A Multi-Agent Microsimulation Model of Toronto Pearson International Airport

Gregory Hoy, University of Toronto[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 (Greater Toronto Airports Authority, 2017). The facilities at Pearson are immense, consisting of numerous 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 terminal buildings. Additionally, the airport serves as a temporary home to hundreds of aircraft, 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.

In this paper, 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.

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 (Greater Toronto Airports Authority, 2017). The passenger movements include arrivals, departures, and transfers from all domestic, international, and trans-border gates across both terminals (McCoomb, Passenger Characteristics & Terminal Layouts, 2014), 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 off any checked baggage 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 (Greater Toronto Airports Authority, 2017). After this stage, passengers enter what is known as the "sterile" part of the terminal, which offers a greater number of amenities including shops, lounges, and restaurants, as well as connections to the aircraft gates through which these passengers

---

[1] Student Paper Competition Winner; published in the 2018 Proceedings of the *Canadian Transportation Research Forum*

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 (McCoomb, Terminal Planning: Sub-Systems - Baggage, 2014). 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.

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.

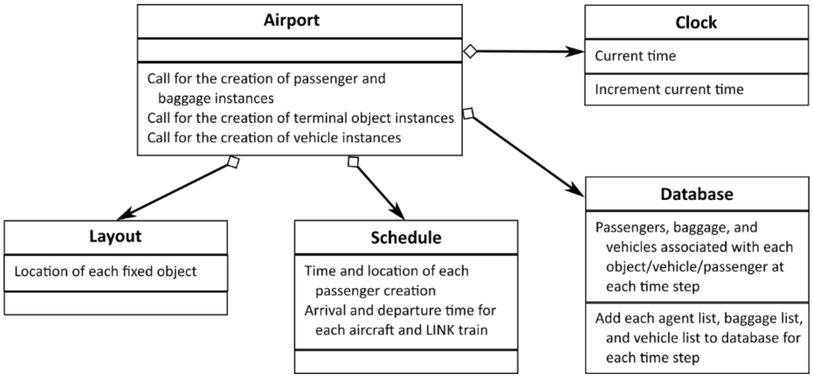
Classes

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 Structure class, with sub-classes for Passenger, Baggage, and Vehicle Structures, and the three Agent classes for each of Vehicles, Passengers, and Baggage.

Airport Class

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 agents, and advancing the simulation Clock. As shown in Figure 1, 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.

Figure 1 Airport class and associated objects

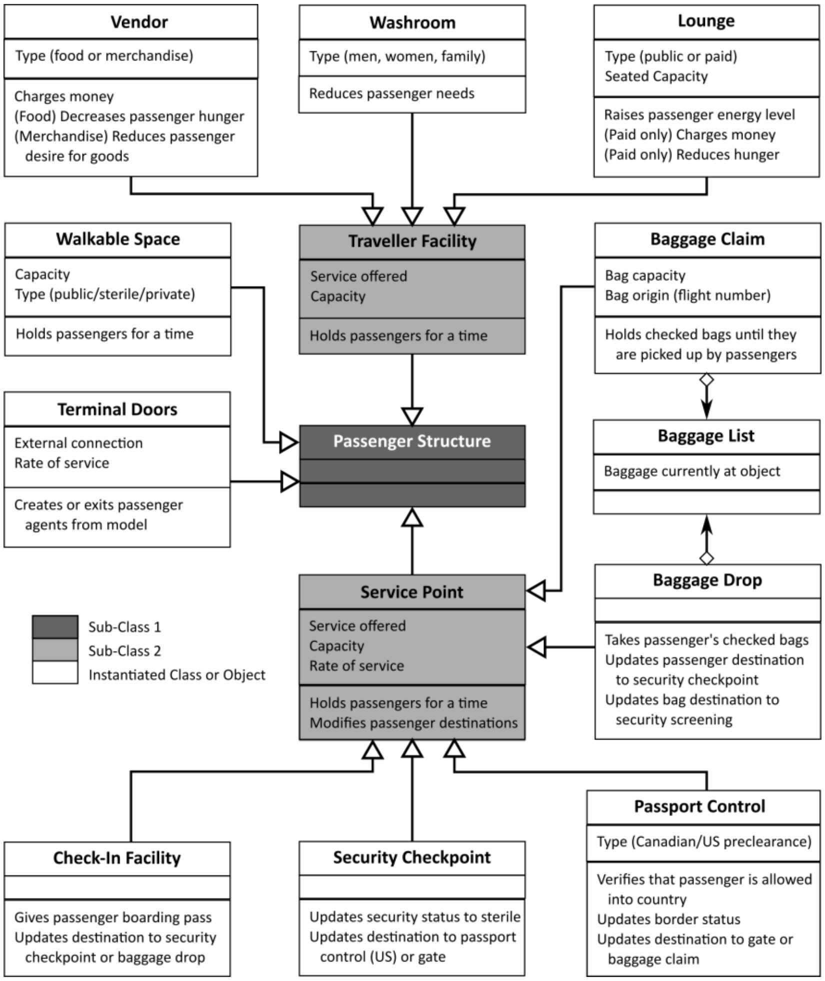


Terminal Structure Class

Based on the Layout object in the Airport class, numerous structures from the Terminal Structure class are instantiated to represent parts of the terminals at Pearson Airport and the airside tarmac and rail links between them. Generally, each Terminal Structure has a name, location, and connections to other instances, all of which are specified by the Layout. To better understand each type of Terminal Structure, this class is broken down into three main sub-classes based on the primary agent class using each structure – these are the Passenger Structure, Baggage Structure, and Vehicle Structure sub-classes. Each of these sub-classes is associated with a matching list object which keeps track of the Passenger, Baggage, or Vehicle agents currently associated with each Structure instance.

Within the Terminal Structure class, Passenger Structures 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 Structures, the Passenger Structure sub-class can be broken down into two sub-classes (Traveller Facility and Service Point) and two instantiable structures (Terminal Doors and Walkable Space), each of which has more specific attributes and behaviours as shown in Figure 2. 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.

Figure 2 Passenger Structure class and sub-classes

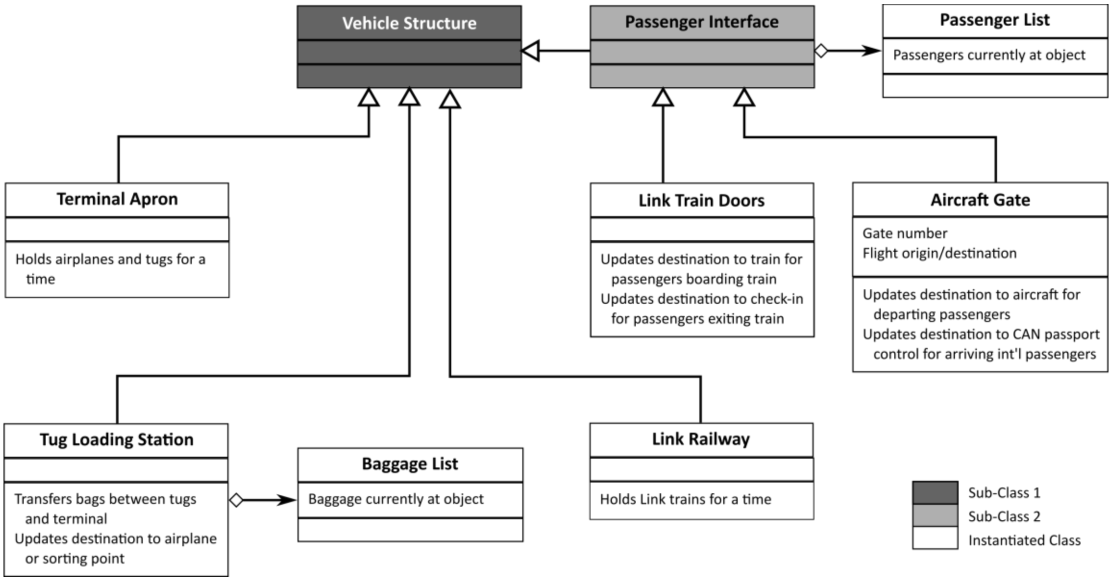


Unlike Passenger Structures, which allow agents on them to make decisions and adjust routing, Baggage Structures actively move and re-route bags through the terminal system to reach their tagged destinations. In general, Baggage Structures each have a capacity/handling rate, which indicates how many bags per hour the structure can process, as well as a directionality (to-aircraft or from-aircraft). Specific instantiated classes of Baggage Structures include Conveyors, which move baggage between points, Security Screening, which scans outgoing bags, and Sorting Points, which send Bags to Tugs or Baggage Claims.

The final sub-class of Terminal Structures is that of Vehicle Structures, which generalize structures that act as 'walkable space' for Vehicles, as well as structures 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 two classes. As shown in Figure 3, some of these classes are additionally associated with Passenger or Baggage List objects, depending on which agent types may ‘use’ instances of the class.

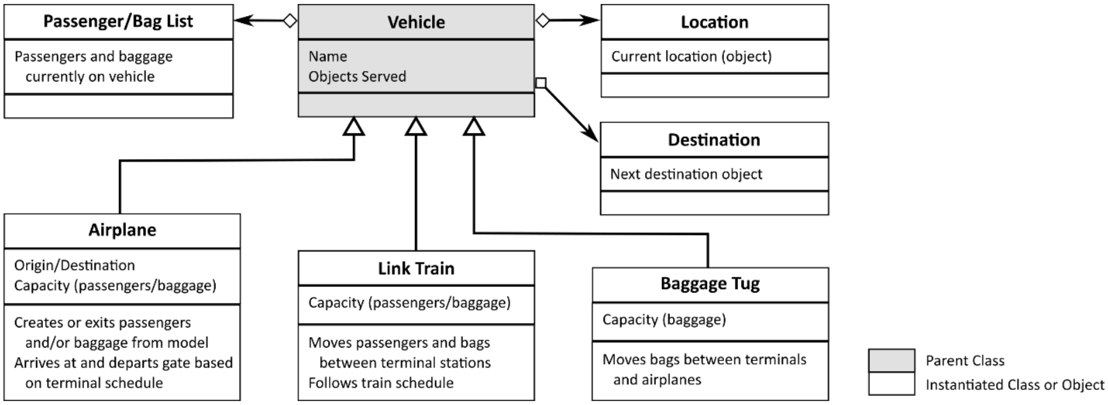
Figure 3 Vehicle Structure class and sub-classes



Vehicle Class

Acting as a mobile connection between structures 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 4, each of which may be changed by other instances 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 noted, specific Vehicle types can only access specific Vehicle Structures – for example, the Link Train can only access Train Door and Railway structures, while Tugs and Airplanes cannot.

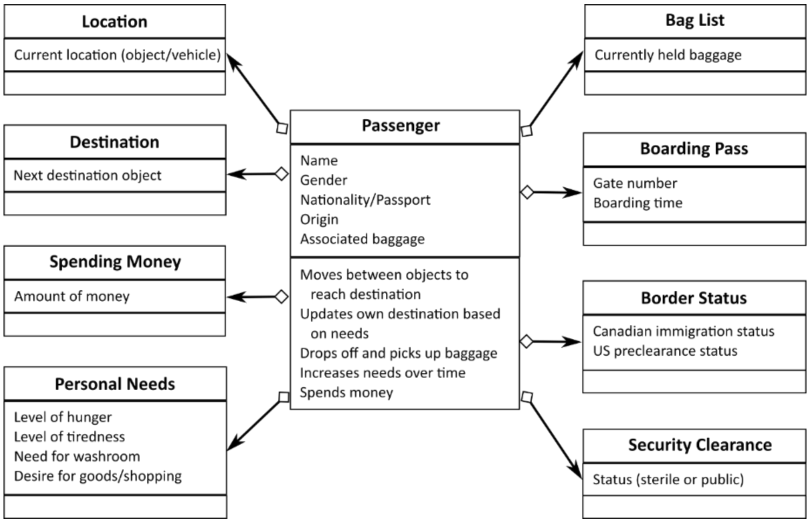
Figure 4 Vehicle class, objects, and sub-classes



Passenger Class

Arguably the most important class in the model, the Passenger class is responsible for defining attributes and behaviours of each Passenger agent. As shown in Figure 5, 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 instances in the simulation – for example, interacting with 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.

Figure 5 Passenger class and objects



Baggage Class

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. Much like the Passenger class, Baggage has fixed attributes (name, type, origin, 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 Passengers, Sorting Points, or Vehicles.

Relationships and Information Flows

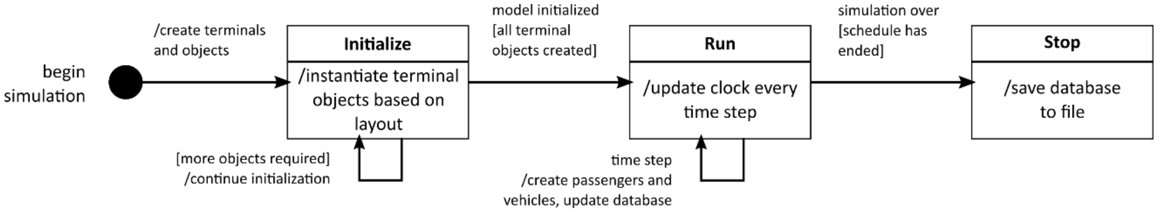
When running a simulation model of Pearson Airport based on the established classes, there are two operational stages that must be followed in order – initialization, where all Terminal Structure instances are created, and running, where Vehicle, Passenger, and Baggage instances are created and terminal operations take place, as shown in Figure 6. 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.

Model Initialization

To start a simulation, 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 Structure instances, such as Walkable Space and Baggage facilities, which will be generated and their attributes will then be configured, as indicated in Figure 6. Some of these attributes, such as which Terminal Structures 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 structure 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 Terminal Structure instances is complete, the Airport then transitions to the second phase of the simulation.

Figure 6 State diagram for the simulation (Airport class)

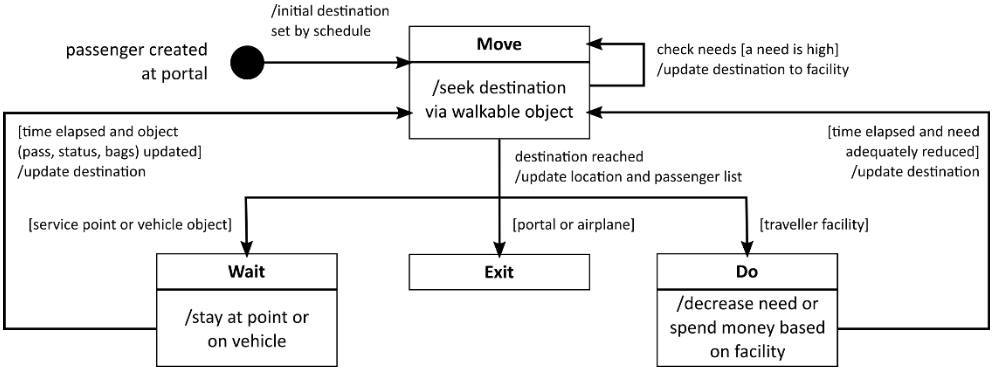


Running the Simulation

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 6. 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.

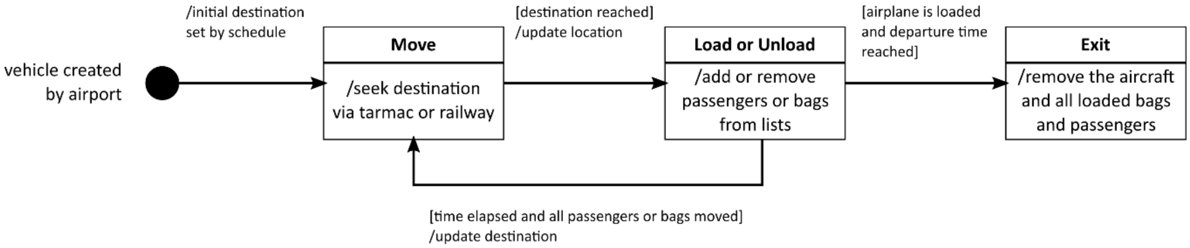
When an instance of the Passenger class is created, the agent will follow the state transition diagram shown in Figure 7 regardless of whether it is departing, arriving, or transferring. This diagram illustrates how each Passenger interacts with their environment (Terminal Structures), as well as what information they use to make decisions. Some sections of this diagram, namely involving the Wait operation at a service point, also indicate how the agent'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 Structure or Vehicle with which it is now associated, which will in turn be recorded in the Database for the current time step. Finally, the change in Personal Needs (hunger, washroom, etc.) over time plays a significant role in determining Passenger behaviours – although it is not shown in Figure 7, Needs will perform a self-call every time step and increase at set rates. This process repeats until checking reveals that one (or more) Personal Needs has reached a threshold, at which point the Passenger updates their Destination to the required facility.

Figure 7 State diagram for Passenger 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 8, 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 airside movements, it is not necessary for Airplanes to re-enter the tarmac before leaving the simulation.

Figure 8 State diagram for Vehicle agents



Data Requirements

In order to operate properly and accurately represent the facility being modelled, each class requires a specific set of data. 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) 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 (McCoomb, Terminal Capacity - Level of Service, 2014).

To represent the various Terminal Structure instances in the model, more specific information about passenger processing, 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 individual airlines and potentially Transport Canada. For security screenings of both passengers and baggage, the Canadian Air Transport Security Authority has information regarding the required protocols (Canadian Air Transport Security Authority, 2017), while the Canadian Border Services Agency (Canada Border Services Agency, 2017) and U.S. Customs and Border Protection (U.S. Department of Homeland Security, 2017) specify 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 components and layouts, processing rates, and maximum capacities of baggage handling systems at Pearson may be obtained from the GTAA.

Much like data about Terminal Structures, 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 (Air Canada, 2017), 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) (McCoomb, Terminal Capacity - Level of Service, 2014), or the comprehensive text "Airport Systems: Planning, Design, and Management" by Richard de Neufville and Amedeo Odoni (Odoni & De Neufville, 2013).

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 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, 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 many simultaneous flight arrivals can put additional strain on transit 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 they influence both the layout of the facility as well as its operating procedures and standards.

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 paper, the framework for such a model has been developed, including detailed attributes and behaviours of the Airport, Terminal Structure, Vehicle, Passenger, and Baggage classes, as well as specific details of their 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 structure, 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, offering the potential to improve both the airport and the surrounding region.

References

Air Canada. (2017). *Our Fleet*. Retrieved April 13, 2017, from https://www.aircanada.com/ca/en/aco/home/fly/onboard/fleet.html

Canada Border Services Agency. (2017). *Airport of Entry (AOE)*. (Government of Canada) Retrieved March 18, 2017, from http://www.cbsa-asfc.gc.ca/do-rb/services/aoe-eng.html

Canadian Air Transport Security Authority. (2017). *Security Screening*. (Government of Canada) Retrieved March 18, 2017, from http://www.catsa.gc.ca/breezethrough

Greater Toronto Airports Authority. (2017). *About Toronto Pearson*. Retrieved March 13, 2017, from https://www.torontopearson.com/en/AboutPearson/#

Greater Toronto Airports Authority. (2017). *Preclearance at Toronto Pearson: A Vital Link Connecting the U.S. and Canada*. Retrieved March 13, 2017, from https://www.torontopearson.com/en/Preclearance/#

Greater Toronto Airports Authority. (2017). *Terminal Link*. Retrieved April 11, 2017, from https://www.torontopearson.com/en/link/#

McCoomb, L. (2014). Passenger Characteristics & Terminal Layouts. Toronto.

McCoomb, L. (2014). Terminal Capacity - Level of Service. Toronto.

McCoomb, L. (2014). Terminal Planning: Sub-Systems - Baggage. Toronto.

Odoni, A., & De Neufville, R. (2013). *Airport Systems: Planning, Design, and Management.* New York: McGraw-Hill Education.

U.S. Department of Homeland Security. (2017). *Automated Passport Control (APC)*. (U.S. Department of Homeland Security) Retrieved March 18, 2017, from https://www.cbp.gov/travel/us-citizens/apc