics
- Entrepreneurship
- Finance
- Human Resource Management
- Management
- Marketing
- Professional Accounting
- Project Management
- Sustainable Development Management
- Biomedical Engineering
- Civil Engineering
- Computer Engineering
- Electrical Engineering
- Energy Engineering
- Engineering Physics
- Industrial Engineering
- Applied Mathematics
- Mechanical Engineering
- Metallurgical Engineering
- Software Engineering
- Aerospace Engineering

- Geological Engineering
- Mining Engineering

Q3 - Which year of study are you currently in?

○ 1^{st}

○ 2^{nd}

○ 3^{rd}

○ 4^{th}

○ 5^{th}

○ 6^{th}

○ 7^{th}

Q4 - How many years of professional experience do you have in your field of work?

○ None

○ Less than 1 month

○ At least 1 month but less than 3 months

○ At least 3 months but less than 1 year

○ At least 1 year but less than 3 years

○ At least 3 years but less than 6 years

○ At least 6 years but less than 10 years

○ 10 years or more

Q5 - How many years of work experience do you have in logistics and operations management?

○ None

○ Less than 1 month

○ At least 1 month but less than 3 months

○ At least 3 months but less than 1 year

○ At least 1 year but less than 3 years

○ At least 3 years but less than 6 years

○ At least 6 years but less than 10 years

○ 10 years or more

Q6 - How many years of work experience do you have in the humanitarian sector?

○ None

○ Less than 1 month

○ At least 1 month but less than 3 months

○ At least 3 months but less than 1 year

○ At least 1 year but less than 3 years

○ At least 3 years but less than 6 years

○ At least 6 years but less than 10 years

○ 10 years or more

Q7 - Have you ever studied logistics?

○ Yes

○ No

Q8 - What is the highest level of education you have completed? (If you are currently enrolled in school, please indicate the highest degree you have received.)

○ Less than a high school diploma

○ High school degree or equivalent (e.g. GED)

○ Some college, no degree

○ Associate degree (e.g. AA, AS)

○ Bachelor's degree (e.g. BA, BS)

○ Master's degree (e.g. MA, MS, MEd)

○ Professional degree (e.g. MD, DDS, DVM)

○ Doctorate (e.g. PhD, EdD)

○ Prefer not to say

Q9 - What type of gamer would you consider yourself to be?

○ Not a gamer

○ Casual (i.e., you dabble in games but in short sessions or infrequently)

○ Mid-core (i.e., you regularly play video games but are not very serious or competitive)

○ Hardcore (i.e., you are a dedicated gamer and play seriously or competitive)

Q10 - Which of these platforms do you usually play games on?

○ Console (Xbox, PlayStation, Nintendo Switch docked w/TV)

○ PC/Mac (Desktop, Laptop)

○ Smartphone/Tablet (iOS, Android, etc.)

○ Handheld Console (handheld Nintendo Switch, PS Vita)

○ VR (Oculus Quest/Rift, PlayStation VR, etc.)