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INCLUDING AIRPORT DUTY-FREE SHOPPING IN ARRIVING PASSENGER SIMULATION AND THE OPPORTUNITIES THIS PRESENTS

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ABSTRACT

Simulating passenger flows within airports is very important as it can provide an indication of queue lengths, bottlenecks, system capacity and overall level of service. To date, visual simulation tools such as agent-based models have focused on processing formalities such as check-in, and not incorporate discretionary activities such as duty-free shopping. As airport retail contributes greatly to airport revenue generation, but also has potentially detrimental effects on facilitation efficiency benchmarks, this study developed a simplistic simulation model which captures common duty-free purchasing opportunities, as well as high-level behaviors of passengers. It is argued that such a model enables more realistic simulation of passenger facilitation, and provides a platform for simulating real-time revenue generation as well as more complex passenger behaviors within the airport. Simulations are conducted to verify the suitability of the model for inclusion in the international arrivals process for assessing passenger flow and infrastructure utilization.

1 INTRODUCTION

Airports are a perfect example of a system where a multitude of factors are in play, many of them undergoing continual change such as technological innovations and the need to provide a secure and safe travel experience in the face of malicious threats. Recent examples of such changes include the introduction of the Airbus A380 passenger jet, and the use of full-body security scanners. Each of these changes will have significant but different implications for the airport structure, the passenger facilitation process, the information and technology required, and ultimately have an effect on passenger experience. Some effects that such changes can have on the airport system are described by Kleinschmidt et al. (2010).

Coupled with this continual change is the large number of independent stakeholders, each having a different perspective on airport operations, and places different criteria on which successful airport operation is measured. For example, passengers want an efficient and pleasant travel experience, policing agencies want to ensure the terminal and aircraft are at low risk of malicious attacks, whilst the airlines, airport and retail firms want to increase passenger throughput and to generate increasing revenues.

Modeling airport systems therefore becomes very important to: (a) analyze the performance or level of service of an existing system, (b) to plan resourcing requirements for a given future flight schedule, and (c) to assist in planning changes prior to their implementation and determine what effects (if any) these have on the overall level of service. Simulation models are particularly important in the latter case since it is extremely impractical to manipulate the live airport system.

There are a number of different methods which have been used for airport modeling, and are broadly divided into macroscopic and microscopic models (de Neufville and Odoni 2003). In this paper, we consider microscopic simulation of the passenger facilitation process using agent-based modeling in order to produce a relative assessment of overall passenger flows within the terminal. We further limit the discussion to passenger movement and thereby exclude all aspects related to baggage handling.

Tosic (1992) provides an early review of airport system models. Due to the presence of mandatory check-points throughout the airport terminal (such as check-in, security screening, immigration, customs, quarantine inspection and boarding), it is no surprise that queue-based models (such as that initiated by Lee (1966)) dominate these reviews. Details of queue-based models are discussed in more detail in Section 2.

Significant examples of airport terminal simulation include the Simple Landside Airport Model (SLAM) proposed by Brunetta et al. (1999). This model estimates the terminal capacity and passenger delays by analyzing different spatial configurations of various check-point facilities. Manataki and Zografos (2009) present a generic mesoscopic simulation based approach using system dynamics and demonstrate on a model for the Athens International Airport for departing passengers. Wang et al. (2008) describes a passenger flow simulation through the use of colored petri nets, which captures passenger delays related to air transportation network cancellations or delays.

All of these models are used to evaluate aspects of passenger flows throughout the terminal based on what-if scenarios, but do not provide visual simulation of passengers moving through the terminal. From our interactions with industry practitioners, we believe this to be a very useful feature for airport passenger simulation as it helps to visually identify bottlenecks and crowding which can be related to the real-time operation with which they are familiar.

Agent-based models (where passengers are the agents) are a useful tool for studying passenger systems since they are able to simulate both the individual actions of passengers, but also the aggregated system behavior, and importantly provide a visual representation of the system. In this way, agent-based models are a good fit for the needs of industry practitioners, and as a consequence, we choose agent-based models as our simulation tool for this study.

In the airport environment, it is important to recognize that passengers not only interact amongst themselves, but also with all the service facilities within the terminal such as check-in, security screening, boarding and even discretionary facilities such as duty-free outlets and restaurants. The models described above (and those discussed in Section 2) focus primarily on mandatory activities through which passengers must proceed (e.g. security), typically excluding simulation of discretionary activities. This is a major shortfall of existing models particularly since retail sales account for large amounts of revenue generation for airports (Torres et al. 2005), but they can also significantly influence passenger facilitation, particularly for arriving passengers. For this reason, in this paper (see Section 3) we present a simple model of inbound duty-free retail shops, and demonstrate the opportunities that this opens for airport operators. Simulations on the arrivals process at the Brisbane International Terminal (Section 4) are conducted to demonstrate the variations in overall facilitation time (i.e. time required to clear all arrivals formalities) that can be observed when retail utilization is included in the passenger simulation model.

2 PREVIOUS STUDIES ON AIRPORT PASSENGER SIMULATION USING AGENT MODELS

As stated in the introduction, queue models are closely linked to a number of service facilities within an airport terminal, namely check-in, security screening, immigration and quarantine inspections, as well as boarding. Consequently, there have been a number of queue models which have been developed for airport passenger flow simulation. A summary of the studies analyzed in this section is provided in Table 1.

Lee (1966) pioneered the application of $M/M/n$ queuing theory to the airport check-in process, where the first M represents a Poisson arrival distribution, the second M exponential service time, and n the number of service facilities. A more recent example has applied queuing theory to modern-day security screening processes (Regattieri, Gamberini, Lolli, and Manzini 2010).

Queuing models are only able to evaluate passenger delays due to a particular service facility, but do not provide an indication of overall travel time from terminal entry to boarding. Agent-based models provide a mechanism for not only incorporating multiple queues into a single model, but importantly also include passenger travel and activities between queues. This is particularly important since discretionary

Table 1: Summary of previous studies on airport passenger simulation.

Authors (Year)	Check-in	Security	Immigration	Boarding	Retail/Discretionary
Lee (1966)	Yes	No	No	No	No
Gatersleben and van der Weij (1999)	Yes	Yes	Yes	Yes	Limited
Kiran, Cetinkaya, and Og (2000)	Yes	Yes	Yes	Yes	Limited
Takakuwa and Oyama (2003)	Yes	Yes	Yes	Yes	No
Regattieri et al. (2010)	No	Yes	No	No	No

activities (such as duty-free shopping or visiting cafes and restaurants) take up the majority of a passenger's time in an airport (Takakuwa and Oyama 2003), and it is therefore important to understand these activities (Popovic et al. 2009).

Gatersleben and van der Weij (1999) developed a full airport model (i.e., for departing, arriving and transferring passengers) for Amsterdam Schiphol Airport to analyze passenger flows, identify spatial bottlenecks, and observe the interaction between consecutive processing facilities. They have included the lounge and pier areas, but acknowledge that this is hard to simulate effectively due to passengers having full control over their actions in these areas. Their model collects passenger waiting time and total number of passengers (i.e. utilization) in these areas.

Kiran, Cetinkaya, and Og (2000) compiled a model of the Istanbul Ataturk Airport for the purpose of identifying bottlenecks through analysis of peak hour flight schedules. One of the outputs of this model is the utilization of duty-free shopping and restaurant areas in order to assist with estimating daily revenue. The simulation is based on population statistics and is not derived from the decisions and associated actions of individual passengers.

Takakuwa and Oyama (2003) analyzed international departure flows at Kansai International Airport in Japan based on discrete-event agent simulation. The purpose of the model is to determine the average time delay for passengers at the various mandatory processing facilities. Between processing points (e.g., check-in and security), passengers are able to "kill time", but this simply involves a waiting period, and no attempt is made to simulate what passengers actually do during this time. This is similar to the level of detail in the simulation of ancillary facilities by Brunetta et al. (1999) and Manataki and Zografos (2009).

From this discussion, it can be seen that previous experience in passenger simulation has been primarily focused on processing activities, with only limited support for discretionary activities. To overcome this limitation, in Section 3 we explicitly incorporate a mechanism by which retail utilization can be incorporated to an agent-based passenger simulation model. We believe that this simple model provides a platform upon which passenger simulation in non-processing areas can be built.

3 SIMULATION MODEL

In this paper, we choose to utilize agent-based models to simulate passenger flow in the airport terminal. Agent-based models provide a model of agent interaction with other agents and the environment (Reynolds 1999), and importantly provide a sense of agent autonomy which is not present in entity-based models. Entities in the latter model are controlled by processes within the system, and not by decisions of the individual agent (Johnstone et al. 2009). For this reason, an agent-based model is more suited to modeling areas of the airport which are not as process-driven such as duty-free shopping.

For this simulation we incorporate the duty-free model discussed in Section 3.1 into an international passenger arrivals process common to Australian airports. A high-level description of this model is presented graphically in Fig. 1. Dotted lines indicate optional activities/transitions between activities.

The major processing points are aircraft disembarkation, immigration and the secondary examination area which incorporates both customs and quarantine (bio-security) checks. Baggage reclaim is regarded as optional as not all passengers will have checked baggage to collect.

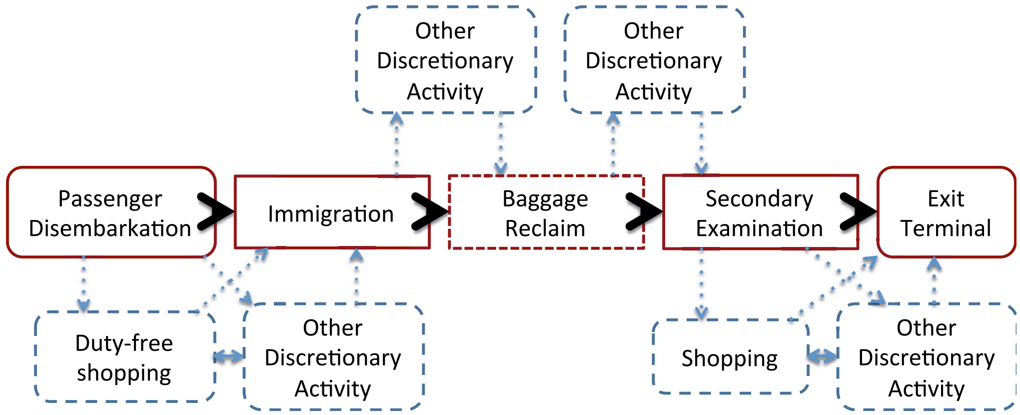

Figure 1: International passenger arrivals process common to Australian airports.

As can be seen, there are a number of areas in which passengers can undertake discretionary activities between the necessary formalities, including duty-free shopping, going to the bathroom, depositing prohibited items in the quarantine bins and obtaining luggage trolleys (among others). To distinguish from these activities, we represent duty-free separately as this is the area of interest to this particular simulation model.

3.1 Duty-Free Retail Model

Duty-free shopping is very popular for the traveling public, and the location of duty-free shopping now accommodates many different purchasing behaviors. In terms of purchasing opportunities of direct relevance to the arrivals passenger process, there are two main purchasing opportunities for arrivals hall duty-free:

1. Purchase prior to travel, where items are collected on arrival back into the airport.
2. Purchase on arrival at the airport.

It is also true that a significant number of passengers will not utilize duty-free, whilst some will enter duty-free without ultimately making a purchase. In the latter case, this may be due to the inability to locate a desired item, or it may be in response to observation of potential delays at the next processing facility.

Taking these behaviors into consideration, it is important that the duty-free model is able to allow for:

- Passengers having the option to enter the duty-free shops or to proceed directly to the next check-point.
- Passengers being able to enter the duty-free shops, browse products and exit without purchasing.
- Passengers being able to enter the duty-free shops, browse products, and proceed to the checkout to purchase items.
- Passengers who pre-purchased duty-free items to enter the store and proceed directly to the checkout to collect the items.
- The potential for passengers to utilize duty-free after noticing long queues at the next processing point.

Accordingly, we have developed a high-level flow model (see Fig. 2) of passenger behavior which captures these requirements. We regard this model as simplistic as it does not yet consider passenger browsing behavior within the store, nor does it provide a fully detailed representation of the spatial configuration, particularly with regard to queuing space and its relation to in-store displays.

This model assumes that passengers do not wish to browse the store once they have made a purchase or collected pre-purchased items (as depicted by the one-way arrow in Fig. 2), and that if they enter duty-free after seeing the length of the immigration queue (decision point 'B') that they will first browse (i.e. they have not pre-purchased items otherwise they would have entered at point 'A').

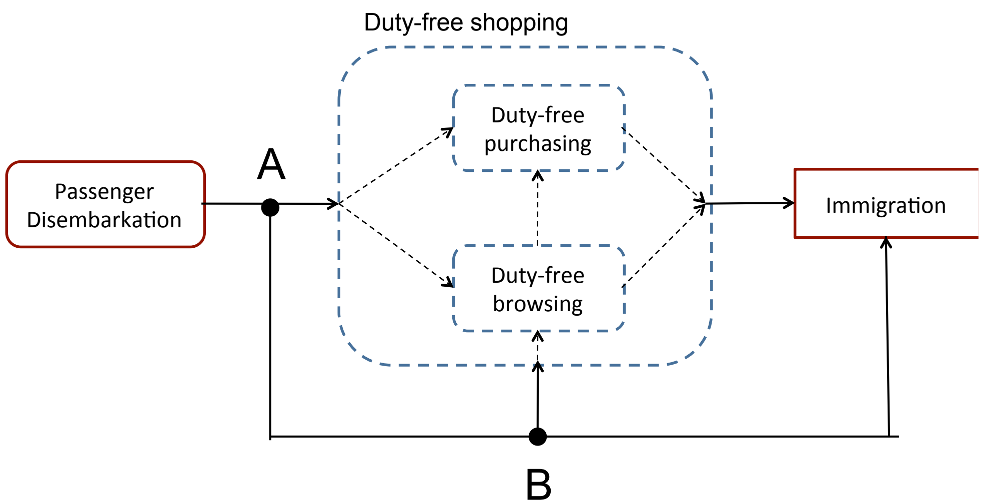

Figure 2: Flow chart depicting proposed retail model.

It should also be noted that decision points can occur at multiple spatial locations. For example, the decision points – as they apply to the simulation model described in Section 4 for Brisbane International Airport – are shown in Fig. 3, where it can be seen that decision point ‘A’ exists in two locations – one for passengers approaching from gates 81 and higher, and one for gates 80 and lower.

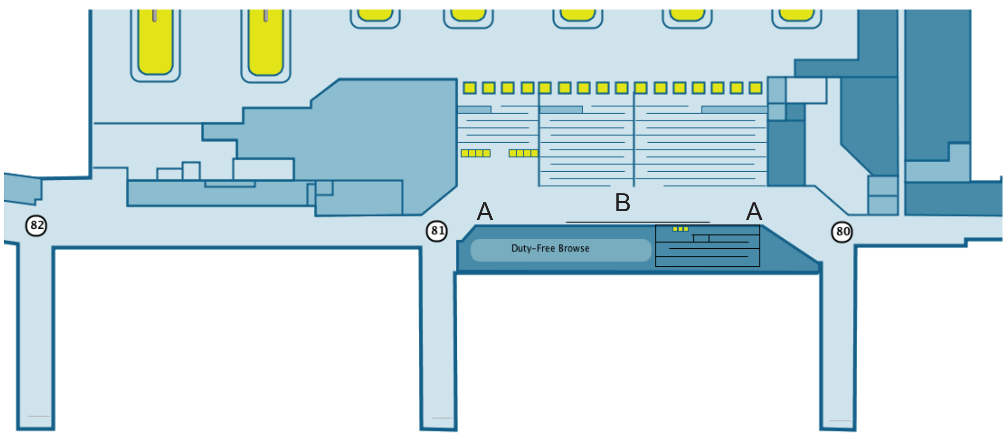

Figure 3: Example of spatial location of decision points (‘A’ and ‘B’) and browsing and purchasing areas in the proposed retail model.

3.2 Benefits of Proposed Model

In the previous section we discussed a simple high-level model to represent duty-free retail at airports (and potentially in other applications). This model has a number of benefits for airport operators over previous models including increased accuracy for passenger flow assessment, and an ability to assess revenue generation based on a particular flight schedule. For researchers, it opens to way to analyze the effects of different purchasing behaviors and business models on retail utilization and resultant queues, and incorporate more advanced passenger behavior characteristics to make agents more autonomous. It also provides a platform for researching methods by which passenger experience might be encapsulated within an agent-based model. These benefits are discussed in detail in the following sections.

3.2.1 Increased Accuracy of Passenger Flow

Agent-based models have already been used extensively to measure aspects of passenger flow, in particular to identify passenger dwell times, queue waiting times, and locating bottlenecks within the airport system (Gatersleben and van der Weij 1999; Kiran, Cetinkaya, and Og 2000; Takakuwa and Oyama 2003). In many cases however this has neglected to include passenger utilization of retail opportunities (and other discretionary activities).

In Australia, airports are encouraged to meet the recommended practice for arrivals procedures outlined in Annex 9 on facilitation provided by the International Civil Aviation Organisation (2005), which states:

Definition 1 *Contracting States, with the cooperation of aircraft operators and airport operators, should establish as a goal the clearance within 45 minutes of disembarkation from the aircraft of all passengers requiring not more than normal inspection, regardless of aircraft size and scheduled arrival time.*

Unlike the recommendation for departing procedures, this recommendation does not limit the performance standard to the mandatory processing requirements. Since there are often retail facilities in this area, the measured 45 minute benchmark will also include time spent in retail. As such, it is imperative to include these facilities in any arriving passenger flow model.

To demonstrate the influence of time spent in retail in the arrivals facilitation path, consider the mean facilitation times shown in Table 2 for passengers in four Australian international airports involved in the "Airports of the Future" project. These summary statistics are based on data provided to the research team by the Australian Customs & Border Protection Service where selected passengers were time-stamped as they moved between points of interest.

Table 2: Impact of utilizing retail for passenger clearance times through international arrivals in Australia.

Airport	Time to ECP		Clearance Time	% Time in Retail
	Retail	No Retail	(Retail Only)	
Brisbane	7'00"	3'30"	27'15"	12.8%
Darwin	8'30"	1'15"	32'30"	22.3%
Melbourne	10'15"	4'30"	35'30"	16.2%
Perth	8'00"	2'45"	37'30"	14.0%

In this instance, the four airports have been chosen as they each have duty-free outlets between the point of aircraft disembarkation and the Entry Control Point (ECP) where immigration checks are undertaken. To understand how much time passengers spend in retail between disembarkation and the ECP (as a percentage of their total clearance time) we show mean times for both passengers who use retail and those who go directly to the ECP. It can be seen for all airports that the time to ECP via retail is more than double the time when proceeding directly to immigration. As a percentage of total clearance time, passengers spend at least one eighth (i.e. 12.5%) of their total time in the duty-free shops, and in the case of Darwin International Airport, almost one quarter of their time.

It is therefore important to appreciate that a significant proportion of the overall clearance time (which is also affected by government agencies conducting arrival formalities, and baggage handlers delivering luggage to carousels) is consumed by passengers in retail. Consequently, changes to these retail stores (e.g. by changing purchasing opportunities) will have a noticeable impact on passenger flow and passenger clearance times against which stakeholders often measure airport performance.

3.2.2 Modeling Advanced Passenger Behavior

Passenger behavior in airports is still not well understood, particularly in relation to discretionary activities. This model adds a number of key aspects which will allow for additional layers of passenger behavior simulation, in particular the presence of multiple decision points around the duty-free shop.

As an example, the decision points could be used to simulate three different types of passenger in respect to their willingness to use airport retail. The first type could include passengers who had decided prior to leaving the aircraft that they wished to entry the duty-free shop, either with the view to make a purchase, or to collect pre-purchased goods. At the other end of the scale are passengers who have no intention of entering duty-free, particularly those business travelers who wish to get out of the airport as quickly as possible. The third passenger type would then be somewhere in between these two extremes; such passengers might be persuaded to enter the duty-free shop because of advertising around the store, or seeing a product that they like. This demographic of passenger may also describe those who are most likely to enter duty-free upon seeing long queues at the immigration checkpoint.

In such a way, the ability to increase the autonomy of the passenger by incorporating more detailed passenger information into the simulation model will enable more complex passenger movements, and will therefore provide airport operators with more realistic passenger flow models. It should be noted however that the current model (and associated simulation) does not try to hypothesize complex passenger decision-making which would dictate the likelihood of individual agents entering duty-free; we simply apply proportions to demonstrate passengers moving through the respective decision points to demonstrate the concepts.

3.2.3 Modeling Revenue Generation

Given that passenger occupation of duty-free has been enabled with the proposed model, and it is also possible to distinguish customers collecting pre-purchased items from those purchasing on arrival, it is now possible to model revenue generation from purchases made in retail facilities. For example, by applying average expenditures to each transaction, it is possible to determine revenue on an hourly or a flight-by-flight basis. The actual value of the average spend could be determined at whatever level of granularity deemed necessary by the airport (e.g., daily average spend, average spend based on originating airport, etc.).

It will also be possible to model the effects on hourly revenue generation created by changes in passenger purchasing behaviors (enabled by modeling of advanced passenger behavior as discussed in Section 3.2.2), and future purchasing models. This will be particularly useful for airport operators to analyze new processes and marketing models prior to implementation in order to see the benefits to airport profits as well as the potential impact on passenger facilitation time.

4 SIMULATIONS

To demonstrate the model in operation, two scenarios have been simulated: (1) passengers do not utilize any duty-free facilities, and (2) passengers are able to use the duty-free facilities under the model proposed in Section 3. The duty-free browsing space and queue and service counters are as shown in Fig. 3. Each scenario was run 10 times, and the results reported here have been averaged across all 10 simulations. In this section we are unable to compare the simulation results with real passengers as sufficient real-world data was not available to generate comparable distributions as presented in this section.

The international arrivals process at Brisbane International Airport on 28th October 2010 was used for this simulation. This flight schedule includes 29 flights throughout the day which brought in a total of 4,868 passengers on that day (as per the airport's passenger monitoring statistics). There are three peak periods which produce significant queues at immigration and quarantine: 5:30am-8am (8 flights), 9am-10am (7 flights) and 4pm-6pm (8 flights). A 15:30:35 ratio of passengers using the electronic immigration kiosks (known as SmartGates), Aus/NZ and Other Nationality queues at immigration respectively was used for both scenarios.

The logical model presented in the Section 3 was implemented in Java based on the flow chart described in Fig. 2 and the spatial locations shown in Fig. 3. The pedestrians travel through the terminal based on speed and directions determined by the social force model for pedestrian dynamics (Helbing and Molnar 1995). The decisions at 'A' and 'B' have been modeled as proportions of the entire population (based on expert elicitation), and not using intelligent agent decision-making (as this is not yet well understood for this scenario). At point 'A', 80% of passengers proceed directly to the immigration queues (and consequently point 'B'), 15% enter the duty-free browsing space, and 5% proceed directly to the duty-free purchase queue to pickup pre-purchased items. For those browsing the shop, 40% of passengers choose to purchase items following a set wait time in the browsing area (which is randomized over a gamma distribution with $\alpha = 3$, $\beta = 10$); the other 60% proceed to the immigration queues. At point 'B', if the immigration queue is full, 80% of passengers arriving at immigration will choose to browse the duty-free shop, whilst the other 20% will remain in a waiting area until there is space for them in the queue. It should be noted that passengers already in the queue will remain in the queue.

To reflect the capabilities this additional model provides to the analysis of passenger flows within the arrivals process, three metrics have been collected: (1) time for each passenger to reach the entry control point (to compare against Table 2), (2) total clearance time for each passenger, and (3) the instantaneous passenger utilization of both the arrivals concourse (which includes the duty-free store) and the ECP.

In the proposed model, the mean time to reach the ECP was found to be 3'05" for passengers bypassing duty-free (the same was found for the original model without retail), and 8'25" for passengers using duty-free. The total clearance time for passengers using duty-free was found to be 27'40" which is only 40" longer than the true mean clearance time. Whilst these numbers don't match the true values in Table 2 (3'30" and 7'00" respectively), they are sufficiently close to suggest that the developed model is a fair representation of the passenger flow at Brisbane International Airport, and in particular for the time spent by passengers in the duty-free store.

Figure 4 provides a closer view of the distribution of the time taken for passengers to reach the Entry Control Point. The 'Original Model' represents the first scenario in which there are no retail opportunities available, whilst the other two are the distributions of passengers in the proposed model. It can be seen that the distributions for passengers not using retail have a number of distinct modes, which are related to the distance of the arrival gate to the ECP. In particular, there is a large proportion of passengers who reach the ECP in less than one minute – these passengers were on flights arriving at gates 80 or 81 which can be seen to be very close to the ECP in Fig. 3.

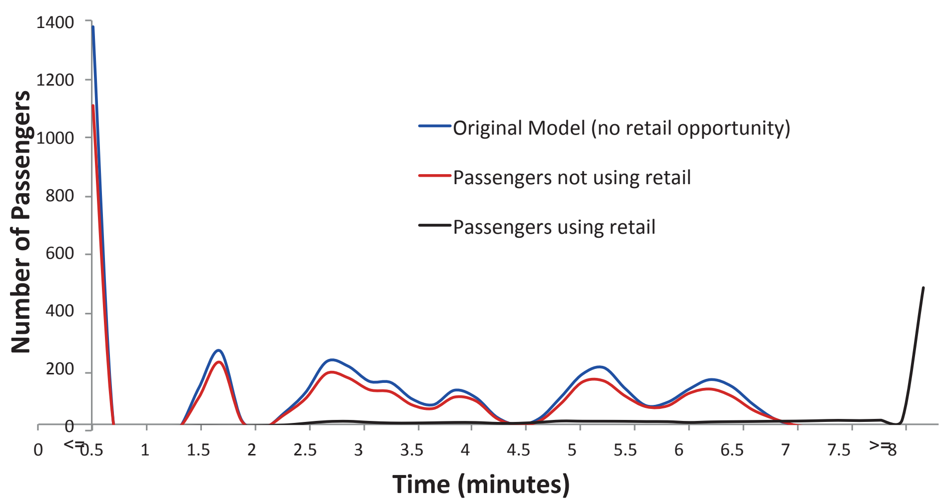

Figure 4: Comparison of distribution of time taken for passengers to reach the entry control point.

Comparing the two distributions where there is no retail use, the shapes of the distributions are very similar, with the magnitudes being reduced in the proposed model due to the fact that some passengers are now using duty-free. This, along with the very similar mean times to reach the ECP, validates that the proposed model does not change the profile of passengers who do not use the duty-free shop.

It can also be seen that only a small proportion of passengers who use retail are able to arrive at the ECP within 8 minutes of disembarkation. This has a number of secondary effects, in particular in relation to instantaneous utilization of airport facilities (which also alters the total clearance time for both passenger groups) as will be discussed later.

The distributions of total clearance times are shown in Fig. 5. In this instance, the shape of the distributions of passengers are very similar, with the important characteristic being the shift in the peak clearance times between the three profiles. For the original model, the peak clearance time was 20 minutes, but the proposed model shows a 19 minutes peak for passengers bypassing duty-free, and 24 minutes for passengers using the available retail store. This reduction in peak clearance time for non-retail passengers can be attributed to the fact that those passengers who are using duty-free have been taken out of the queues which results in the other passengers being processed sooner at immigration as well as at quarantine.

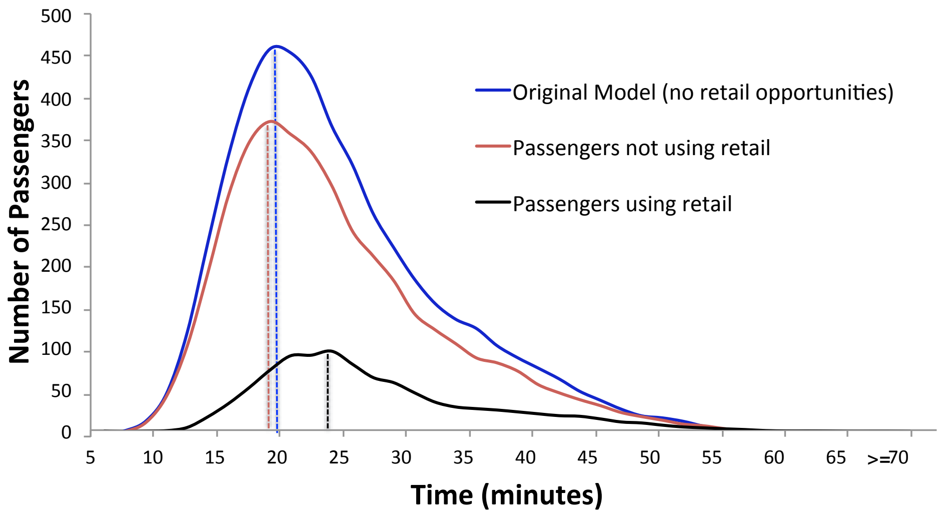

Figure 5: Comparison of distribution of time taken for passengers to clear all arrivals formalities.

This phenomenon is further validated by assessing the instantaneous utilization (i.e. number of passengers in the space at a particular time) of the pre-ECP corridors (known as the concourse) and entry control point as shown in Fig. 6. In particular, it is seen that the peak utilization of the ECP during the morning mini-peak period are reduced as passengers are spread through both the ECP, the concourse and the duty-free area. The effect of passengers arriving from the duty-free store at a later time than the other passengers is observed around both 6:10am and 8:24am where there is a more gradual decrease in utilization as passengers filter through from duty-free after the other passengers have been cleared. These two characteristics, alongside the observations related to Fig. 5 provide airport operators with a clearer picture of performance, particularly in terms of infrastructure utilization upon which the International Air Transport Association (IATA) Level of Service standards are calculated.

5 CONCLUSION & FUTURE WORK

Airport passenger flow modeling is very important for understanding airport level of service based on passenger delays, queue lengths, and number of passengers occupying particular spaces. A number of studies have been completed previously in this area – these have focused on the formalities associated with departures and arrivals, and not on passenger interaction with ancillary facilities such as duty-free shops.

In this paper we have proposed a simple model for capturing basic interactions with retail facilities in the airport. In particular, this model enables the consideration of different purchasing behaviors such as pre-purchasing and collecting items on arrival back to the airport, purchase on arrival, and browsing

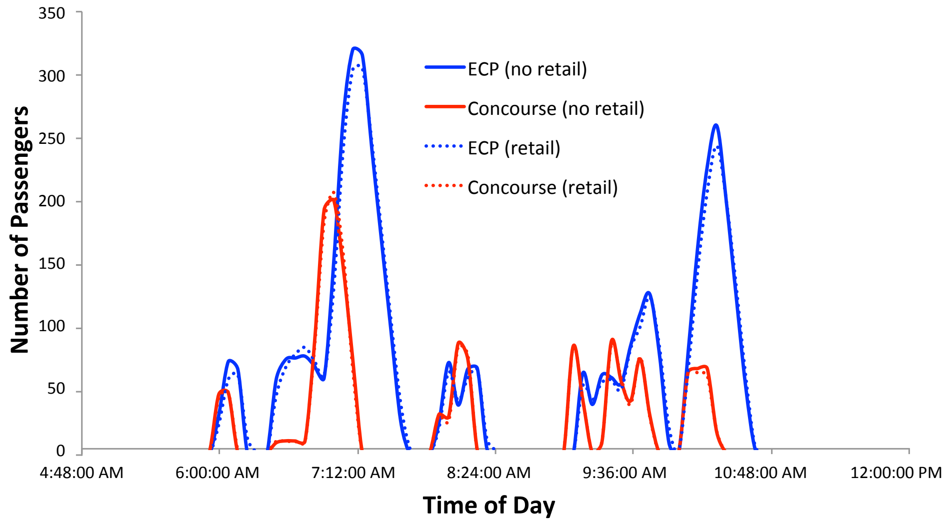

Figure 6: Comparison of entry control point and arrivals concourse instantaneous utilization for the simulation models with and without a retail opportunity.

without purchasing. It achieves this through two key areas within the retail area: the browsing space, and the checkout queue and associated service.

To complement these two key areas, a number of decision points have also been incorporated to reflect some basic passenger decisions in relation to retail utilization. The first point separates passengers either to the browsing space (for perusing products), the queue space (to collect pre-purchased items), or on to the next processing facility without entering the duty-free shop. The second point provides the ability to assess how passengers behave when they see a long queue at the next processing stage: they have the option to join the queue, or to browse the duty-free store whilst they wait for the queue to reduce. A point with the duty-free store allows passengers to move from browsing the store to queuing at the checkout, or to leave the store without purchasing.

Two scenarios were simulated in the Brisbane International Terminal: one in which no retail opportunities were available (as per previous work), and one which utilizes the proposed model. The analysis of the simulations verified the functionality of the model, even though the statistics varied slightly from the statistics gathered from observation of passengers in the arrivals process at Brisbane International Airport.

The simulations also highlighted that the proposed model is able to provide a more realistic analysis of the true passenger flow and instantaneous space utilization. In particular, it was observed that by diverting some passengers to the duty-free shops, passengers bypassing retail were able to clear all arrivals formalities slightly faster, the peak space utilization at the ECP was reduced, and the ECP service was required for a longer time period following peak periods. Both effects were due to the diversion of passengers to duty-free which ensured they reached the immigration queues in a more staggered fashion, reducing peak queues and spreading the flow of passengers over a longer time span.

Given the development of the retail simulation model presented in this paper, we plan to validate the observed results with the real behaviors of passengers – validation has proven difficult to this point in time due to a lack of comparable sales data and other forms of analysis including video analytics. As part of the "Airports of the Future" project, we are in the process of collecting and analyzing data in these forms. We then anticipate to use this model to perform analysis of revenue generation based on real-time activity in the retail area and on varying retail expenditure behaviors. It is also anticipated that we can extend the autonomy of each passenger's interactions with retail and other airport facilities based on a more detailed model of passenger characteristics in order to give each passenger a decision model as opposed to using global population proportions to separate passengers amongst duty-free and the immigration queues as used in this study. Consequently, this will enable the agent-based simulation environment to be extended to capture elements which describe passenger experience in these areas, not just dwell times and delays.

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REFERENCES

Brunetta, L., L. Righi, and G. Andreatta. 1999. "An operations research model for the evaluation of an airport terminal: SLAM (Simple Landside Aggregate Model)". *Journal of Air Transport Management* 5 (3): 161–175.

de Neufville, R., and A. Odoni. 2003. *Airport systems planning design and management*. McGraw-Hill, Inc.

Gatersleben, M., and S. van der Weij. 1999, December. "Analysis and simulation of passenger flows in an airport terminal". In *Proceedings of the 1999 Winter Simulation Conference*, edited by P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 1226–1231. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Helbing, D., and P. Molnar. 1995, May. "Social force model for pedestrian dynamics". *Physical Review E* 51 (5): 4282–4286.

International Civil Aviation Organisation 2005, July. *Annex 9 to the Convention on International Civil Aviation: Facilitation*. International Civil Aviation Organisation.

Johnstone, M., V. Le, S. Nahavandi, and D. Creighton. 2009, December. "A dynamic architecture for increased passenger queue model fidelity". In *Proceedings of the 2009 Winter Simulation Conference*, edited by M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin, and R. G. Ingalls, 3129–3139. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Kiran, A., T. Cetinkaya, and S. Og. 2000, December. "Simulation modeling and analysis of a new international terminal". In *Proceedings of the 2000 Winter Simulation Conference*, edited by J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 1168–1172. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Kleinschmidt, T., A. Goonetilleke, C. Fookes, and P. Yarlagadda. 2010. "A Multi-Disciplinary Approach for the Design and Management of Airport Terminals". In *Proceedings of the 3rd International Manufacturing Technology, Design and Research Conference*, edited by B. Satyanarayana and K. Ramji, 57–62.

Lee, A. 1966. *Applied Queuing Theory*. London: MacMillian and Co. Ltd.

Manataki, I. E., and K. G. Zografos. 2009. "A generic system dynamics based tool for airport terminal performance analysis". *Transportation Research Part C: Emerging Technologies* 17 (4): 428–443.

Popovic, V., B. Kraal, and P. Kirk. 2009. "Passenger Experience in an Airport: An Activity-centred Approach". In *Proceedings of International Association of Societies in Design Research Conference*, edited by K.-P. Lee, 1–10.

Regattieri, A., R. Gamberini, F. Lolli, and R. Manzini. 2010. "Designing production and service systems using queuing theory: principles and application to an airport passenger security system". *International Journal of Services and Operations Management* 6 (2): 206–225.

Reynolds, C. 1999. "Steering behaviors for autonomous characters". In *Proceedings Game Developers Conference*, edited by A. Yu, 763–782. San Jose, CA, USA.

Takakuwa, S., and T. Oyama. 2003, December. "Modeling people flow: simulation analysis of international-departure passenger flows in an airport terminal". In *Proceedings of the 2003 Winter Simulation Conference*, edited by S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice, 1627–1634. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Torres, E., J. Dominguez, L. Valdes, and R. Aza. 2005. "Passenger waiting time in an airport and expenditure carried out in the commercial area". *Journal of Air Transport Management* 11:363–367.

Tosic, V. 1992. "A Review of Airport Passenger Terminal Operations Analysis and Modelling". *Transportation Research Part A: Policy & Practice* 26 (1): 3–26.

Wang, D., L. Sherry, G. Donohue, and B. Hackney. 2008. "Passenger Flow Simulation (PFS) In A Complex Networked Transportation System". Submitted to International Conference on Research in Air Transportation.

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