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Towards a digital twin of the PRM service in airports based on semantic tools

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Abstract

This article presents an approach to the digital twin of an airport, which aims to assist in the management of passengers with reduced mobility (PRM). Various technologies and data models have been employed to simulate the life cycle of PRMs within airports, identifying the different resources required at each stage of the journey. A Goal Oriented Action Planning (GOAP) model is utilized to simulate the behavior of PRMs. The Unity Real-Time Development Platform was employed to program the simulation and visualize the path of the PRMs in a virtual representation of the airport facility, based on an imported Industry Foundation Classes (IFC) model. A data semantic integration approach was utilized to facilitate the connection between data collection and processing in the design of the digital twin.

Keywords: Digital Twin; Passengers with Reduced Mobility; Airport Management; Simulation

1. Introduction

The number of passengers with reduced mobility (PRM) transiting through European airports is increasing and they represent a growing proportion of the total number of passengers. European regulations stipulate that airport managing bodies must guarantee PRM assistance services free of charge and with a high level of quality, and that the cost of PRM assistance services must be charged equally to all passengers using the airport. A logical consequence of such a regulatory context is the need for more resources and more investment by airport management in this service, which is generally reflected in air fares.

The planning and real-time operation of PRM assistance at airports is subject to a high degree of uncertainty from a number of sources, including:

- incidents of airport operations such as flight cancellations, delays or diversions;
- the dynamic nature of airport facilities, which require continuous maintenance and modifications that affect the evolution of the service, such as when some areas or airport facilities become inoperable.;
- the circumstances of the PRM assistance service at airports, such as assistance requested without prior reservation, which must be provided in accordance with European regulations.

The management of PRM services is even more complex due to the number of stakeholders involved in the process: airlines, ground handlers, airport managers and

PRM assistance service managers need to exchange data dynamically in order to provide a timely and quality service and avoid delays that can affect the entire airport operation.

The depicted scenario highlights the need to develop new tools that can help the PRM service managers to make better decisions, improve their coordination with other stakeholders, and allow them to respond more quickly to changing situations in daily operations. For example, problems related to the assignment of assistance agents to PRM services, the sizing or relocation of agents based on demand, or the redistribution of material resources (ambulifts, wheelchairs, etc.) could benefit from more robust decision frameworks.

The digitization and automation of systems is proving to be the most effective way to move towards decision support systems linked to real systems. In this sense, and especially in more controlled environments, such as the industrial one, the use of digital twins is increasing in recent years. In the large service infrastructure sector, the implementation of these systems has been slower due to the high uncertainty and variability of the processes involved. In addition to the complexity of the environment, one of the major constraints to the most rapid integration of these systems is the existence of multiple information systems that need to interoperate adequately. For this purpose, Semantic Web technologies appear as a promising opportunity to facilitate communication between heterogeneous systems, to capture and formally relate domain knowledge, and even to enable inference from existing information to find new relationships and knowledge.

To obtain an effective digital twin of an organization such as an airport, even focused on a specific problem such as PRM management, there are many intermediate steps to be taken. These include the adequate reproduction of the physical environment of the infrastructure; the incorporation of business logic to be able to simulate the behavior of the fundamental elements of the system (such as human resources or passengers); the definition of the communication with the sensors and actuators placed in the facility; or the creation of dashboards that facilitate decision making more related to the strategic or planning level.

This conference contribution focuses on the creation of a simulation/visualization environment of the PRM service in an airport based on UNITY (`https://unity.com`). The digital twin uses the Building Information Modeling (BIM) of the airport to generate the virtual environment. Within it, the key physical elements of the airport service are semantically identified, such as: boarding gates, check-in counters, PRM meeting points, etc. In turn, airport operational data such as flights, attendants, agents, etc. are loaded into the simulation environment from a semantic repository based on a PRM service ontology.

2. State of the art

Despite the lack of consensus in a unique definition, the term digital twin has been in use for more than 20 years. Reviews such as those of Barricelli et al. (2019) have collected almost 30 different definitions, generally connected to the construction of a virtual representation of a specific manufacturing process or device. The concept has evolved to cover a wider range of potential "twins", from plants in farming management (Skobelev et al., 2020), to organizations (Parmar et al., 2020) or infrastructures (Khan et al., 2022). In the specific field of airport management, the closest approach that we can find in the literature is that from Conde et al. (2022), who developed a digital twin of the airport with the aim of reducing delays in commercial flights due to flight turnaround events.

Digital twins are not merely simulations; rather, they require a seamless connection, and real-time data exchange between the digital and physical worlds in order to enable a continuous (or, at least, periodic) synchronization between both twins (Barricelli et al., 2019). Besides, digital twins can be applied to different levels of the physical system (component, process ...), and at different life-cycle phases (design, decomission ...) (Abisset-Chavanne et al., 2024).

Barricelli et al. (2019) also defined a common set of characteristics that usually identifies a digital twin. One of such characteristics is that they constantly receive data from different sources, so they "must exploit proper ontologies for data comprehension and formalization". The term ontology can be defined as a "formal and explicit specification of a shared conceptualisation of a domain of interest" (Gruber, 1993). Therefore, an ontology can be used to establish common semantics for the data from different sources, providing a shared and machine-comprehensible vocabulary for information exchanges between dispersed interacting agents. This way, the use of Semantic Web technologies represent an opportunity to achieve an effective digital twin, especially when we move from pure manufacturing environments (which are controlled environments by definition) to infrastructure or organization onsets.

Karabulut et al. (2024) systematically reviewed the joint use of ontologies and digital twins. They differentiated their findings according to the objective of the ontology, i.e., system/data modeling, semantic interoperability, semantic relation extraction, and reasoning facilitation. They also distinguished among the layers of the digital twin architecture where the ontology is used (both internally to a layer, e.g. to describe concepts in the physical layer; and among layers, i.e., to map concepts from the physical to the digital layer). Their discussion highlighted the opportunities that ontologies bring to the generalization and adoption of digital twins.

Notwithstanding the substantial investment of companies such as Amazon in integrated digital twin solutions (Amazon Web Services, Inc., 2024), there is still gap for addressing these challenges with other tools. In our work, Unity (Unity Technologies, 2024) represents a pivotal component in the development of the digital twin. Other projects have also employed this engine for this purpose. For example, Chen et al. (2024) use Unity to develop a tangible airport digital tower system that supports collaborative air traffic management operations using an augmented reality headset. Jiang et al. (2023) utilize Unity to develop an ubiquitous digital twin model for the information management of complex infrastructure systems based on Domain-Driven Design. Li et al. (2022) integrate Unity and Robot Operating System (ROS) to develop a digital twin for a small-scale robotic manufacturing station. Robles et al. (2023) introduce an open-source framework designed to create compositional digital twins: these are sophisticated digital replicas that connect various entities or subsystems to form a more complex digital twin, facilitating the sharing of knowledge and data connections. Within this flexible framework, Unity was used to build 3D representations of the components of this digital twin.

3. Design of the digital twin framework

The management of PRMs at an airport involves a number of processes and resources, as already analyzed in a previous contribution (Herrera Martín and Castilla Rodríguez, 2019). Resources include agents, who are the assistants who accompany PRM at the airport, to or from the aircraft they are boarding or disembarking from; and drivers who handle the ambulifts. For departures, PRMs arrive at the airport in advance and go to a meeting point, where one or more agents come to assist them. The agents accompany the PRM to the aircraft and assist them through check-in and security. At the boarding gate, the agents escort the PRM to the aircraft, either through the jet bridge or assisted by an ambulift. Once the PRMs are on the aircraft, the agents continue to assist them until they are seated. A similar process is followed for arrivals and transferring.

The design of our digital twin mimics real-time operations involved in managing PRM assistance. Figure 1 summarizes the main components involved in the digital twin and the information flows among them. Solid black arrows represent information flows driven by semantic web technologies, i.e., information flows where the ontology serves as an interoperability driver. According to the definitions in the review from Karabulut et al. (2024), our ontology would follow the objectives of serving as a common system/data modeling and enhancing the semantic interoperability among the involved systems. The ontology is available at https://gitlab.com/ull_ontologies/paremont/v1.0, and defines the collection of concepts and relationships related to the PRM management in an airport. It contains 122 classes, 84 object properties and 27 data properties, intended to represent the data required for all service quality control, service operations and tactical service planning. The full description of the methods, results and usage examples for the ontology are currently under review and awaiting publication.

Returning to Figure 1, the schema divides the components of the digital twin into three layers: physical, digital and application.

3.1. Physical layer

The physical layer, where the actual agents and PRMs reside, requires the deployment of a number of sensors to effectively track real-time operations. For instance, we would require indoor location tracking systems for all PRMs, agents, and other resources, including ambulifts. Additionally, crowd monitoring technologies (Fadzil1 et al., 2021) would be beneficial for identifying optimal routes. Beacon technology and/or RFID could be employed to collect this information. This data would be utilized to feed the visualization engine after being interpreted in terms of the ontology classes and relationships. The physical layer also includes the devices that the agents would utilize, which would receive the instructions generated by the optimization and analysis applications connected to the simulation engine. Once again, the ontology would serve to transform the results of such applications into meaningful instructions to the agents.

3.2. Digital layer

Essentially, the digital layer contains the simulation/visualization engine. This layer is responsible for the online visualization of current airport operations, as well as for the simulations required to analyze the impact of unexpected situations and to support subsequent decision-making processes.

In this article, we propose the use of Unity as a potential solution to develop this engine. As a development and gaming engine, Unity provides a programming environment that enables the creation of routines and other functionalities, thus facilitating the development of a simulation engine that is directly connected to the visualization functionalities. Unity offers a range of functionalities that may be suitable for incorporation into a digital twin, including: a graphics engine for rendering 2D and 3D graphics; an embedded simulation of physical laws; programming and scripting capabilities; and a smooth integration with various artificial intelligence tools and algorithms.

The simulation/visualization engine receives inputs from several sources defined in the physical layer (sensors measuring real-time operations), but also in the application layer (such as the infrastructure layout, and third-party systems that define supplementary information on flights, the remainder of passengers or bookings for PRM assistance services). This engine also interacts with optimization and data analysis applications.

3.3. Application layer

The application layer encompasses a number of applications and information systems that are either directly or indirectly connected to the digital layer.

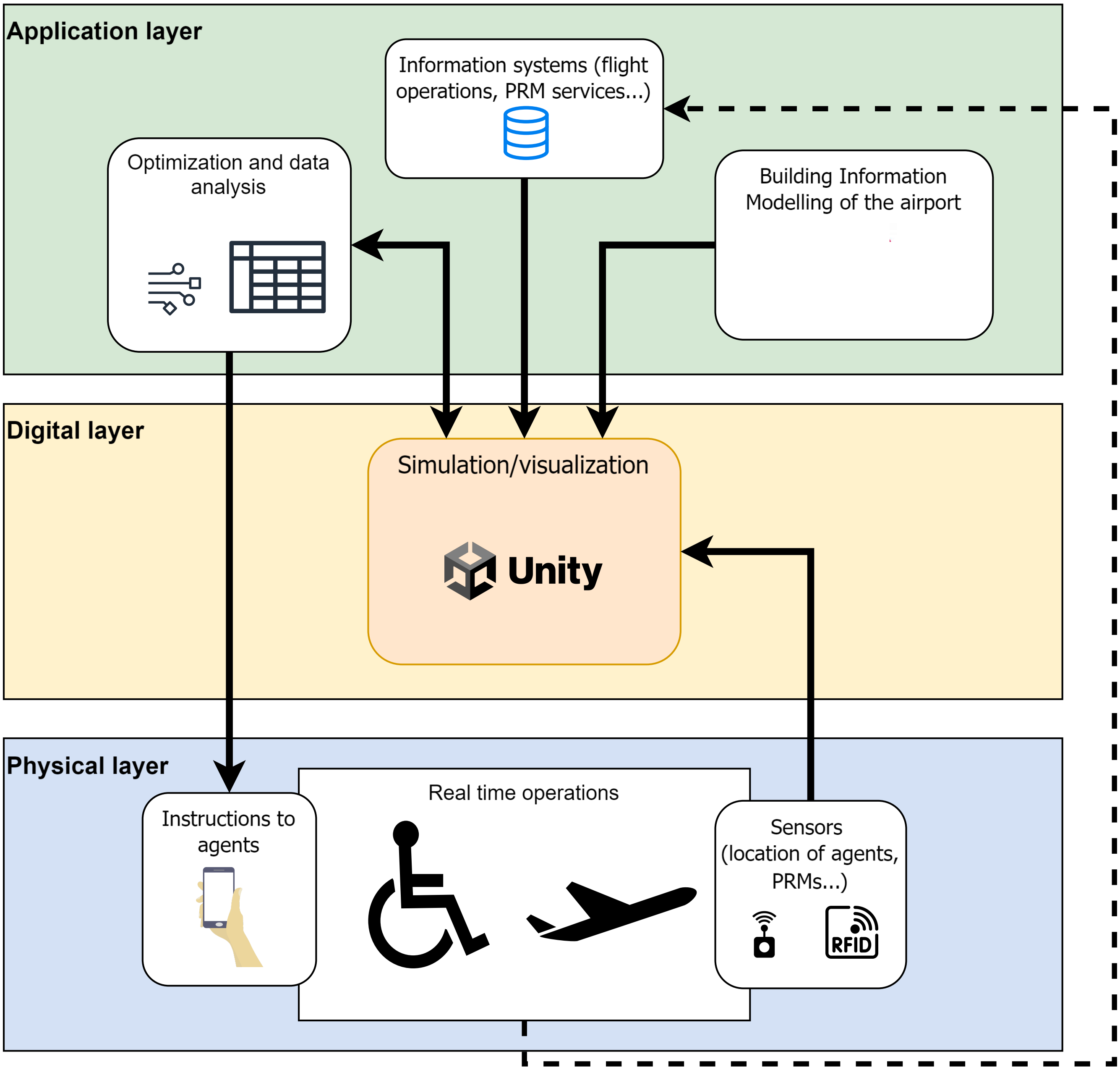


Figure 1. General schema of the components of the proposed solution. Solid black arrows represent interactions where interoperability is enabled by means of semantic web technologies. Dashed arrows represent other information flows.

The digital twin uses a BIM model of the airport to represent the virtual 3D environment of the facility. The BIM model is represented in accordance with IFC schema and serves to generate and sustain the visualization/simulation scenario. Despite the fact that IFC has become the *de facto* standard for BIM information exchange, it is a complex and redundant scheme due to the necessity to represent objects and relationships for a wide range of architecture, engineering, construction and operation (AECO) subdomains (Eastman et al., 2010). The use of Semantic Web technologies and ontologies (e.g., ifcOWL) provide greater ability to integrate, combine, and link building data with data from other domains. (Herrera-Martín et al., 2022).

Furthermore, the digital twin receives and processes information from the third-party information systems that handle the current state of flight operations (in order to react to incidents, delays, etc.), but also the PRM booking system for assistance services. The defined ontology serves as a common interoperability framework among these information systems and the digital twin. Consequently, a common knowledge corpus unifies concepts

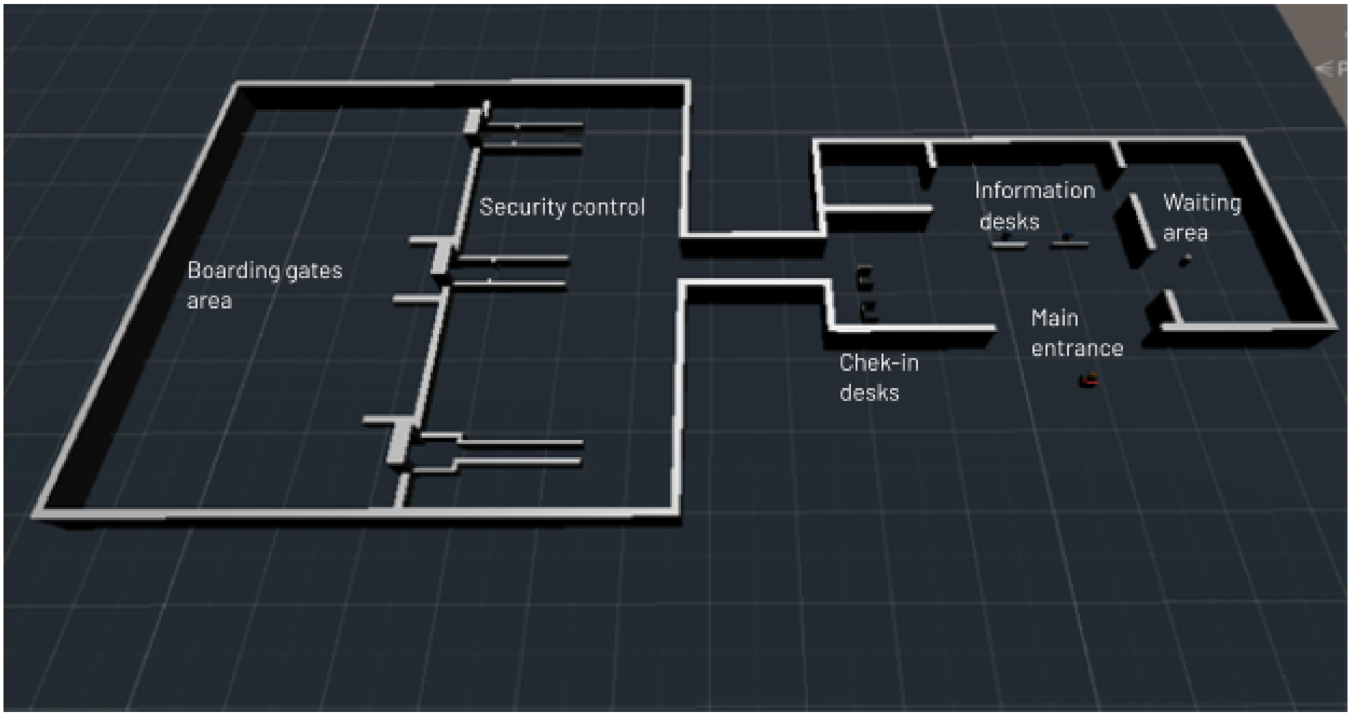


Figure 2. General layout of a simplified airport

such as Flight, PRM, Passenger or Agent.

Finally, this layer would provide space for the implementation of various optimization and data analysis applications. For instance, at the operational level, there would be applications to assist in the assignment of agents to services, as well as to create optimal routes through the dynamic environment of the airport, relying on simulation results in the event of an unexpected occurrence (hence the bidirectional arrow between this box and the simulation engine). There would also be room for applications at he planning level, such as tools for creating shift rosters or determining workforce requirements.

4. Prototype of the visualization/simulation engine

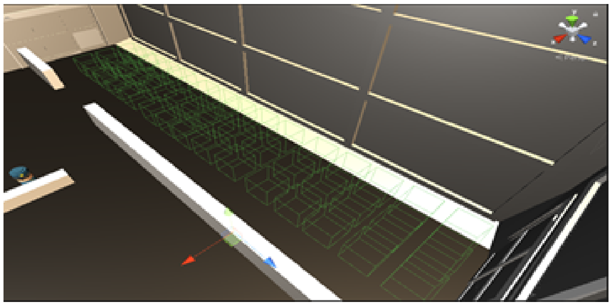
Although the entirety of the digital twin is still in the design phase, a preliminary prototype of the simulation and visualization engine has been developed, based on a simplified airport (Figure 2). At present, the engine is only capable of simulating the departure workflow of PRMs, and it is not linked to a physical system. Nevertheless, Unity facilitates this kind of connection in a straightforward manner, as evidenced by previous contributions (Robles et al., 2023; Li et al., 2022).

This simple layout comprises the same key areas as an actual airport:

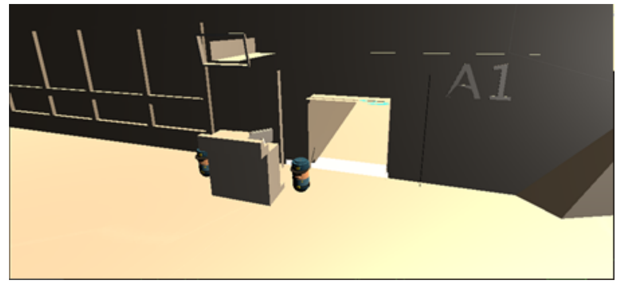
- Main entrance: The entry point for PRMs. In the simulation, the PRMs spawn around this area.
- Information desks: Some of the PRMs are assumed to move first to the information desks.
- Waiting area (Figure 3a): The area where PRMs wait for the agents to start the assistance service.
- Check-in desks (Figure 3d): PRMs are accompanied by agents to these desks. The simulation may include different check-in strategies, such as centralized or separated desk for PRMs, and priority lines.
- Security control (Figure 3c): The next stop for PRMs is the security control. As with check-in desks, different strategies would be implemented in the simulation depending on the service needs.
- Boarding gates area (Figure 3b): The simulator may consider that airlines implement different boarding strategies for PRMs, such as making them enter the aircraft first, or even last; as wekk as utilizing alternative routes or ambulifts.

In our prototype, agents move following the Goal Oriented Action Planning (GOAP) model (Orkin, 2008). This model defines *actions* that agents are capable of undertaking, such as going to the waiting room. These *actions* are accompanied by a set of *preconditions* and *effects*. *Preconditions* are necessary requirements for a particular *action* to be planned, while *effects* modify the state of the simulation and determine which new *actions* can be planned next. *Goals* (such as "boarding") are also defined for the agents.

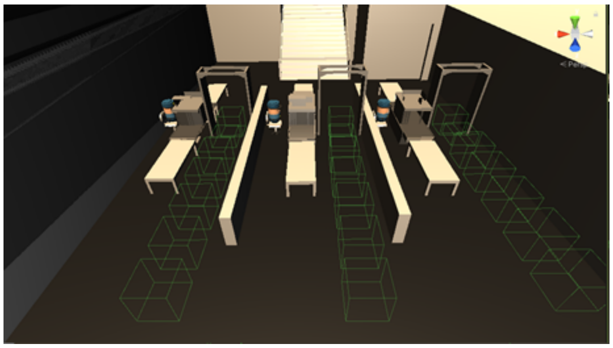
The GOAP model employs a dynamic approach to planning sequences of *actions* that enable agents to achieve their *goals*. Each action is associated with a cost, so if there is more than one sequence of *actions* that can achieve a



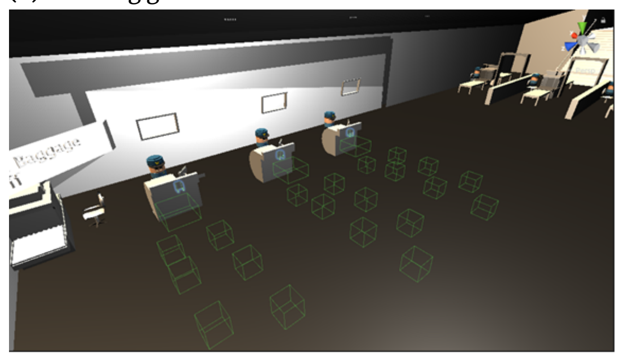
(a) Waiting area



(b) Boarding gate



(c) Security control



(d) Check-in area

Figure 3. Detail of some key areas of the airport's digital twin.

goal, the sequence with the lowest cost is planned. Moreover, each agent is capable of pursuing multiple *goals*, with a specific order of priority. Consequently, the planner endeavours to attain the most prioritized *goal*, and if that is not feasible, it attempts to devise a plan for the subsequent one, and so forth.

Since *actions* depend on certain *preconditions* being met, if we change the conditions of the simulation, these *actions* may no longer be available. This will force the GOAP system to plan a different sequence of *actions* to fulfill a certain *goal*, or even to discard a *goal* and plan actions to achieve another *goal* of lower priority.

The versatility of the GOAP system in action planning allows for the simulation of different scenarios and analysis of the agents' performance in achieving their goals, which in turn provides insights that inform decision-making in the real scenario. For instance, unanticipated circumstances, such as flight delays or congested areas impeding the passage of PRMs, can be simulated to compel the GOAP system to dynamically replan the actions of agents transporting PRMs to take different routes or select alternative destinations. Subsequently, the impact of the aforementioned unanticipated occurrence on the time required for the PRMs to reach their new destination would be evaluated. Based on the findings of this analysis, a determination is made as to whether any alternative course of action should be implemented in the actual scenario.

5. Conclusions

The utilization of flexible technologies, such as Unity, enables the creation of a visualization/simulation engine that accurately reproduces the airport layout and the real-time actions of PRMs and their assistants within the airport environment. This same system can be employed to simulate and assess different solutions when unexpected events occur, such as the accumulation of passengers in a specific area of the airport, maintenance interventions, or flight delays. Further work is required to achieve a fully functional digital twin: in its current level of development, our approach involves simulation but not an actual interaction with the real environment. Nevertheless, the prototype presented in this paper provides evidence that a feasible solution is possible.

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