# Evaluation of a centralised transportation assistance system for passengers with special needs at a Canadian airport

Mehmet A. Begen*

Ivey Business School,
Western University,
London, Ontario, Canada
Email: mbegen@ivey.uwo.ca
*Corresponding author

Richard Fung

Fraser Health Authority,
Vancouver, British Columbia, Canada
Email: rfung1@gmail.com

Daniel Granot and Frieda Granot

Sauder School of Business,
University of British Columbia,
Vancouver, British Columbia, Canada
Email: daniel.granot@sauder.ubc.ca
Email: frieda.granot@sauder.ubc.ca

Chris Hall

Boart Longyear,
London, UK
Email: hall.cs@gmail.com

Bailey Kluczny

Strongside Technologies,
Lake Country, British Columbia, Canada
Email: bailey@strongside.ca

**Abstract:** Transportation assistance for travellers with special needs (e.g., disabled, sick, elderly, unaccompanied minors) is provided at most airports, and the demand for this service is increasing every year. At most airports, air carriers are independently responsible for this service, and they set their own service levels and practices. We expect that a centralised system would increase resource efficiency and passenger satisfaction. We conduct an evaluation of such a centralised system at a Canadian airport using two distinct and independent models: simulation and queuing. We find that consolidating the service produces higher levels of service quality for passengers while, at the same time, uses fewer resources. We also discuss the pros and cons of a centralised system from the perspectives of the airport authority, the airlines, and the passengers. Our methodology may be applied to other airports worldwide to evaluate a centralised transportation assistance system for passengers with special needs.

**Keywords:** airport passenger transportation; passengers with special needs; simulation modelling; queuing analysis.

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**Biographical notes:** Mehmet A. Begen is an Associate Professor of Management Science in the Ivey Business School at the Western University. Besides Ivey, he is also cross-appointed at the departments of Statistical and Actuarial Sciences and Epidemiology and Biostatistics at Western. He is an Industrial Engineer and Certified Analytics Professional (CAP) with research interests in management science applications, healthcare operations management, scheduling, simulation, and data-driven approaches. He worked in management consulting before his PhD studies (http://www.ivey.uwo.ca/Faculty/MBegen).

Richard Fung received his BASc degree in Computer Engineering from Simon Fraser University in Burnaby, British Columbia, Canada in 2003 and MM degree in Operations Research from the University of British Columbia in Vancouver, British Columbia, Canada in 2005. Since then, he has been with the Fraser Health Authority in Surrey, British Columbia, Canada where he is currently a Senior Operations Engineer.

Daniel Granot is an Affiliates Professor of Management at the Operations and Logistics Division, Sauder School of Business, University of British Columbia. He held visiting positions at Stanford University, Tel Aviv University and IBM. His main research interests are game theory, combinatorial optimisation and supply chain management. He has published extensively in operations research journals as well as game theory journals, and he is an INFORMS Fellow.

Frieda Granot is an Advisory Council Professor of Management Science at the Operations and Logistics Division, Sauder School of Business, University of British Columbia. She held visiting positions at Stanford University, The Hebrew University, Tel Aviv University and IBM. Her main research interest is combinatorial optimisation, and her papers have been published in such journals as *Mathematics of Operations Research*, *Mathematical Programming*, *Management Science*, *Operations Research and Networks*. She is a member of the Order of Canada, a recipient of the Queen Gold Jubilee and she is an INFORMS Fellow.

Chris Hall is an Engineer and has an MBA. He worked in the oil industry for 17 years in exploration, initially in technical maintenance, but lately in operational management. In his current role, he ensures the flow of skilled personnel and equipment to the correct sites in various African countries is in line with signed contracts, enabling efficient work flows for his company. He has always been fascinated in and had passion for aviation since his early days in the air cadets at university, gaining a commercial helicopter pilots licence later and getting involved in this airport project.

Bailey Kluczny is a simulation specialist who helps organisations face their complex challenges with evidence-based confidence. As the founder and principal consultant with Strongside Technologies, he helps clients in transportation, manufacturing, and health care quantify the benefits and risks of planning options while using clear visualisations to communicate system behaviour and scenario results (http://www.strongside.ca).

## 1 Introduction

The demand for transportation assistance service at airports for travellers with special needs is on the rise as both the popularity of air transportation and the size of elderly population continue to increase (IATA, 2015; Department of Transport, 2015; Darcy and Ravinder, 2012). Transportation assistance services are available at most airports around the world (Chang and Chen, 2012a; Konert and Ephraimson, 2008; Reinhardt et al., 2013) in the form of wheelchairs and electric carts (golf carts) that are used to transport special-needs passengers (elderly, sick, unaccompanied minors and disabled) to and from airplanes and terminals. Transportation assistance can also include support staff travelling with a passenger who has a special needs, including interpretation services.

In this study, we analyse the transportation assistance system for travellers with special needs at a Canadian airport in 2004. For confidentiality reasons, we do not disclose the identity of the airport and instead refer to it simply as ‘the airport’ or ‘the airport authority’. Currently at the airport and at other Canadian airports, air carriers are independently responsible for the transport of their passengers. The passengers may request assistance at any time before or during their progress through the airport (Air Canada, 2016; WestJet, 2016) and each air carrier sets its own definition of acceptable customer service levels and practices (Personal communication, 2004, 2016; The Airport, 2016). Some carriers use their own staff and resources to handle this responsibility, while others employ contractors (Personal communication, 2004). The service includes getting special-needs passengers to or from their flights, to general meeting areas in the airport, or to connecting flights (Chang and Chen, 2012a; Personal communication, 2004).

Since each airline provides its own service according to its own definition, service time, service quality, and service levels vary significantly across the industry. The airport authority was concerned with this variability and wanted to evaluate a centralised system for all airline passengers with special needs. The aim of this paper is to address this issue, i.e., to analyse the impact of such a centralised system at the airport. The airport authority defines a service level as ‘x% of the passengers will wait no more than y minutes for a service’. In this study, we were not given the x and y values. Instead, we used our models to find the required resource levels of the centralised system for a given service level and determine achievable service levels with the currently available resources. The proposed centralised system was expected to provide uniform service levels, increase efficiency and use fewer resources. With ever-increasing passenger volumes, a more efficient transport assistance system will become increasingly important in future years (Chang and Chen, 2012a, 2012b; IATA, 2015; Department of Transport, 2015; Darcy and Ravinder, 2012).

We develop two different independent models – simulation and queuing – to determine operational strategies and resource levels. We use these two methodologies because the system is highly stochastic (e.g., number of passengers requiring a special-needs service; in-airport processing times, including security checks) and the variables of interest vary significantly during the day. Indeed, using these two different models allowed us as to generate meaningful strategies and evaluate the performance, such as wait times of special-needs passengers for a service in the consolidated system, more accurately. We find that consolidating the service for special-needs passengers would provide higher levels of service using fewer resources. Explicitly, it would lead to a 24% reduction in wheelchair inventory, a 47% reduction in the number of electric carts and fewer dedicated staff for the transportation service.

Finally, we note the relevance of our study to the one-belt-one-road (OBOR) initiative by the Chinese Government. The OBOR calls for the increase of cooperation and economic integration, through the building of infrastructure, broadening trade and improved transport links, in countries situated at the Original Silk Road and the Maritime Silk Road. Though the OBOR region currently does not include North America, the airport is one of the most important hubs between Asia and North America. Moreover, our study, which is concerned with improving service for special-needs passengers and, as such, improving airport operations, can guide other airports in the world and, in particular, those in the OBOR region, improve services for their special needs passengers and contribute to the efficient movement of goods and people among countries in the OBOR region.

The paper is organised as follows. In the next section, we present the current-state analysis at the airport. In Section 3, we describe our models and discuss the data. Section 4 presents the analysis and our recommendations are given in Section 5. Section 6 concludes the paper.

## 2 Current state analysis

To understand the system and current operations at the airport, we conducted numerous interviews and observed and recorded our observations of the relevant processes. Our interviews and observations took place during 2004. The airport authority made it possible for us to meet with each major airline representative, airport personnel responsible for the service to passengers with special needs and representatives of all ground-handlers. Our contact at the airport authority scheduled the interviews with these stakeholders and we interviewed them at their offices. Our objective was to understand the operations and services for passengers with special needs from the perspective of the airport authority, airlines and ground-handlers. A consultant for the airport authority has confirmed that individual air carriers are still in charge of services provided to their passengers with special needs and that the airport authority did not implement the changes suggested in 2004. This is further confirmed by the major air carriers' websites and the airport's website (Air Canada, 2016; WestJet, 2016; The Airport, 2016). We note though that the airport is still considering a centralised system alternative (Personal communication, 2016).

Our analysis of the problem was also informed by studies concerning the transportation of special-needs passengers in the airport and other airports (Greater Toronto Airport Authority, 2004; MSP, 2004; Picard, 2004) and by Canadian and American regulations governing such services (Konert and Ephraimson, 2008; Department of Transport Act, 1978; Office of the Secretary Department of Transportation, 2001).

## *2.1 Air carrier operations*

Air carriers use one of three business arrangements for transporting their special-needs passengers:

- Manage the service themselves with their own staff and equipment.
- Contract the service to an alliance partner carrier.
- Contract the service to a ground-handling company.

Large and local airlines tend to manage the service themselves, while foreign airlines usually contract the service either to another carrier or to a ground-handling company. There are a few exceptions to these practices. For example, a carrier may contract a ground handler to provide personnel for wheelchair operations only during peak periods (Personal communication, 2004). All parties in our study expressed a clear perception that employing dedicated staff resulted in a better level of service and a better all-round experience for the passengers (Personal communication, 2004).

Air carriers are obligated to service requests that are made 48 hours in advance by special-needs passengers and they are expected to make every effort to service requests made less than 48 hours in advance (Konert and Ephraimson, 2008; Department of Transport Act, 1978).

We determined the current inventory levels of equipment used to transport passengers by performing a physical count and by verbal accounts and we found that the airport uses approximately 34 electric carts and 350 wheelchairs in 2004. In terms of staff, each cart requires a driver and each wheelchair requires a pusher. The wheelchair pusher can be an accompanying traveller or an agent.

## *2.2 Scope of the service*

Air carriers have different policies with regard to the scope of the service provided (Personal communication, 2004; Air Canada, 2016; WestJet, 2016). While all carriers consider the check-in desk as the starting point of the service for a departing passenger, some do provide a service in exceptional circumstances to meet passengers at the curb. A more common scenario involves a carrier providing a wheelchair to a family member, upon request, to assist a service passenger to the check-in desk. Research shows that the service scope for passengers with special needs is complex, that these needs may differ from one passenger to another and that there is room for improvement (Shaw and Coles, 2004; Chang and Chen, 2011); for example, the services provided need to vary with respect to severity of disabilities and the satisfaction of passengers with special needs is low compared to the importance of the services provided. A centralised system as proposed in this paper can be more specialised and focus on individual passengers with special needs and address their needs.

After check-in, a departing special-needs passenger is invariably transported to the gate lounge area. However, the hand-over of responsibility to aircraft cabin crew can occur at different locations: the gate lounge itself, the aircraft door (i.e., ground staff transport the passenger down the connecting Jetway), or the aircraft seat (i.e., ground staff assist the passengers to their seat).

Arriving passengers also require varying degrees of service, currently provided at different levels by the carriers. A carrier always transports a special-needs passenger to the baggage carousel (including through the arrivals processes of immigration and customs in the international terminal); however, the passenger's degree of mobility determines where the special service ends.

### *2.3 Performance metric: service level*

There is a direct relationship between wait times [and/or time in the system (TIS)] and perceived service quality (Personal communication, 2004; Correia and Wirasinghe, 2010). All carriers are acutely aware of aircraft turnaround times (Personal communication, 2004; Brunetta et al., 1999; Mathaisel, 1996; Mumayiz, 1990) and focus on any situation where the management of special-needs passengers affects turnaround times (Personal communication, 2004) (e.g., a passenger transported late to a gate which, in turn, delays a flight departure). However, most carriers apply a soft metric to track the ongoing performance of their services and the only input most carriers receive regarding their level of service comes from the number of complimentary letters and complaints they receive (Chang and Chen, 2012a; Personal communication, 2004). It is our understanding that, just like non-special-needs passengers, wait time is the most important factor that affects service quality for special-needs passengers. Furthermore, the airport authority is a non-profit organisation so that improving services and their quality for all passengers is a top priority and perceived more important than other criteria (such as cost minimisation). In our discussions with the airport authority, we determined a service level to be defined as 'the percentage of special needs service passengers taking less than a determined target time to complete their airport processes' as there will be always a proportion of passengers whose service time will be longer than the target time. Based on our and airport's experiences we chose the percentage as 95%.

## 3 Models and data

Since an airport's centralised system for special-needs passengers is not available, we built two independent models in order to validate our model – a queuing model (with a user interface) and a simulation model – and compared their results to obtain at least a partial validation. Another reason for developing two models hinged on the fact that their purposes were different. Simulation could handle more details (especially for the international and transborder terminals modelling), but it was difficult to maintain. Alternatively, with its user interface, the queuing model could easily serve as a decision support tool and it was easy to maintain and run. We quantified the benefits of a centralised system over the current system and provided recommendations for service levels, corresponding resource levels and operating configurations.

We note that many studies in the domain of passenger transportation at airports have already been carried out (Tošić, 1992; Brunetta et al., 1999; Mathaisel, 1996; Mumayiz, 1990; Barnhart et al., 2003); for example, security screening (Atkins et al., 2003), boarding of passengers onto airplanes (Bazargan, 2007; Van Landeghem and Beuselinck, 2002; Nyquist and McFadden, 2008) and passenger flow analysis (Jim and Chang, 1998; Casado et al., 2005; Setti and Hutchinson, 1994). However, among the existing papers on air passenger transportation, we are not aware of any study that considers a consolidation of services at an airport for transportation assistance of passengers with special needs. The closest study we could find is by Reinhardt et al. (2013), in which the authors study a transportation system of passengers with reduced mobility (PRM) at an airport. The authors develop a mathematical model to schedule a bus-style service to minimise the number of PRMs left unserved and to minimise the total unnecessary travel time. The focus of Reinhardt et al. (2013) model is operational and is concerned only with a small subset of the transportation system for passengers with special needs at an airport. On the other hand, our study takes place at the strategic level and performs an evaluation of the entire transportation system for passengers with special needs at an airport and uncertainty is taken into account explicitly in our modelling.

### *3.1 Queuing model*

Queuing theory is devoted to the mathematical analysis of queues and is especially concerned with queue length and average time spent by customers in the queue and in the system and resource utilisation. In the domain of air travel, it was used, for example, to model and analyse congestion at airports (Regattieri et al., 2009; Daniel, 1995; Peterson et al., 1995). We developed a specific queuing model and built an end-user tool in Excel VBA (Microsoft, 2015) to analyse the wheelchair and electric cart service at the airport for all terminals. Figure 1 shows a screenshot of the queuing tool, which we used to keep track of passenger movements and resource usage. The passenger generator and the service passenger analyser are the tool's two main components.

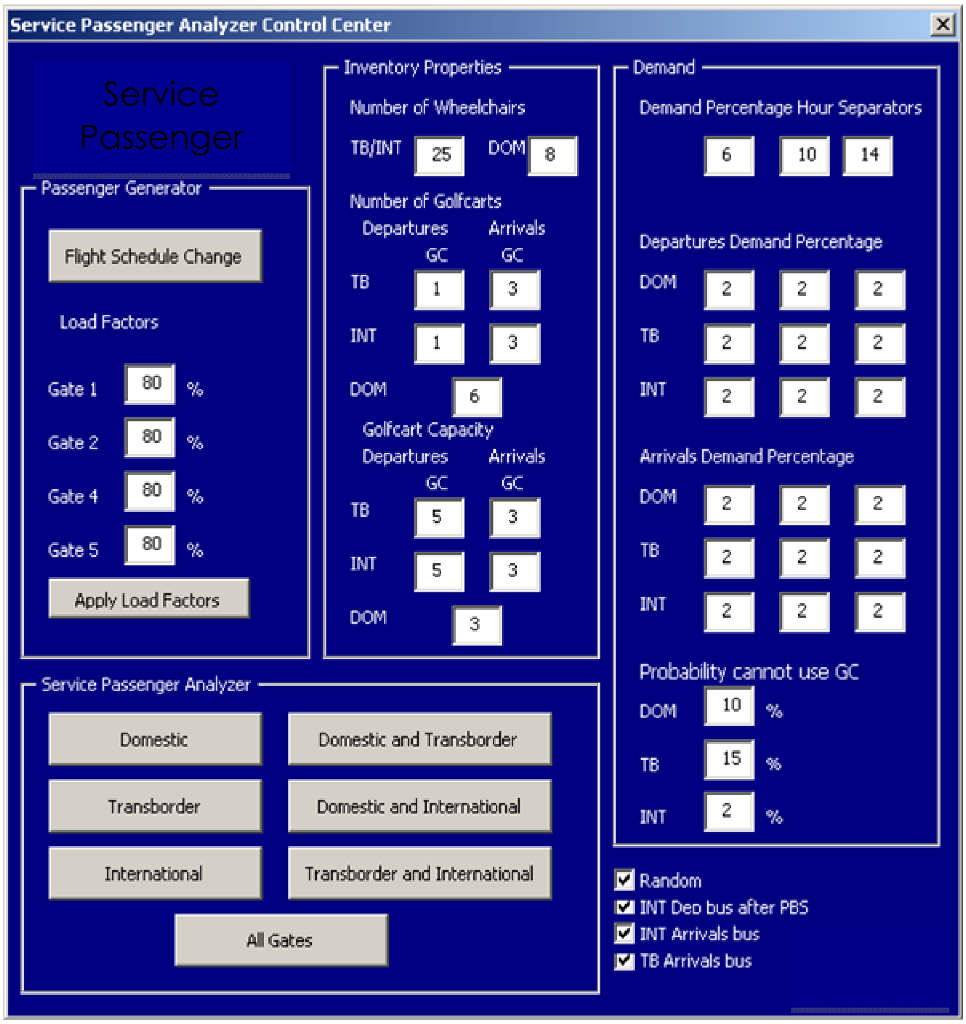
In our model, for each of the terminals, all flight gates were aggregated together into one location and the passenger generator estimated the number of passenger arrivals for a departing flight. We used the same method as in Atkins et al. (2003) to compute this estimate with a triangular distribution (i.e., each flight's passenger arrival process was given by a triangular distribution). For example, the first passenger for a given flight arrived four hours before the flight departure time, most of the other passengers arrived two hours in advance and the last passenger arrived 45 minutes before the flight departure time. For arrivals, a user-specified percentage of the passengers on the flight represented the special-needs passengers and within the special-needs passengers, a user-specified percentage of these special-needs passengers represented the wheelchair-serviced passengers.

The inputs for the tool were:

- load factors for flights
- number of wheelchairs and electric carts for each terminal
- electric cart capacities
- demand percentages

- the probability that a special-needs passenger could use an electric cart for whatever reason
- operational strategy option choices.

**Figure 1** A screenshot of the queuing tool (see online version for colours)




Load factors and demand percentages were required to determine how many passengers and special-needs passengers were expected for each flight. The resource levels and capacities affected wait times and time-in-system for passengers. The probability that a passenger would need to be transported in a wheelchair determined how resources were used.

The tool was used to conduct 'what if' scenarios to find configurations using the fewest resources to meet a given service level (e.g., x% of passengers will wait no more than y minutes for a service). We conducted scenario analysis on different operational strategy combinations by changing the options. The operational strategies included wheelchairs, electric carts operating as scheduled buses and electric carts dispatched as necessary like a taxi service. Specifying zero electric carts resulted in scenarios having only wheelchairs. Setting to zero the probability that passengers use electric carts resulted in scenarios with only wheelchairs.

We tested scenarios on many service configurations by varying the following options:

- bus-style carts from international check-in or from past pre-board screening (PBS)
- bus-style carts from past transborder PBS or all wheelchairs
- electric carts drop off transborder and international arrival passengers after they clear Canada Customs passport control or after baggage has been collected
- resource levels.

The passenger generator created demand arrivals, which were then sent to corresponding queues, depending on which processes were required by the passengers. The queues kept track of resource use and passenger times throughout the processes. Since a special-needs passenger might use multiple types of resources from different pools, the times through each of the processes were passed between resource pools. When the passenger finished with one resource pool, the next pool continued the service. The outputs of the tool included:

- passenger time in the system
- passenger wait times
- resource utilisation.

The outputs of the tool provided some insights related to resource scheduling. For example, the wheelchair usage chart (see Figure 2) could be used to estimate the number of wheelchair pushers required during different times of the day.

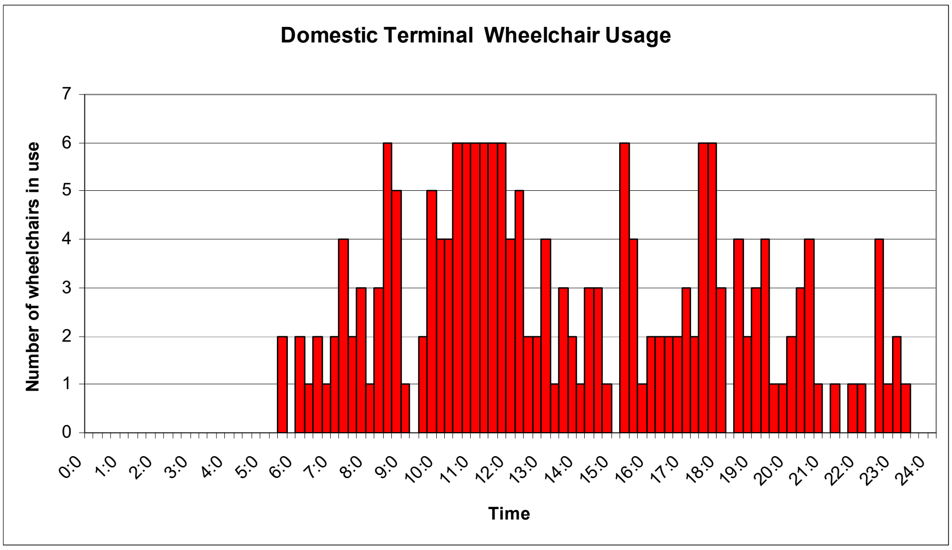
### *3.2 Simulation model*

In addition to the queuing tool, we built a simulation model for the international and transborder terminals. That is, we built a digital prototype representation of these terminals to predict the behaviour of our proposed solutions under various settings, which had more sophisticated service processes than the domestic terminal. We developed the simulation model in Arena (Rockwell, 2015). The model drew its passenger demand data from flight schedules. Once passenger demand was generated, a logical network guided the passengers through their respective airport processes. Passengers could be transported using wheelchairs, electric carts, or a combination of the two. The outputs of the model included processing times, wait times, resource utilisations, queue lengths and service levels. Processing-time data took into account the congestion levels at the terminals as our data collection was performed at peak times.

### *3.3 Connecting passengers model*

We considered the connecting special-needs passengers separately because of the long travel distance between the domestic and the international/transborder terminals. We first used our data to find the connecting passenger ratios from one terminal to another and we determined the number of passengers who required a connection for a given flight schedule. Then, we built a separate (spreadsheet) model to determine the effectiveness of an electric cart bus service between the terminals.

**Figure 2** Wheelchair utilisation (see online version for colours)




## *3.4 Data*

We obtained data from three sources:

1 data from carriers regarding their current services

2 manual data collected by our research team

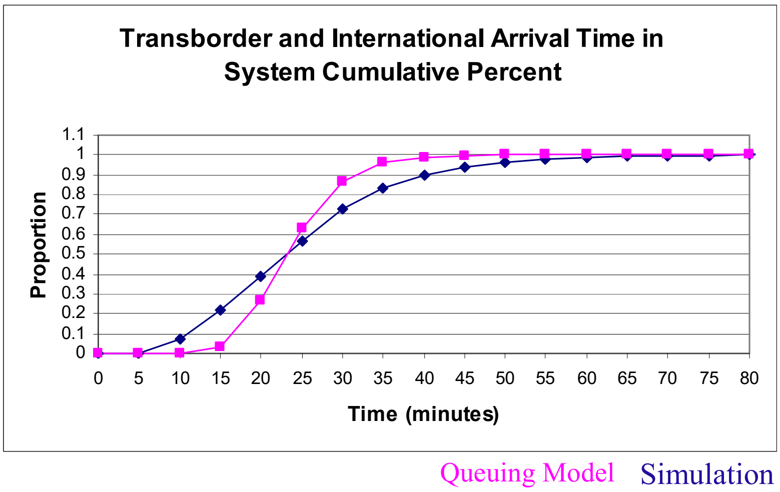
3 data collected by certain contractors in the terminals (by request of the airport authority) on our behalf.

In addition to demand data collection at the terminals, we obtained data collected on behalf of US Homeland Security and data collected by PBS operators. The literature estimates the demand ratio by special-needs passengers as 1% (Reinhardt et al., 2013); that is, the number of special-needs passengers is 1% of all passengers. Besides demand data, we collected service-time data for all the relevant processes throughout the proposed common-use, special-needs passenger transportation system. These service times at Canada Customs and Immigration, US Homeland Security, baggage retrieval and PBS were measured during both peak and non-peak periods. Finally, travel-time data for wheelchairs and electric carts was collected between many locations throughout the airport.

### *3.5 Model validation*

Validating the two models was a challenge for this study. Since the centralised system was not yet in existence, there was no historical data that could be used to validate our model outputs. To accommodate this factor, we determined that by running the same scenario on both models and comparing the results, we would be able to validate our models. We ran many different scenarios and the majority of the results were indeed similar. Only in extreme cases – such as when too few wheelchairs or electric carts were being used – did the results differ. However, for the important scenarios, particularly for those that were candidates for the final results and recommendations, the models produced similar outputs (e.g., mean, standard deviation, median, 95th percentile and distribution shape). As an example, Figure 3 compares arrival time distribution of the queuing model (the curve with squares) and simulation model (the curve with diamonds) for the recommended scenario, with 26 wheelchairs and eight electric carts in use for transborder and international arrivals.

**Figure 3** Comparison of arrival time distribution in the two models (see online version for colours)




## 4 Analysis

We ran different scenarios to determine the most efficient methods of operation and the number of resources required to meet an acceptable service level (time in the system). We used the queuing model for the domestic terminal and the simulation model for the other terminals. Due to the proximity of the international (INT) and transborder (TB) terminals and their distance to the domestic terminal, the international and transborder terminals were given a separate pool of resources in our analysis. There is a possibility of resource-sharing with the domestic terminal, but this sharing would be limited due to the time it takes to bring the resources over. (If such sharing was possible, the benefits of the consolidated system would be even greater; hence, our results can be considered as conservative estimates for the savings.)

Based on our initial data analysis, process observations, interviews with all stakeholders and brainstorming with the airport authority, we first defined the scope of the proposed service (e.g., where does it start, where does it end, how the passengers with special-needs transferred between different levels of airports, standards). After determining the scope, we prepared an initial list of scenarios considering different types of resources (e.g., electric charts, wheel chairs), resource levels and transfers rules. Then we met with the airport authority, air carriers and ground handlers to refine and confirm the final list of scenarios as presented below.

### *4.1 International and transborder terminals*

We ran each scenario 100 times. As a first step, resource levels and demand percentages were fixed and scenarios with different operating strategies were compared. These strategies and scenarios are given in Table 1.

Figure 4 shows the 95th percentile of arriving passengers' time in the system for different scenarios using various resource levels of wheelchairs (WC) and electric carts (EC). Scenarios 5 and 6 yielded the best results. Between these two, the only difference was in international departures, where an electric cart was used in scenario 5 versus wheelchairs in scenario 6. Statistics comparing scenarios 5 and 6 are shown in Table 2. Since Scenario 6 used only wheelchairs for transborder departures, an extra electric cart was added for arrivals in order to ensure a comparison with equal resource levels. Based on Figure 4 and Table 2, we chose scenario 5 because it handled transborder departures better than scenario 6. Transborder departure was the only area that used a different operational strategy between the two models.

**Table 1** Scenarios tested

| *Scenario #* | *INT/TB arrivals* | *TB departures* | *INT departures* |
|---|---|---|---|
| 1 | Electric cart when possible | Wheelchair | Wheelchair |
| 2 | Electric cart when possible | Wheelchair to PBS then transfer to electric cart | Wheelchair to PBS then transfer to bus-style electric cart |
| 3 | Electric cart when possible | Bus-style electric cart from check-in desk | Wheelchair to PBS then transfer to bus-style electric cart |
| 4 | Electric cart when possible | Bus-style electric cart from check-in desk | Wheelchair |
| 5 | Electric carts hand off passengers to wheelchair agents once Canada Customs passport control is clear | Bus-style electric cart from check-in desk | Wheelchair to PBS then transfer to bus-style electric cart |
| 6 | Electric carts hand off passengers to wheelchair agents once Canada Customs passport control is clear | Bus-style electric cart from check-in desk | Wheelchair |

**Figure 4** Scenario analysis, 95th percentile of time in system (minutes) (see online version for colours)

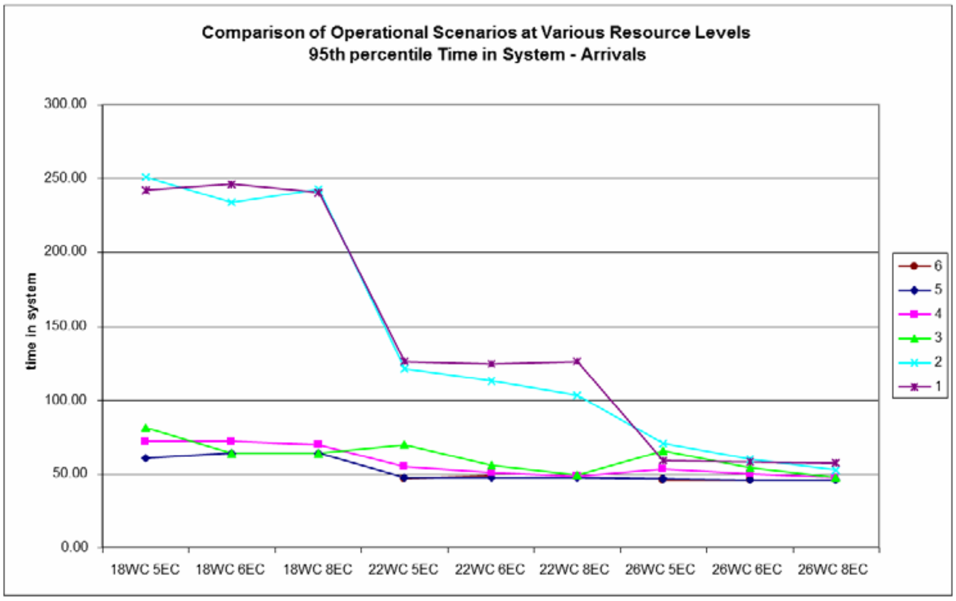



**Table 2** Comparison between Scenario 5 and Scenario 6

| | | *Scenario 5* | | | *Scenario 6* | | |
|---|---|---|---|---|---|---|---|
| *2% ratio* | *Wheelchairs* | *22* | *26* | *30* | *22* | *26* | *30* |
| | *Electric charts* | *5* | *5* | *5* | *6* | *6* | *6* |
| Arrivals TIS | Average | 24.89 | 24.59 | 24.53 | 24.7 | 23.95 | 23.81 |
| | 95th percentile | 47.65 | 46.58 | 46.60 | 48.02 | 45.80 | 45.44 |
| TB departures TIS | Average | 23.83 | 23.81 | 23.74 | 26.58 | 26.17 | 25.92 |
| | 95th percentile | 36.85 | 36.74 | 36.75 | 41.16 | 40.29 | 40.08 |
| International departures TIS | Average | 14.29 | 14.23 | 14.51 | 12.71 | 13.08 | 13.25 |
| | 95th percentile | 30.22 | 29.61 | 31.97 | 24.71 | 25.21 | 28.45 |
| *3% ratio* | *Wheelchairs* | *22* | *26* | *30* | *22* | *26* | *30* |
| | *Electric charts* | *5* | *5* | *5* | *6* | *6* | *6* |
| Arrivals TIS | Average | 43.6 | 29.08 | 25.46 | 39.88 | 28.79 | 25.41 |
| | 95th percentile | 138.73 | 61.42 | 48.59 | 122.42 | 61.64 | 49.14 |
| TB departures TIS | Average | 27.13 | 24.95 | 24.38 | 29.65 | 27.64 | 26.69 |
| | 95th percentile | 42.99 | 38.84 | 37.60 | 46.46 | 42.34 | 40.98 |
| International departures TIS | Average | 22.57 | 22.99 | 22.59 | 17.67 | 20.84 | 18.06 |
| | 95th percentile | 70.54 | 76.27 | 72.74 | 39.40 | 53.92 | 42.55 |

After selecting the operating characteristics, we sought the required resource levels to achieve an acceptable service level. We tested a range of resources in Scenario 5 to find the correct level of resources – between four and eight electric carts and between 10 and 30 wheelchair pushers. After analysing the results, we determined the minimum resource levels that would yield an acceptable service level. Our analysis showed that there was little to no gain in efficiency beyond five electric carts. As well, when the service ratio was 2%, the system performed quite well with only 18 wheelchair pushers and four or five electric carts. However, when the percentage of special-needs passengers was increased to 3%, a minimum of five electric carts and 26 wheelchairs was required to maintain an acceptable service level. Specifically:

- 26 wheelchair pushers and five electric carts (with drivers)
- one bus-style electric cart for transborder departures
- two bus-style electric carts (leaving from check-in) for international departures.

Table 3 summarises the results. The recommended resource levels were determined as sufficient for handling peak demand loads. Clearly, this level of resources would not be required for the entire day. Utilisation graphs from simulation runs show the average and maximum number of resources kept in use over the entire day. The peak resource levels would be required only during 11:00–14:00 and 16:00–18:00. During the other times, less flight activity took place and thus, resource requirements were lower. As an example, Figure 5 shows the average and maximum number of resources kept in use over the entire day.

**Figure 5** Average and maximum number of resources kept in use over the entire day (see online version for colours)

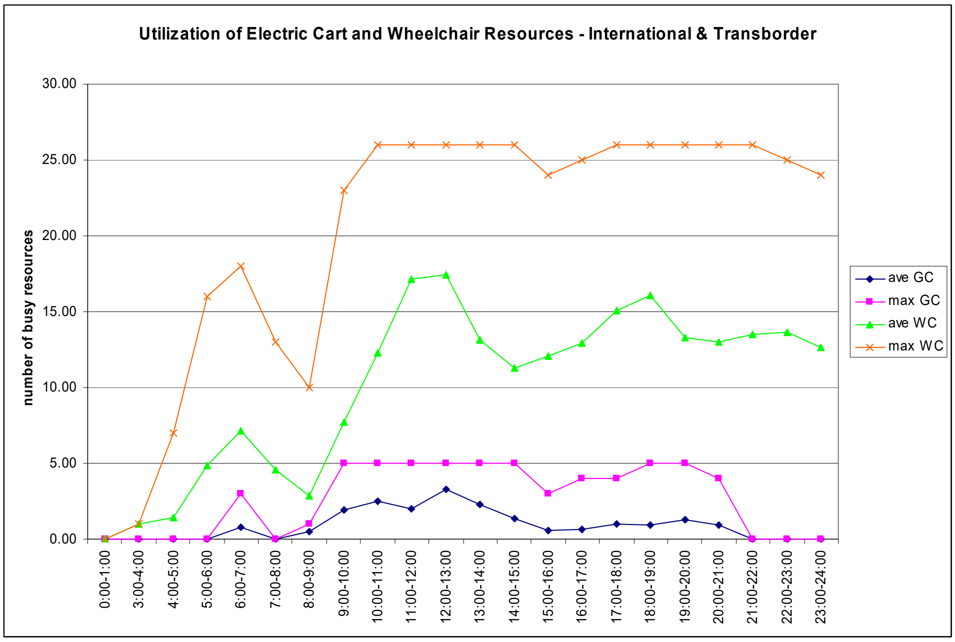


**Table 3** Comparison of different resource levels for recommended operational scenario

| | | *Scenario 5* | | | *Scenario 6* | | |
|---|---|---|---|---|---|---|---|
| | *Wheelchairs* | *22* | *26* | *30* | *22* | *26* | *30* |
| *2% ratio* | *Electric charts* | *5* | *5* | *5* | *6* | *6* | *6* |
| Arrivals TIS | Average | 24.89 | 24.59 | 24.53 | 24.7 | 23.95 | 23.81 |
| | 95th percentile | 47.65 | 46.58 | 46.60 | 48.02 | 45.80 | 45.44 |
| TB departures TIS | Average | 23.83 | 23.81 | 23.74 | 26.58 | 26.17 | 25.92 |
| | 95th percentile | 36.85 | 36.74 | 36.75 | 41.16 | 40.29 | 40.08 |
| International departures TIS | Average | 14.29 | 14.23 | 14.51 | 12.71 | 13.08 | 13.25 |
| | 95th percentile | 30.22 | 29.61 | 31.97 | 24.71 | 25.21 | 28.45 |
| | *Wheelchairs* | *22* | *26* | *30* | *22* | *26* | *30* |
| *3% ratio* | *Electric charts* | *5* | *5* | *5* | *6* | *6* | *6* |
| Arrivals TIS | Average | 43.6 | 29.08 | 25.46 | 39.88 | 28.79 | 25.41 |
| | 95th percentile | 138.73 | 61.42 | 48.59 | 122.42 | 61.64 | 49.14 |
| TB departures TIS | Average | 27.13 | 24.95 | 24.38 | 29.65 | 27.64 | 26.69 |
| | 95th percentile | 42.99 | 38.84 | 37.60 | 46.46 | 42.34 | 40.98 |
| International departures TIS | Average | 22.57 | 22.99 | 22.59 | 17.67 | 20.84 | 18.06 |
| | 95th percentile | 70.54 | 76.27 | 72.74 | 39.40 | 53.92 | 42.55 |

### 4.2 Domestic terminal

We evaluated the performance in the domestic terminal with fewer scenarios (i.e., since it has fewer processes). The recommended strategy is much like the current operation. During non-peak times, electric carts should be ready to meet passengers at the arrival gates and at the check-ins. At peak times, electric carts can loop from the cleared sides of the terminal to the gates, picking up arrivals and departures on their trips. To be conservative, we assumed a higher demand ratio (3%) and Table 4 displays time in the system (TIS) performance as a function of the number of electric carts.

**Table 4** Time in system, in minutes, for 3% demand, in the domestic terminal

| *Number of electric carts* | *Departures* | | *Arrivals* | |
|---|---|---|---|---|
| | *Average TIS* | *95th TIS* | *Average TIS* | *95th TIS* |
| 3 | 230 | 535 | 279 | 544 |
| 4 | 119 | 239 | 126 | 243 |
| 5 | 50 | 97 | 51 | 97 |
| 6 | 25 | 49 | 25 | 48 |
| 7 | 20 | 29 | 20 | 31 |
| 8 | 19 | 25 | 19 | 26 |
| 9 | 19 | 21 | 18 | 22 |

We recommended using seven electric carts and six wheelchair pushers in the domestic terminal (based on average TIS). At this level, 95% of domestic special-needs passengers would take less than 31 minutes to complete their airport processes. At all times, radio communication should ensure that a central command can contact electric carts and wheelchairs if special circumstances arise. Utilisation charts could be used to fine-tune the required number of electric carts and wheelchairs during the day if desired.

### 4.3 Connecting passengers

Since travel times between terminals may change, depending on the number of people in the airport corridors, we tested scenarios with different bus travel times. Table 5 shows the results of the simulation for the highest number connecting passengers of arrivals per hour.

**Table 5** Connecting passengers simulation results

| | | |
|---|---|---|
| Electric cart capacity (passengers) | 5 | 7 |
| Arrivals per hour (passengers) | 21 | 21 |
| Travel time (minutes) | 10 | 10 |
| Average time to connect (minutes) | 12 | 10 |
| 95th percentile time to connect (minutes) | 18 | 13 |

From the above results we can conclude that a single electric cart acting as a bus between the terminals would suffice for connecting passengers. A five-passenger electric cart achieves 12 minutes average time to connect, whereas a seven-passenger cart's average time to connect is 10 minutes. The difference between the two carts becomes more visible when we look at the 95th percentile values. Based on these values, we recommend a seven-passenger cart.

### *4.4 Sensitivity analysis*

We performed a sensitivity analysis on the cart speed, demand and baggage-retrieval time.

#### *4.4.1 Electric cart velocity*

The airport authority regulations limit an electric cart speed to a brisk walk (~2.2 metres per second). However, many of our observations suggest that carts travel faster than this 'limit'. Nevertheless, we tested scenarios using a velocity of half that of a brisk walk. We found that, for arrivals and transborder departures, when lowering the speed, the effect on TIS was negligible. However, for international departures, the average time increased by six minutes and the $95^{th}$ percentile increased by 21 minutes. This result is not surprising, since for international departures, travel time makes up a significant portion of TIS for special-needs passengers. Thus, there would be a need for more carts if the vehicles truly did not travel at a brisk walking speed. However, the airport's relatively wide and straight corridors make it possible for carts to travel at a consistent brisk walking speed most of the time.

#### *4.4.2 Peak demand*

Seasonal and daily flight traffic varies and this factor implies fluctuation in the number of passengers requesting assistance. Summer is the busiest season and, to be conservative, a busy summer day flight schedule was used for most of the analysis of this study. Also, we ran a scenario on the busiest day to see the effects of increased demand. For the majority of passengers, the TIS did not increase significantly. For departures, average service times and 95th percentile service times were affected by only a couple of minutes, but times for arriving passengers increased significantly – by 5 and 10 minutes, respectively.

#### *4.4.3 Process baggage time reduction*

Waiting at the baggage carousel made up a significant proportion of agent time used for arriving special-needs passengers. If this time could be reduced or eliminated, agents would be released earlier and could attend to other responsibilities. Sensitivity analysis was used to study whether it would be worthwhile to expedite the luggage of special-needs passengers. Results showed that ensuring that the baggage is ready for pick-up when the agent brings a passenger to the carousel would reduce agent service time by approximately 15 minutes. Therefore, if possible, the baggage of special-needs passengers should be promptly handled.

## 5 Recommendations

Table 6 provides a summary of the recommended operational strategies.

**Table 6** Recommended operational strategies

| *Terminal* | *Arrivals* | *Departures* |
|---|---|---|
| Transborder | Electric carts drop off passengers to wheelchair agents once Canada Customs is cleared. | Wheelchair passengers through US Homeland Security processes. Electric carts 'bus' passengers to gates. |
| International | Electric carts drop off passengers to wheelchair agents once Canada Customs is cleared. | Electric carts pick up passengers at check-in. Take passengers through PBS and then to gate. |
| Domestic | Electric carts pick up passengers at gate and drop off at elevators and escalators, bus-style. Wheelchair from gate, down elevators and help with baggage if necessary. | Electric carts pick up passengers at waiting lounge near check-in and take through PBS and to gate, bus style. |

The number of wheelchairs and electric carts at the airport can be significantly reduced using the recommended configurations. Indeed, in total, 15 electric carts are recommended for operation in the transborder, international and domestic terminals and one additional electric cart is recommended as a bus between the domestic terminal and the international/transborder area for connecting passengers. To account for maintenance and electric cart down-time, we suggest having two additional electric carts, for a total of 18 electric carts. We estimate wheelchair inventory requirements for the consolidated system as follows:

- 30 wheelchairs in use by agents during demand peak
- 2 wheelchairs at each gate, for approximately 60 gates
- 20 wheelchairs in the arrival carousels for transborder and international use
- 20 wheelchairs at each terminal's check-in counters for lending and miscellaneous staff use.

Thus, the total number of wheelchairs recommended for the entire airport comes to approximately 230. With the current estimates of 300 to 400 wheelchairs at the airport, a significant amount of inventory can be removed. In summary, our inventory recommendation results with a 24% reduction in wheelchair inventory, a 47% reduction in electric carts and significantly fewer dedicated staff required for transportation services. The recommended numbers for electric carts and staff are given in Tables 7 and 8.

**Table 7** Recommended number of electric carts

<table>
<tr><th>Terminal</th><th>Arrivals</th><th>Departures</th></tr>
<tr><td>Transborder</td><td rowspan="2">5</td><td>1</td></tr>
<tr><td>International</td><td>2</td></tr>
<tr><td>Domestic</td><td colspan="2">7</td></tr>
<tr><td>Connecting passenger bus</td><td colspan="2">1</td></tr>
<tr><td>Safety Stock</td><td colspan="2">2</td></tr>
</table>

**Table 8** Recommended staffing levels

| *Terminal* | *Arrivals* | *Departures* |
|---|---|---|
| Transborder<br>International | 26 | |
| Domestic | 6 | |

Centralisation of the wheelchair and electric cart service represents a substantial change for air carrier agents at the airport. An overall increase in service level and customer satisfaction is expected, as well as improved resource-use efficiency, better resource monitoring and cost reduction. The centralised system would provide consistent and higher quality service for all airlines with specialised and experienced service providers. Airlines are expected to cut costs by reducing their equipment and staff and can better focus on their core business. However, some disadvantages for some carriers may exist. For example, transferring control of the wheelchair and electric cart service to a third party may be worrisome for some carriers, especially those that hold customer service as a high priority. Additionally, a centralised system would mean more responsibility, cost and liability for the Airport Authority. Table 9 lists some of the pros and cons for the affected parties.

## 6 Conclusions

We investigated the feasibility and potential performance of a consolidated transportation service for special-needs passengers at the airport. Currently, air carriers are responsible for their own special-needs passengers and it is anticipated that a consolidation of these services would result in efficiencies and improved service.

We used analytical models to analyse the performance of a consolidated service and to identify effective operating strategies. We carried out sensitivity analysis to evaluate the robustness of our results, verified the validity of our recommended operational strategies and presented the pros and cons of a proposed centralised system from the perspective of the airport authority, airlines and passengers. Our methodology can be conceptually applied to other airports with a non-centralised transportation service for passengers with special needs, in order to quantify the effect of replacing the non-centralised system with a centralised system. Of course, actual implementation would entail some adjustments in view of the possible different processes and relevant data at the airport under study. The portability of our approach is especially important as the demand and number of services is expected to increase for most airports in the future.

Our study has some limitations. Since a centralised system does not yet exist, we could not validate our model in the traditional way and had to resort to building two different models of the proposed centralised system and compared them against each other. We further note that an implementation of a centralised system may face potential challenges and may raise issues that would have to be negotiated by all parties in advance (e.g., sharing of responsibilities, division of costs and accountability of the service in case of a service disruption or failure). Investigation and development of solutions for these potential challenges stand out as directions for future research.

In spite of the limitations identified above, the potential savings and improvements of a centralised system are significant and strongly suggest that the consolidation of the transportation assistance process for special-needs passengers deserves further research.

**Table 9** Pros and cons of centralised service

| *Party* | *Pros* | *Cons* |
|---|---|---|
| Airport authority | • Consistent service for passengers<br>• Monitoring capabilities<br>• Control over customer service<br>• Reduction in inventory | • Additional responsibility<br>• May not recover costs from air carriers<br>• Increased liability |
| Air carriers | • Loss of responsibility, focus on core business<br>• Cost effective. Removal of inventory replacement and maintenance costs. Potential to reduce staff levels. | • Yield control over passengers to third party<br>• Lose some advantages of resource pooling<br>• May lose electric carts for unaccompanied minors and VIPs.<br>• Less flexibility in serving its customers due to dependence on a third party |
| Passengers | • Overall higher service levels<br>• Consistent service provided regardless of air carrier used<br>• Experienced service providers<br>• More assessable service<br>• Will feel less burdensome if dedicated staff used | • Discontinuous agent service |

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