A Multi-Agent Microsimulation Model of Toronto Pearson International Airport

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Abstract

Toronto Pearson International Airport is both the largest and busiest airport in Canada, but due to its size and complexity, many of its system behaviours may not be well understood. In this report, an agent-based microsimulation model of the airport terminals is proposed, encompassing passenger and baggage movements within the facilities as well as some vehicle movements around the terminals. This model includes five main classes, providing detailed attributes and behaviours for all parts of the terminals and the agents who use them, as well as three state transition diagrams that outline the steps of initializing and running a simulation. While this model is primarily a conceptual framework, some potential sources of data for calibration and validation are discussed, as are the interactions of the airport with other major infrastructure and regulatory systems in the Greater Toronto Area. Finally, the potential use of this model as a planning and improvement tool is considered.

1. Introduction

Located on the western edge of the City of Toronto, Pearson International Airport is Canada's largest and busiest airport, moving over 41 million passengers each year on nearly 450,000 flights [1]. The terminal facilities at Pearson are immense, consisting of hundreds of check-in stations, security checkpoints, customs and border preclearance facilities, traveller amenities, and more, all spread across millions of square feet of space in two buildings, shown in Figure 1. Additionally, the airport serves as a temporary home to hundreds of aircrafts, and a more permanent home to dozens of airside vehicles and the Link train that connects both terminals. Moreover, these facilities, services, and vehicles must all work together in a complex system to safely and efficiently move thousands of passengers every day.

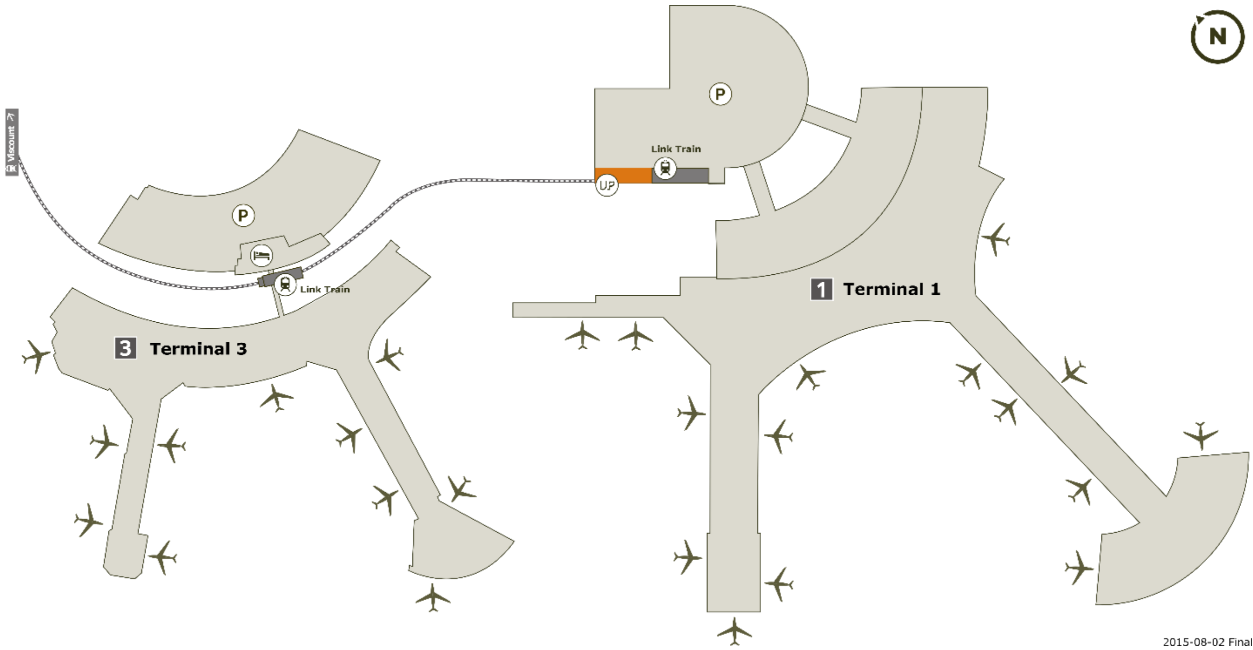

Figure 1: Map of Toronto Pearson International Airport [2]

In this report, an agent-based microsimulation model of Pearson Airport's terminals is proposed, starting with an overview of the two terminals and their major components. Based on this information, sets of major classes and sub-classes are outlined, detailing their attributes and behaviours. Next, the relationships between these classes are described and the information flows that influence these relationships and behaviours are highlighted, including details about how the model steps through time. Finally, some sources of calibration and validation data are provided, and the airport's interactions and relationships with other systems are explored. Using this model, it will be possible to gain a better understanding of Pearson Airport's complex behaviours based on the behaviours of its numerous sub-systems.

2. Model Framing and Background

At the most basic level, an airport terminal is a system that moves passengers from one aircraft to another, or between aircraft and ground transportation (cars, buses, trains), but there is plenty more to consider when developing a model of the facility. First, to manage the scope and level of detail in this model, passenger movements within both terminals are the primary focus, from curbside doors and Link train stations on the landside to airplanes on the airside [3]. The passenger movements include arrivals, departures, and transfers from all domestic, international, and trans-border gates across both terminals [4], but do not include any "meeters and greeters" or passengers simply using the facility to transfer between surface transit modes. In addition to passengers, this model also accounts for their baggage (checked and carry-on) as well as basic vehicle movements between terminals and on the tarmac (airplanes, baggage tugs, and the Link train).

For departing passengers, the process of using the airport starts at a curbside terminal door where they enter a check-in hall. Here, they have the option to rest in the lounge, make a purchase at a restaurant or shop, or use the washroom if needed. They proceed to a check-in point (staffed counter or automated machine) to obtain their boarding pass, drop any checked baggage off at a bag drop, then go to the security checkpoint that matches their flight destination. If the passengers are travelling to a destination in the United States, they will also have to proceed through Pearson's border preclearance facility, which handles roughly 10% of the airport's annual traffic [5]. After this stage, passengers enter what is known as the "sterile" part of the terminal, shown for Terminal 1 in *Figure 2*. This space offers a greater number of amenities including shops, lounges, and restaurants, as well as connections to the aircraft gates through which these passengers eventually depart. While passengers move through these walkable spaces and facilities, their bags are routed under their feet by a series of conveyors and sorting points, receiving their own security screening before reaching a tug loading station [6]. Once an aircraft is ready at a gate, tugs move the baggage from the terminal to the aircraft's cargo hold while passengers board the aircraft via the terminal gates.

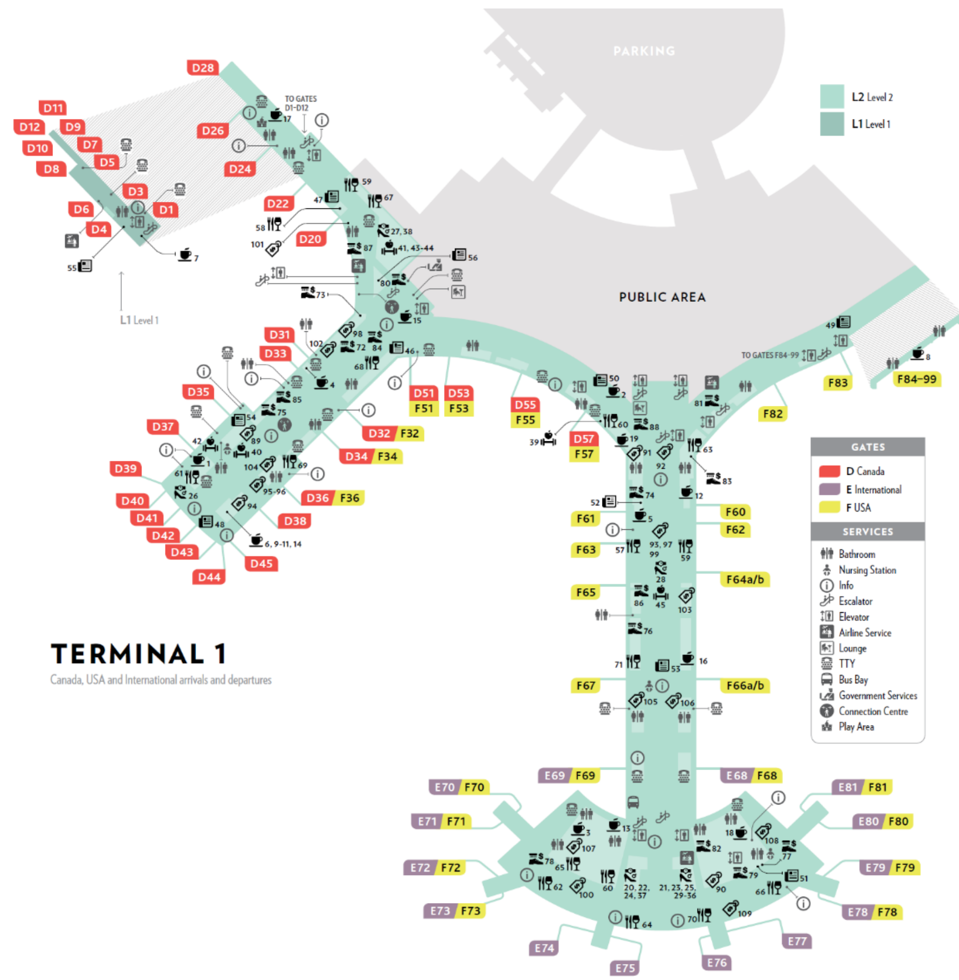

Figure 2: Pearson Airport Terminal 1 – After Security [7]

Arriving passengers and bags follow a similar, but reversed, process to reach their destinations – they exit their aircraft via the terminal gates or tugs, get reunited at a baggage claim carousel, then proceed to passport control (if their flight originated in the United States or internationally) before leaving the terminal. Finally, transfer passengers and bags follow many of the same steps as arriving passengers and bags, but may proceed straight from one gate to another within one terminal or use the Link train to move between terminals, behaving like departing passengers once they enter the second terminal.

3. Classes

Inside the airport system, five main classes and three major sub-classes are used to define the attributes and behaviours of each instantiated agent or object. Specifically, these are the airport class, which governs the overall simulation, the terminal object class, with sub-classes for passenger, baggage, and vehicle objects, and the three agent classes for each of vehicles, passengers, and baggage.

3.1 Airport Class

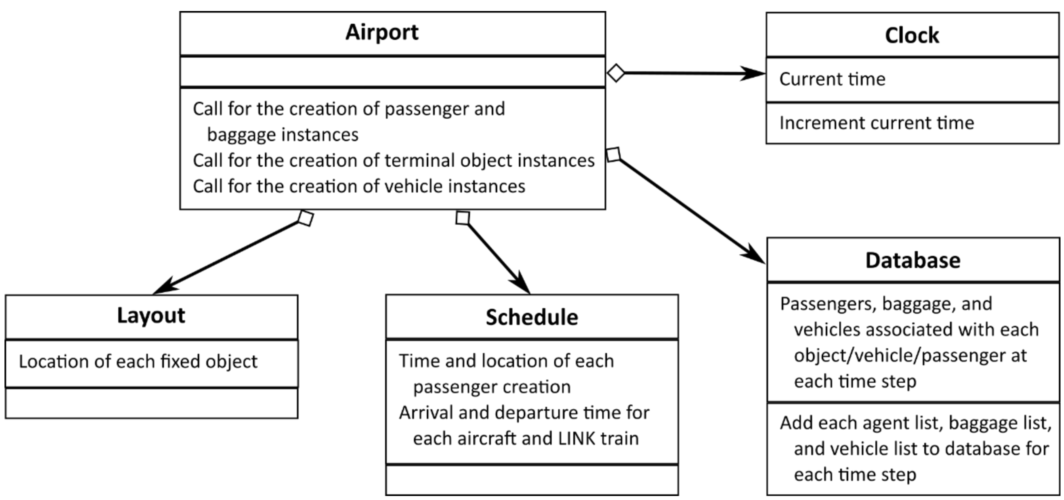

Figure 3: Airport class and associated objects

Framing the entire simulation model is the airport class, which is responsible for initializing the model, managing the creation and movement of vehicle agents, timing the creation of new passenger instances, and advancing the simulation clock. As shown in *Figure 3*, the class has three behaviours that involve calling for the creation of object and agent instances, in addition to four objects (layout, schedule, database, and clock). The layout and schedule objects are static and may be read, but not modified, by other classes and instances in the model, while the clock and database are dynamic and update themselves at each time step.

3.2 Terminal Object Class

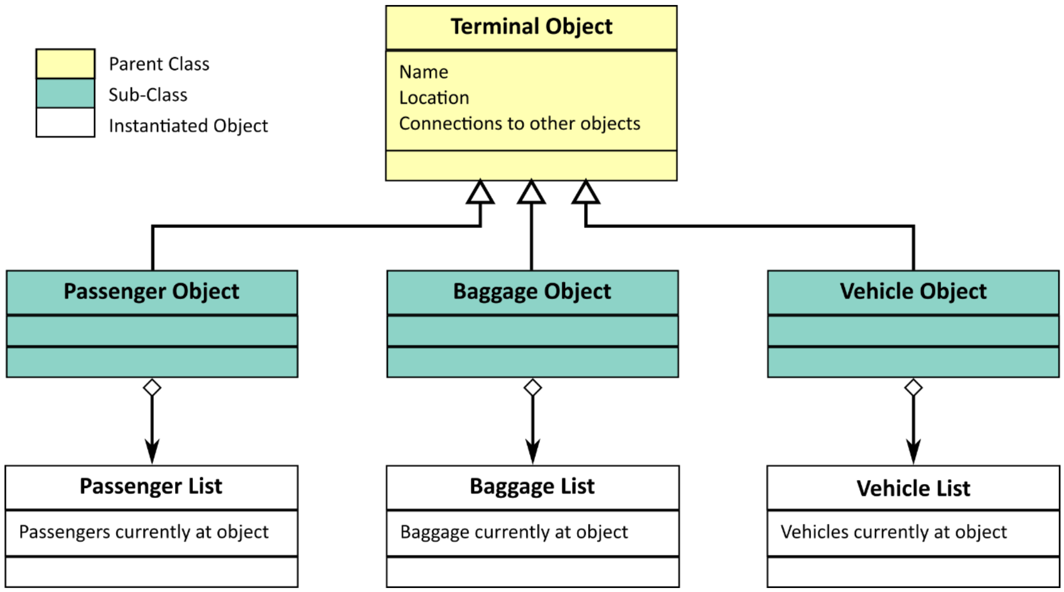

Figure 4: Terminal Object class, sub-classes, and associated list objects

Based on the layout object in the airport class, numerous objects from the terminal object class are instantiated to represent parts of the terminals at Pearson Airport and the airside tarmac and rail links between them. Generally, each terminal object has a name, location, and connections to other objects, all of which are specified by the airport layout. To better understand each type of terminal object, this class is broken down into three main sub-classes based on the primary agent class using each object – these are the passenger object sub-class, baggage object sub-class, and vehicle object sub-class. Each of these sub-classes is associated with a matching list object, as shown in *Figure 4*, which keeps track of the passengers, baggage, or vehicles currently associated with each instance.

3.2.1 Passenger Object Sub-Class

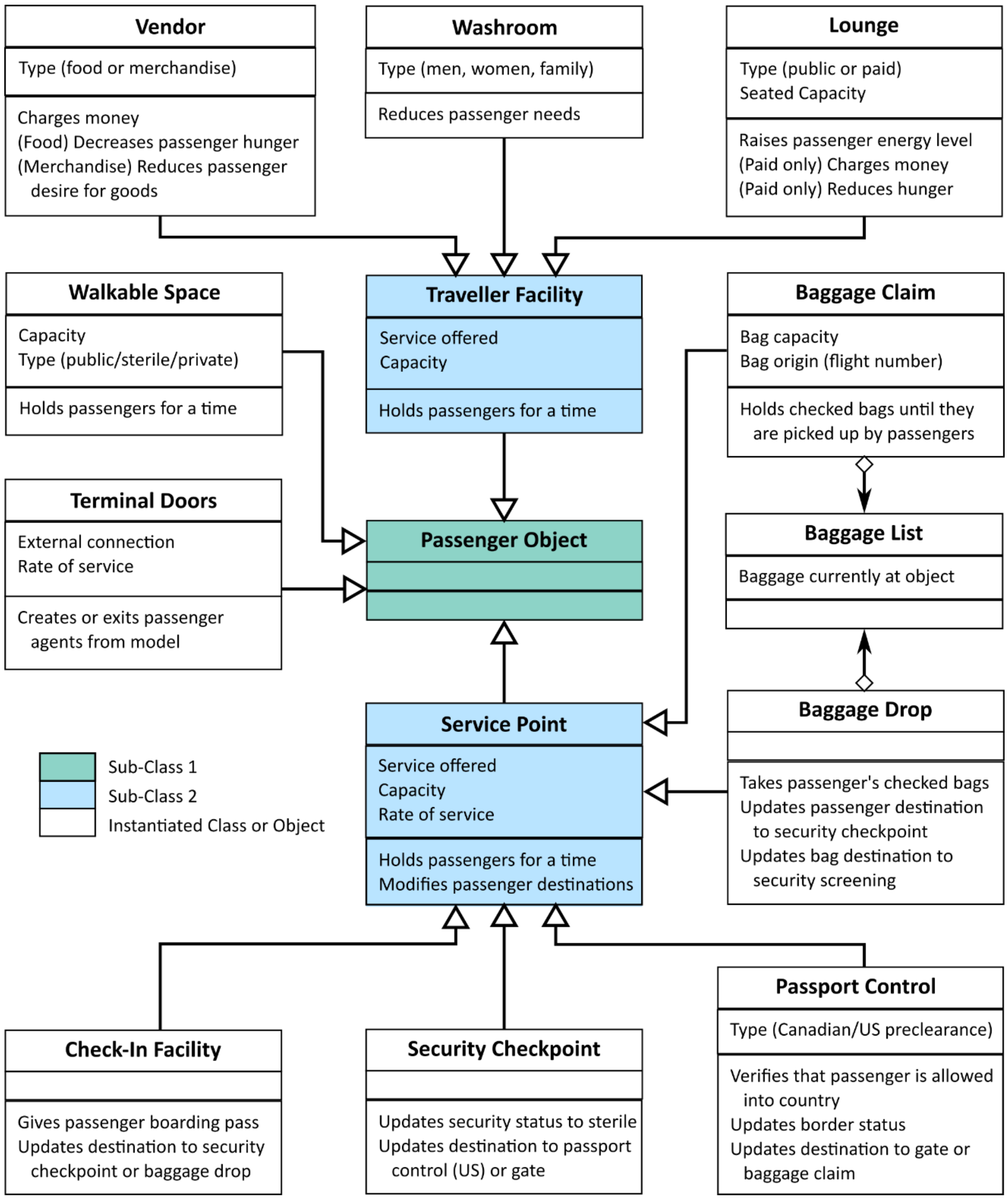

Figure 5: Passenger Object class and sub-classes

Within the terminal object class, passenger objects represent any stationary parts of the terminal buildings that passenger agents can access and may use while they are at the airport. Much like terminal objects, the passenger object sub-class can be broken down into two sub-classes (traveller facility and service point) and two instantiable objects (terminal doors and walkable space), each of which has more specific attributes and behaviours as shown in Figure 5. It is important to note that the baggage claim and baggage drop classes (sub-classes of service point) are each associated with a baggage list object in addition to a passenger list object, as both are interfaces between passenger-accessible space in the terminal and the checked baggage handling system.

3.2.2 Baggage Object Sub-Class

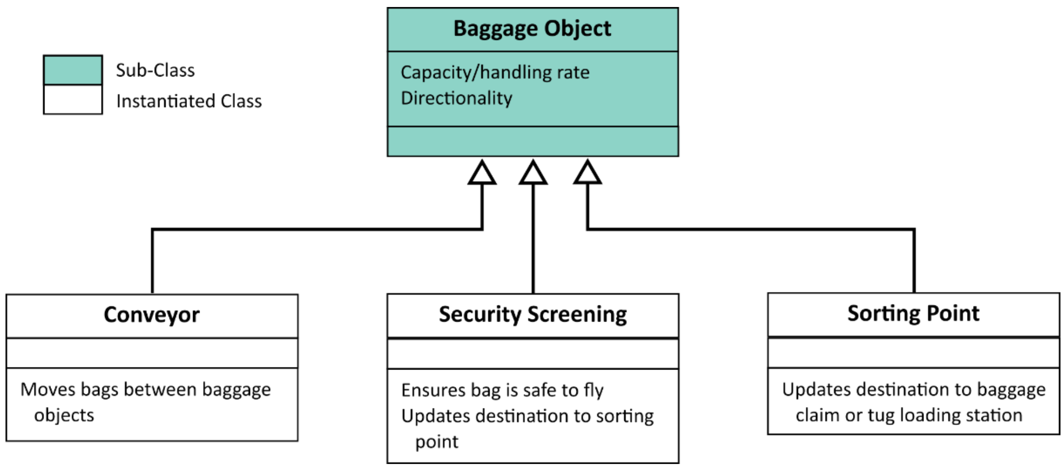

Figure 6: Baggage Object class and sub-classes

Unlike passenger objects, which allow the agents on them to make decisions and adjust their routing, baggage objects actively move and re-route bags through the terminal system to reach their tagged destinations. In general, baggage objects each have a capacity/handling rate, as shown in Figure 6, which indicates how many bags per hour the object can process, as well as a directionality (to-aircraft or from-aircraft). Specific instantiated classes of baggage objects include conveyors, which move baggage between other fixed points, security screening, which scans outgoing bags, and sorting points, which send bags to tugs for loading or to baggage claim for retrieval.

3.2.3 Vehicle Object Sub-Class

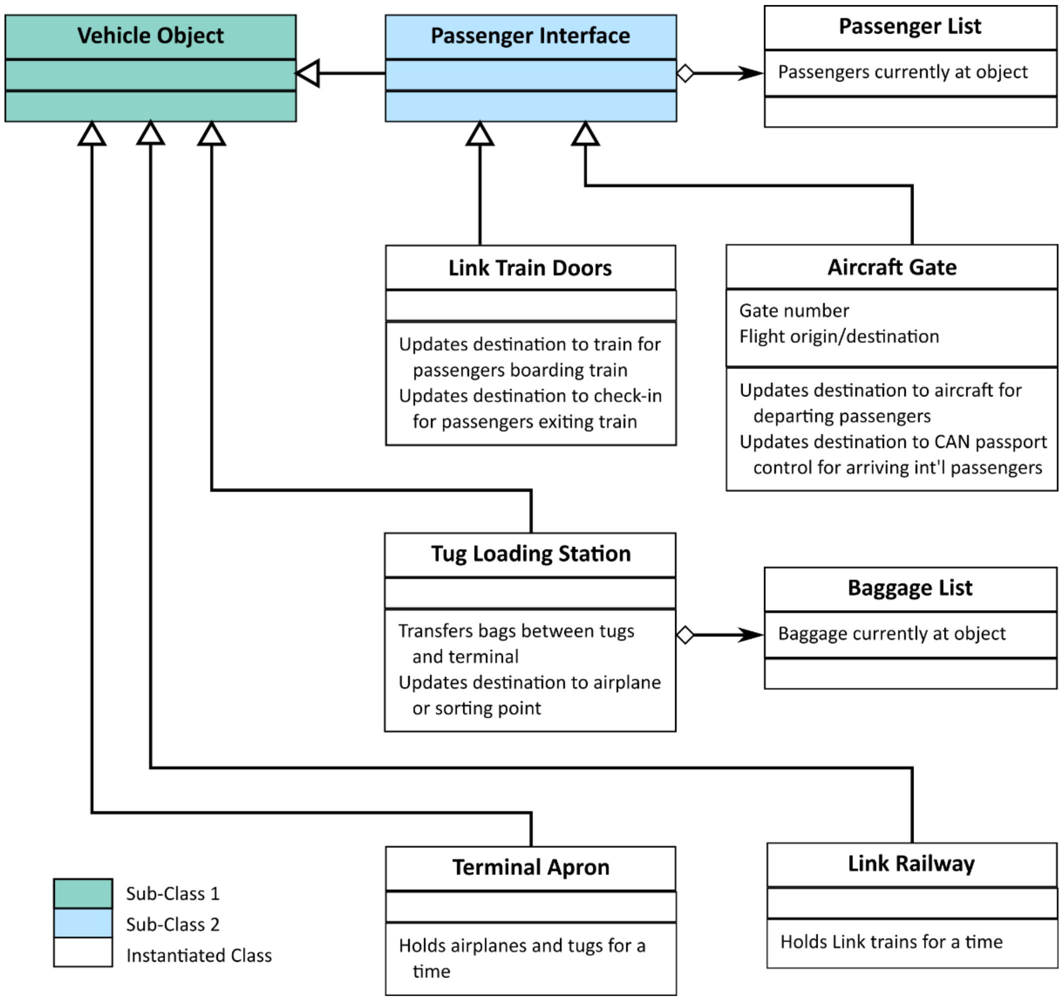

Figure 7: Vehicle Object class and sub-classes

The final sub-class of terminal objects is that of vehicle objects, which generalize a number of objects that act as 'walkable space' for vehicles, as well as objects that act as interfaces between vehicles, passengers, and baggage. The class contains three directly instantiable classes, namely the terminal apron, Link railway, and tug loading station, as well as the passenger interface sub-class, which in turn instantiates Link train doors and aircraft gates. As shown in Figure 7, some of these classes are additionally associated with passenger or baggage list objects, depending on which agent types may 'use' instances of the class.

3.3 Vehicle Class

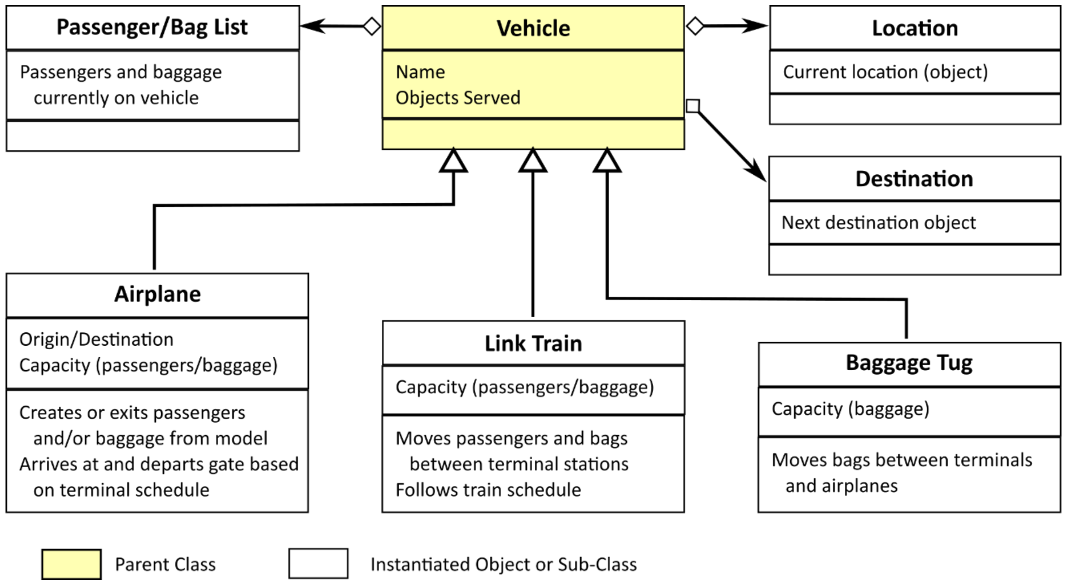

Figure 8: Vehicle class, objects, and sub-classes

Acting as a mobile connection between objects in the airport, and in some cases as an origin or destination for other agents, vehicles are an important part of this model of Pearson Airport. All vehicle instances are associated with three objects, namely a passenger/bag list, location, and destination, as shown in Figure 8, each of which may be changed by other objects in the model. The specific sub-classes generalized in the vehicle class are the airplane, which serves as an origin and destination for passengers and baggage, the link train, which moves passengers and baggage between the two terminals, and the baggage tug, which moves bags between airplanes and the terminals. As indicated in Section 3.2.3, specific vehicle types can only access specific vehicle objects – for example, the Link train can access the train doors and railway objects, while tugs and airplanes cannot.

3.4 Passenger Class

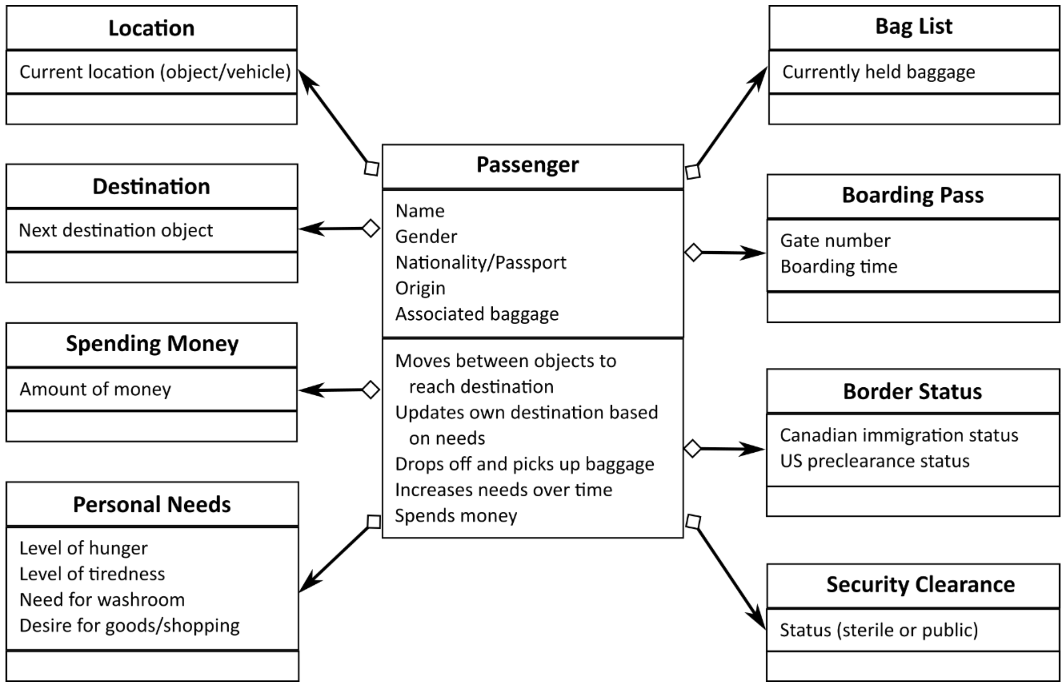

Figure 9: Passenger class and objects

Arguably one of the most important classes in the model, the passenger class is responsible for defining attributes and behaviours of each passenger agent. As shown in Figure 9, each passenger has static attributes, such as their name and origin, as well as a set of behaviours that allow them to reach their final destination while satisfying their needs. In addition, each passenger is associated with a set of simple objects that can be modified by the passenger or by other objects in the simulation – for example, using a baggage drop will remove any checked bags from the passenger's bag list, or a passenger may update their immediate destination to a restaurant if they are hungry.

3.5 Baggage Class

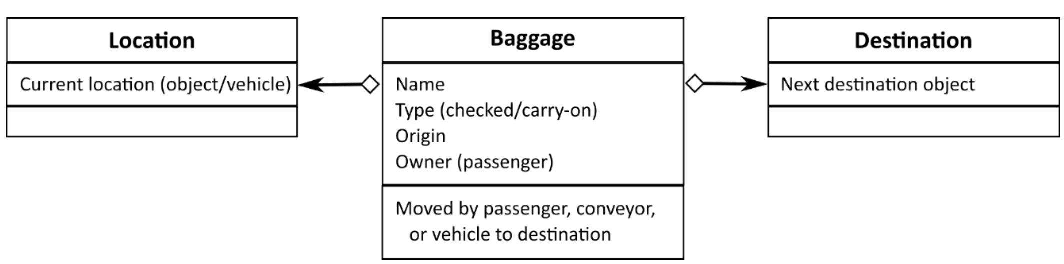

Figure 10: Baggage class and objects

The final class in this model is the baggage class, which simply outlines the attributes, behaviours, and objects associated with each instantiated piece of baggage as shown in Figure 10. Much like the passenger class, baggage has fixed attributes such as its name, type, and owner, as well as location and destination objects that can be externally modified. However, the key difference is that baggage cannot move itself or change its destination – these operations are performed by the passenger in possession of the bag or by the objects it interacts with (such as a sorting point or baggage tug).

4. Relationships and Information Flows

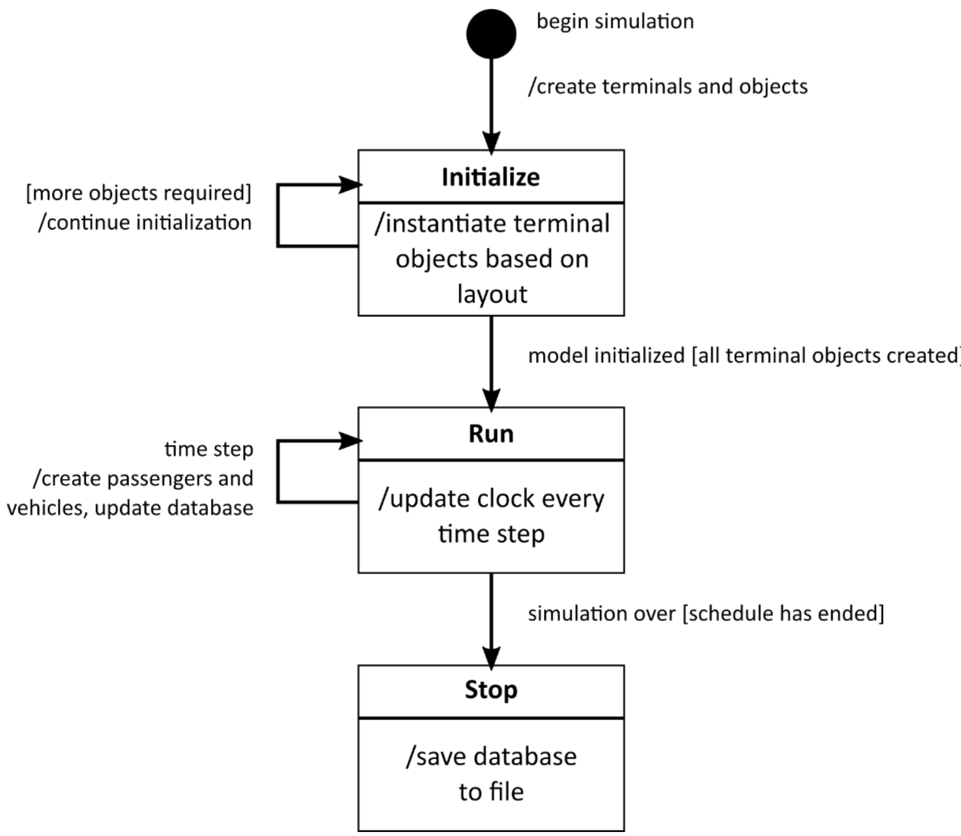

Figure 11: State diagram for the simulation (airport class)

When running a simulation model of Pearson Airport based on the established classes, there are two operational stages that must be followed in order – initialization, where all terminal object instances are created, and running, where vehicle, passenger, and baggage instances are created and terminal operations take place, as shown in Figure 11. Within each phase, relationships between the instances are defined and information flows between various classes and objects, providing insight into the overall behaviour of the terminal.

4.1 Model Initialization

To start a simulation run, an instance of the airport class must be generated, along with its layout map, schedule, and clock objects. The layout and schedule are provided as inputs by the modeller, as these define the scenario that will be tested. Based on the layout, the airport will call for the creation of terminal object instances, including walkable space and baggage handling facilities, which will be generated and their attributes will then be configured, as indicated in Figure 11. Some of these attributes, such as which terminal objects connect to each other, are defined by the layout, while others, such as the rate of service at a service point, would be provided by the modeller based on real-world data. Multiple instances of any sub-class of fixed objects can be instantiated, as long as no two instances represent the same physical space – all instances must tessellate rather than overlap. Once the airport's call for the creation of fixed object instances is complete, the airport then transitions to the second phase of the simulation.

4.2 Running the Simulation

In the second phase of the simulation, the clock starts running and the model begins stepping through time. These time steps are uniform at 15 seconds each, which allows the model to run relatively quickly and efficiently while preserving enough detail to identify potential issues within the airport. At each time step, the airport creates passenger and airplane instances based on the schedule, moves vehicles and baggage around the terminals, and updates the database, as shown in Figure 11. In addition, the schedule provides airplanes with information about whether they should serve as origins or destinations for agents, as well as lists of passengers and baggage to create if they are 'arriving' in the model. Like the airport class, instances of the passenger and vehicle classes also undergo state transitions as the model runs, which are described in detail in the following sections.

4.2.1 Passenger State Transitions

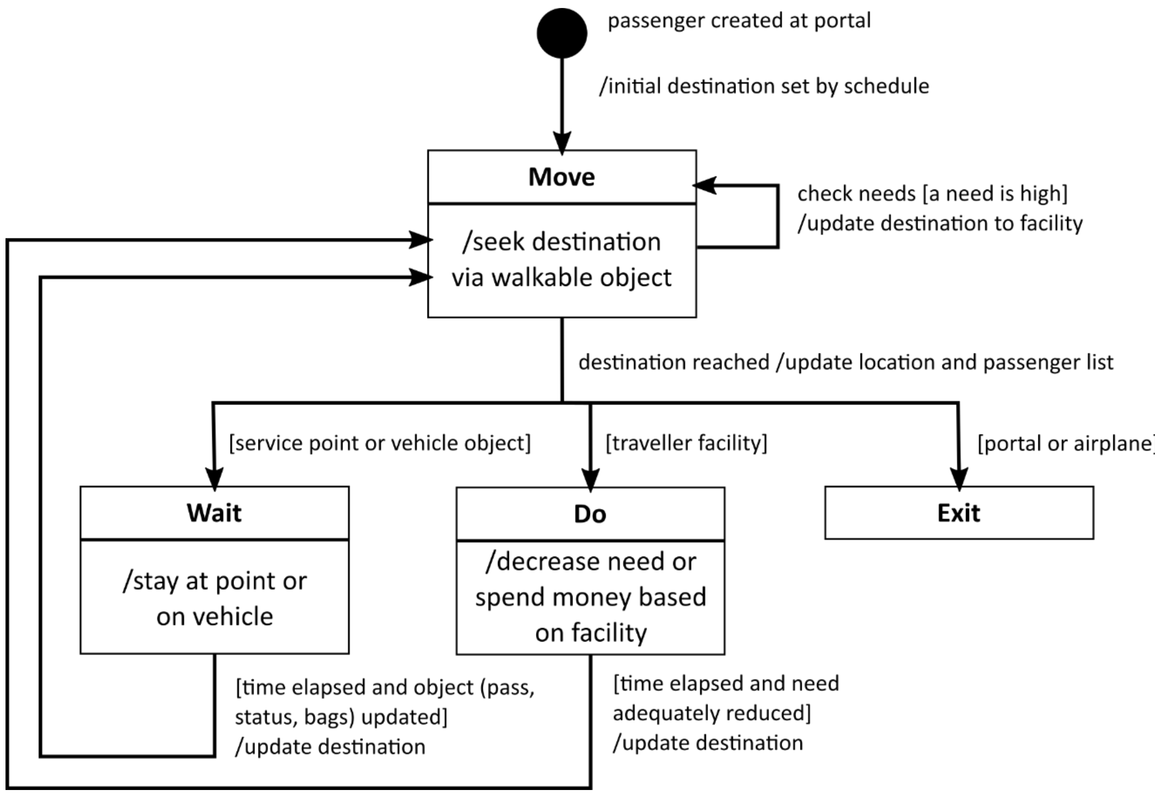

Figure 12: State diagram for passenger agents

When an instance of the passenger class is created, they will follow the state transition diagram shown in Figure 12 regardless of whether they are departing, arriving, or transferring. This diagram illustrates how each passenger interacts with their environment (terminal objects), as well as what information they use to make decisions. Some sections of this diagram, namely involving the Wait operation at a service point, also indicate how the passenger's progression to their goal is dependent on their objects (boarding pass, security status, etc.) and next destination being checked and modified externally. Further, it is important to note that upon reaching any destination, the passenger will pass information about its new location to the passenger list of the terminal object or vehicle with which it is now associated, which will in turn be recorded in the terminal database for the current time step. Finally, the change in passenger needs (hunger, washroom, etc.) over time plays a significant role in determining passenger behaviours – although it is not shown in Figure 12, passenger needs will perform a self-call every time step and increase at set rates. This process repeats until checking the needs reveals that one (or more) has reached a threshold, at which point the passenger updates their destination to the required facility.

4.2.2 Vehicle State Transitions

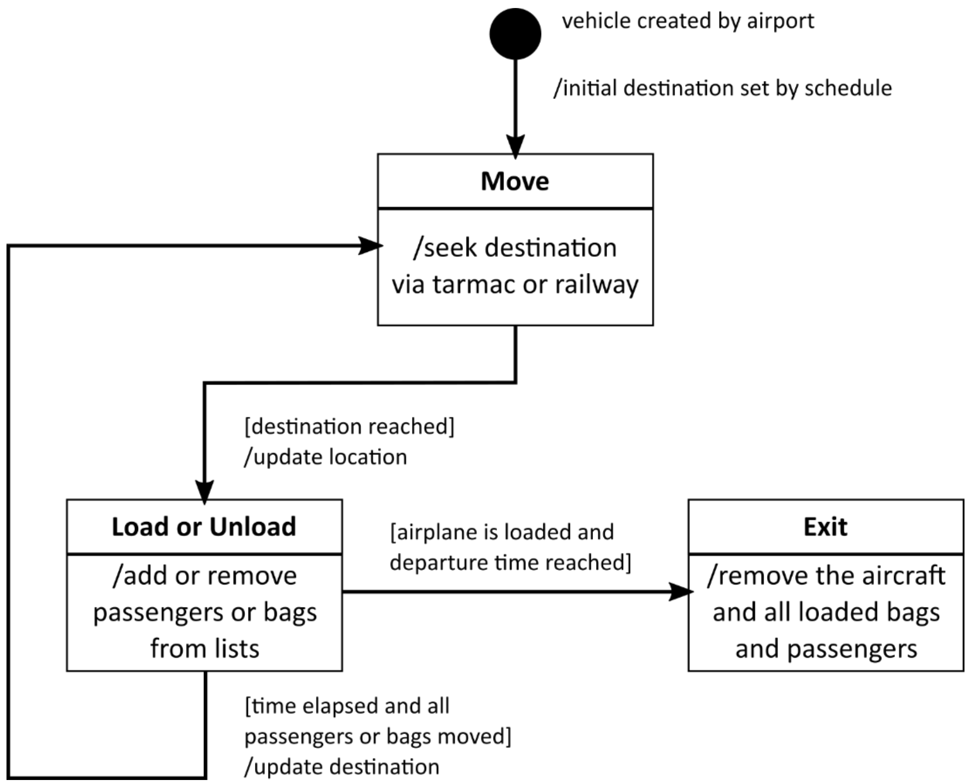

Figure 13: State diagram for vehicle agents

When a vehicle instance is first created by the airport, it may be at the start of the simulation (for Link trains and baggage tugs), or at a scheduled point during the simulation (for airplanes). Regardless, all vehicles follow the state transition diagram in Figure 13, which shows that vehicle instances can either be in motion or holding and loading/unloading passengers or bags. The only special case is for airplanes, which transition to the exit state once loading is completed at a gate – since this model does not describe taxiway or runway movements, it is not necessary for these vehicles to re-enter the tarmac before leaving the simulation.

5. Data Requirements

Based on the classes introduced and their relationships, it is clear that each class requires a specific set of data to operate and accurately represent the facility being modelled. First, the airport class requires Pearson Airport's hours of operation and daily flight schedules, as well as information about the terminal layout, facilities within the terminals, and vehicles used for the Link train and on the tarmac. In general, this information can be obtained from the Greater Toronto Airports Authority (GTAA) [8] and from maps and info pages on the Pearson Airport website. However, if one wishes to use this model framework to simulate a different airport or one that is under development, plans and forecasts may be required from airport authorities or consultants, and data from similar facilities elsewhere may be used as a reference [9].

To accurately represent the various terminal object instances in the model, more specific information about passenger processing, passenger amenities, and baggage handling is required, as the attributes and behaviours of these sub-systems contribute significantly to the overall behaviour of the airport. For service points, including check-in and security, information about average service durations and wait times could be obtained from the GTAA, but individual airlines and other government bodies are likely to have more detailed information. For security screenings of both passengers and baggage, the Canadian Air Transport Security Authority (CATSA) [10] has information regarding the required protocols, while the Canadian Border Services Agency (CBSA) [11] and U.S. Customs and Border Protection (CBP) [12] specify the protocols for international and trans-border travel, respectively. For other traveller facilities, including lounges and restaurants, the GTAA should have information about how much money is spent by passengers and their average stays at each facility. Finally, the GTAA also has information about the baggage handling systems implemented within each terminal, including their processing rate, maximum capacity, and the layout of all conveyors, sorting points, and security screening stations.

In order to model the vehicles, baggage, and passengers moving through the airport, some additional information is necessary. Much like data about terminal objects, the GTAA should have some information about the behaviours and attributes of passengers using the airport, such as their origins, destinations, and numbers of checked bags. However, this data should also be available from the airlines serving Pearson Airport, such as Air Canada and WestJet. These airlines can also provide information about the airplanes they use to serve the airport, including bag and passenger capacities [13], as well as which gates can accommodate each type of aircraft. Any additional information about airport operations can be gathered from Airport Cooperative Research Program (ACRP) reports prepared by the Transportation Research Board, spreadsheet models developed by the International Air Transport Association (IATA) [9], or the comprehensive text “Airport Systems: Planning, Design, and Management” by Richard de Neufville and Amedeo Odoni [14].

6. Interactions with External Systems

Even though this model is designed to function on its own using data, plans, and schedules provided for Pearson Airport, it must be acknowledged that in reality, the airport does not operate in isolation and is in fact dependent on many external systems. First, the airside operations at Pearson are highly dependent on the system of airlines serving the airport (Air Canada, WestJet, American Airlines, Delta, etc.), as gate assignments, runway clearances, and landing times must be agreed upon in advance by all parties. Further, any delays at Pearson have the potential to propagate through the airline systems and affect ‘downstream’ airports, and similarly delayed incoming flights have an impact on other flights and passengers at Pearson. On the other side of the facility, groundside transportation (highways, parking, and public transit) can affect passengers’ ability to reach the airport on time, while a large number of simultaneous flight arrivals can put additional strain on airport bus routes. The airport is also dependent on the groundside transportation network for the delivery of goods, such as food, merchandise, and supplies, that are essential to keeping the facility and its sub-systems running. Finally, Pearson Airport's operations depend on decisions made by various levels of government and regulatory agency, as these have the potential to influence both the layout of the facility as well as its operating procedures and standards.

7. Conclusions

With hundreds of daily flights arriving and departing across two terminals, Toronto Pearson International Airport is a fantastic example of a complex system, and its behaviours can be well represented using an agent-based microsimulation model. In this report, the framework for such a model has been developed, including detailed attributes and behaviours of the airport, terminal object, vehicle, passenger, and baggage classes, as well as specific details of their numerous sub-classes. Further, state transition diagrams for passenger and vehicle agents have been outlined, in addition to a diagram that describes the progress of the entire simulation. To fully detail this model, sources of data including airlines serving Pearson Airport, the GTAA, and CATSA, have been found for each object and agent, and the potential interactions of this model with external models and systems have been considered. Although Pearson Airport only serves as a small piece of the transportation network in the Greater Toronto Area, it is essential for growing the region's economy and providing connections with the rest of the world. With proper calibration and validation, this agent-based model can provide insight into the airport's operations and highlight potential enhancements, providing the potential to improve both the airport and the surrounding region.

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