2016 Global Congress on Manufacturing and Management

Framework for airport outbound passenger flow modelling

Sultan Alodhaibi[a], Robert L. Burdett[b**], Prasad KDV. Yarlagadda[a,*]

[a]School of chemistry, Physics and Mechanical Engineering, Science and Engineering Faculty, Queensland University of Technology, Brisbane, QLD 4001, Australia .
[b]School of Mathematical Science, Science and Engineering faculty, Queensland University of Technology, Brisbane, QLD4001, Australia.

Abstract

This paper focusses upon passenger flow issues within airport terminals and includes all activities occurring between curb-side and boarding. To improve passenger flow and associated planning activities, a simulation framework is developed using Discrete-Event Simulation (DES). The DES is built using ExtendSim V9.2 simulator software from Imagine That. The model can be used to evaluate the efficiency of the outbound operational processes including check-in, security screening, immigration & custom and boarding. It can also assist management to identify potential bottlenecks in the system. The main input of the model is the flight schedule. A case study of the Brisbane international airport was analysed.

Keywords: discrete event simulation,Passenger flow, airport terminal analysis.

* Corresponding Prasad KDV Yarlagadda. Tel.: +6-173-138-5167; Fax: +6-173-138-3381.
E-mail address: y.prasad@qut.edu.au.

1. Introduction

Airports play a substantial role in economic growth, connecting cities and nations. Numerous passengers travel through airports every day. According to the International Air Transport Association (IATA) (2014) more than 3 billion passengers used air travel as a transportation means worldwide in 2013 – up 5.1% from 2012. Airports are complex systems, and they handle two types of passenger flow systems, the first is departure passenger flow and the second is arrival passenger flow. Each one of these systems has its own procedures. The departure procedures include airport access facilities, check-in security screening, immigration and custom and boarding. While the arrival procedures include disembarking procedures, immigration, baggage claims, custom and quarantine and leaving the airport. The departure flow of passengers system is more important because it has the greatest impact on the entire operation of passenger terminals and other elements of the airport. According to (De Neufville, Odoni, Belobaba, & Reynolds, 2013) the departure process, which sometimes involves services provided to transit passengers, typically requires a significantly longer time than the arrival process. Some airports have a slightly different process and new airports to be designed in the future may require further changes to the standard process in light of the new security concerns being faced in our modern world.

Airport terminals have many problems that can impact passenger handling flows. Safety concerns in recent times have caused many changes to security screening procedures and this impacts passenger throughput times. After the incident of 11th September 2001, when terrorists brought down the twin towers in New York by using passenger planes, airport security has become more critical. Another problem that faces modern airports is limited infrastructure capacity, including the available number of resources such as numbers of common check-in counters kept open and number of personnel available.

At the same time, there are serious policies that airports have to consider concerning the processing of passengers. These policies include: the weight of luggage; the identification of passengers; the safety of security checkpoints; the need for smart systems and methods; and the extension of the major airport infrastructure, which is typically time-consuming and costly (Barnhart, Fearing, Odoni, & Vaze, 2012; Manataki & Zografos, 2009). Recently an investigation of passenger experience and airport operational efficiency found that that "The less time the customer spends in the systems, the higher the satisfaction" (Guizzi, Murino, & Romano, 2009).

2. Related work

This section reviews the existing works on airport passenger flow modelling, focusing particularly on departure system to measure the performance of workstations and to understanding which factors affect passenger flows. According to (Wu & Mengersen, 2013) existing airport models can be categorised into four sets "capacity planning, operational planning and design, security policy and planning, and airport performance review". These models can be analytic, simulation, and hybrid approaches as well. They require different levels of detail (e.g. macroscopic, microscopic, and mesoscopic) and have deterministic and stochastic characteristic (Wu & Mengersen, 2013; Zografos & Madas, 2006). The models capture different performance metrics for 'operational efficiency', including service time, queue length, and congestion. In recent years, simulation modelling has become popular not only for passenger flow analysis, but also for integrating and simulating two or multiple systems/components (Pitchforth, Wu, Fookes, & Mengersen, 2015). Takakuwa & Oyama (2003) developed a microscopic simulation model to investigate passenger flow in an entire airport terminal building with a primary focus on international departures. They noted that check-in time is the highest, at about 80% of the whole terminal waiting time. In addition, (Ma, Fookes, Kleinschmidt, & Yarlagadda, 2012; Ma, Kleinschmidt, Fookes, & Yarlagadda, 2011) and (2012) provided a similar microscopic simulation model represented by an agent-based model and mainly focused on human   factors (i.e. passenger characteristics). The proposed model was used to study check-in operations of passengers and

their use of discretionary facilities. Holding advanced passenger traits in the agents were found to make the simulations more realistic, hence, the peak check-in queuing times could be reduced by distributing passengers over the full range of facilities. Hybrid approaches have been seen in the literature repeatedly. For example, (Olaru & Emery, 2007) have employed both simulation models and genetic algorithm (GA) optimisation to model and analyse departure procedures. They used this model as a process of organisational adjustment to evaluate airport operations efficiency, infrastructure impacts and operational changes.

In addition, process models are often used to give a complete view of terminal operations with respect to passenger capacity and processing time. An example of process models is discrete event model, accordingly (Verbraeck & Valentin, 2002) stated that "DES is often used to model system where complex processes are combined with a limited infrastructure of capacity". One of best definitions for DES was given by (Dorton & Liu, 2015), they defined DES as "a general collection of theories, methods, and applications to replicate behaviour of real systems for assessment or experimentation". Several authors, each with different aims, proposed that DES be utilised to analyse departing passenger flows (Guizzi et al., 2009; Novrisal, Wahyuni, Hamani, Elmhamedi, & Soemardi, 2013; Rauch & Kljajić, 2006). Guizzi, Murino *et al.* (2009) believed that passengers behave differently at the airport due to their experiences; therefore it is difficult to forecast delays and priority. Their simulation model aims to predict delays in a logical and rational way, in the area of check-in and security check point. This would take into account the available capacity and the volume of passengers, based on time of day and passenger behaviour. The Rock well Arena simulation software tool was used in this study to provide the results of the average queue length and waiting time. Alternatively, Rauch & Kljajić (2006) constructed their model by General Purpose Simulation System (GPSS), a simulation programming language. To identify system bottlenecks the authors aimed to analyse departure processes, from check-in to boarding, at a specific time before departure. Key factors such as passenger arrival pattern, passenger service time, and operating process were measured. Similarly, Novrisal et al (2013) developed their model to analyse congestion problems in departure process at Soekarno-Hatta International Airport in Indonesia. The model's objectives were to reduce processing and waiting time in the system. It was found that the number of check-in counters needed to be increased, with approximately 61% of total time spent in check-in queues during the departure process. Limited research has been conducted on potential interactions between the flow of inbound and outbound passengers, including the potential of the inbound passengers to draw significant personnel resources. For example in the customs and immigration areas, processing outbound passengers may delay inbound passengers. This causes an obvious need to model and optimise these interactions under realistic terminal conditions.

3. Research Aims and Methodology

3.1. Aims

This article's focus is the development of improved simulation models for airports. The main objective of this research is to develop a model that can accurately evaluate how an airport will perform. We intend to consider both inbound and outbound processes in one holistic approach. In this article however only the outbound processes are discussed. In later work we will jointly consider inbound and outbound. To the best of our knowledge, modelling/simulating both outbound and inbound procedures is seldom performed.
The purpose of modelling passenger flows is to inform management and to help them make future investment decisions that will affect the performance of the airport and passenger's satisfaction. In the air transportation industry there are many decisions that can be made and there are large financial consequences. Hence improving an airport is a challenging task.
These issues make the airport a challenging and worthwhile area to employ the simulation process (Kamyszek, 2014). (Manataki & Zografos, 2009) confirmed that simulation can handle the unevenness, complexity and

stochastic nature of the airport terminal as well. In this paper, a simulation model was constructed for Australian International airports. The model will focus only on the left-hand side part (see Fig 1), including the processing domains of departure including arrival check-in, security screening, immigration and customs, and boarding. This model will be the first step towards the development of the final model (outbound/inbound). The proposed model is a generic model for many reasons. The first reason is that the physical structure can be altered easily to model different terminal layouts, as each airport behaves differently and processes passengers differently. Another reason is that it allows modellers to carry out different flight schedules, which is the main input of the model. The model will provide more accurate outcomes in representing flows of departing and service processes. It is also expected to help with decision making activities. The analysis will take into account a variety of performance metrics such as average waiting time, average queue length and utilization rate per terminal facility. A wide range of what-if scenarios can be explored throughout the model in order to help with more effective decision-making in airport terminal operations planning, design and management.

3.2. Methodology

In this section we introduce a generic framework to model the flow of passengers through the outbound processes of an airport. Each system has its own particular flows, and each needs different infrastructure and services. With the increasing demand for air transportation and new security policy, there are many operations that are influenced by limited resources and infrastructure. These constraints can create significant bottlenecks, long passenger queues, congestion and overall delays. The integration of these airport systems is a hard, complex and politically sensitive topic. The principal aim is to find methods that can be used to optimise airport system performance in terms of passenger flows. The development of a holistic framework for analysing airport system performance is essential because each entity within the system is inter-dependent with each other. This type of framework is important to answer questions associated to airport system performance. As explained previously, the rapid increase in the numbers of passengers, and commonly existing limitations on physical expansion of airport facilities, has produced a significant problem for the future development of the air travel industry.

We have considered the development of a discrete event simulation model to simulate an entire airport's outbound (i.e. departure) and inbound (i.e. arrival) systems (Fig.1) and to analyse a variety of performance metric associated with passenger flows. The performance metrics of interest in this article are average queue length, average waiting time, utilization rate. Discrete event simulation is well suited to complex systems with limited infrastructure capacity constraints (Verbraeck & Valentin, 2002).
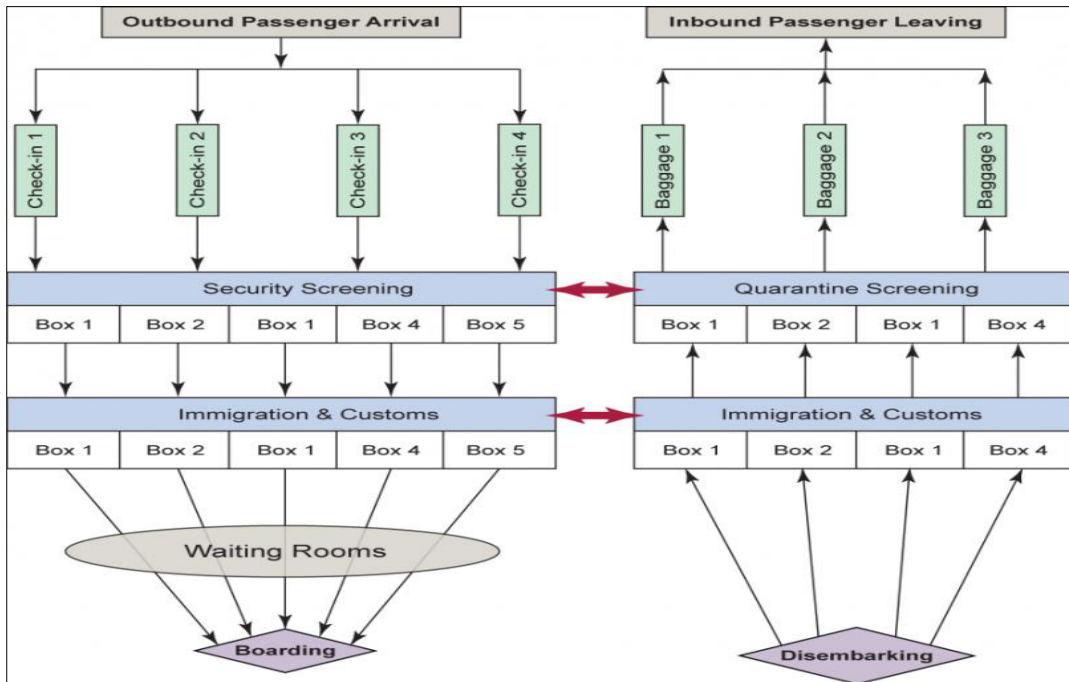
Figure **1**: The approximate schematic for the proposed ExtendSim model simulating the operations for the International Terminal Airport including inbound and outbound lines of passengers.

3.3. Model architecture

The design of a model is extremely important. If not implemented correctly, then the model may not accurately portray real life events and may provide incorrect results. It may also be difficult to make enhancements later if the details of the airport changes or further questions need to be asked. Good model design will always try to provide for scalability, i.e. can the same model be easily used on another terminal, or be used to design a new terminal. The simulation run time needs to be long enough to represent a complete cycle that the airport experiences. This period of time was determined from the flight schedule provided by the airport, one week, and was chosen to allow for differences in schedules for different parts of the week. For example, weekends and public holidays, workdays, and holiday periods. The model can also be run for just a day, depending on the questions that need to be answered.

The structure of the model is built around the basis of a hierarchical model structure. In this context, the proposed model is organised into two hierarchical levels:
   (i)   The first level of the hierarchy reflects the airport departure systems breakdown into a set of the main departure procedures.
   (ii) The second level describes the intricate details of the different sub-processes in the airport terminal.

Specifically, the main departure procedures by which the airport terminal model consists of are:
   •   Arrival characteristics, including distribution of arrivals, method of arrival (car, bus, train), number of bag, class of travel and time of travel.
   •   Check-in process, including type of check-in (e.g. kiosk, online with bag, business and economy), and assigning each flight to specific check-in counters.

- Security screening, including x-ray check for the common security screening line, X-ray for diplomatic people and secondary screening check (Random check).
- Immigration processing, including smart gate service, and the common counter for passport control.
- Boarding procedures, including boarding time, waiting time at gate, boarding strategy, jetway capacity and flight capacity.

3.4. Parameters and Assumptions of the Model

(i) 92% of passengers travel with economy class and only 8% travel business class.
(ii) A passenger arrival profile has been constructed. We assume that 75% of passengers use private cars, 10% use buses and 15% use trains.
(iii) It assumed that 65% of passengers use the airport counter, 20% check in online, 15% use the kiosk.
(iv) The number of bags is between zero and two.
(v) Passengers proceed directly from facility to facility.
(vi) The processing time at each main departure procedure is as follows:

- At the check-in counter, the processing time is based on the number of bags. We assume that each bag needs 0.5 min to be processed.
- At the security screening, we assumed that processing distribution is Erlang distribution with k = 0, mean = 0.5.
- In the immigration we assume that the processing time is a triangular random variable with a max of 2 minutes, most likely value of 1 minute and with minimum of 0.2 minutes.

4. Case Study

The simulation framework has been applied to the Brisbane International Airport (BNE). A model has been developed that includes the main characteristics of the BNE with regards to passenger flow and processing, and with respect to a variety of functional areas and facilities. To validate the model, four different load factors are evaluated. The load factor is the proportion of a planes total number of seats that are occupied. The load factors considered are as follows: (50%, 60%, 75%, 100%). Several flight schedules have been analysed to understand their impact on passenger arrival profile and terminal facilities.

4.1. Impact on arrival process

The arrival pattern of passengers and the rate of passenger arrivals is affected by flight departure times and the destination of flights. According to (Rauch & Kljajić, 2006) passengers with early flights generally arrive later than the statistical average. The mode of arrival to the terminal depends on the modal split. The modal split is the proportion of passengers that use private cars, trains and buses. Figure 2 and 3 demonstrate passenger arrival patterns per mode of transport, and shows the distribution of passenger arrivals over time (in 10-min intervals). We assume 75% of the BIA passengers use private cars, 10% bus and 15% train.
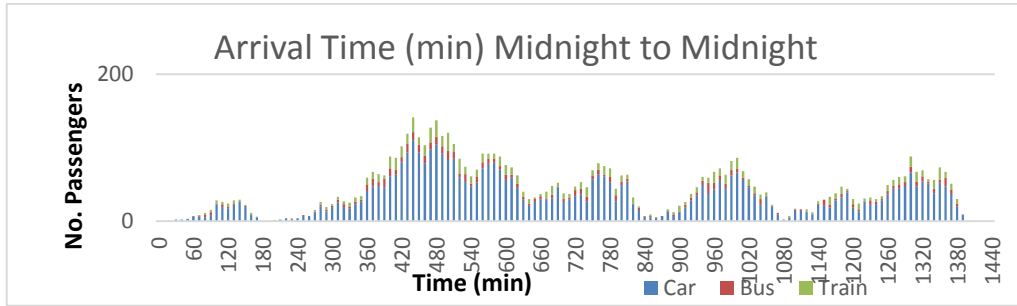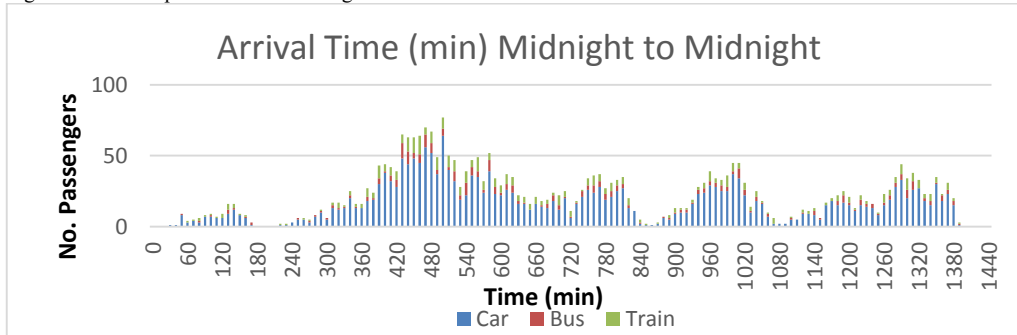
Figure 2: Arrivals patterns for 100% flights full.

Figure 3: Arrivals patterns for 50% flights full.

It can be observed that two high peaks occur in the morning between 8:20 to 10:30 a.m. Two lower peaks also occur in the early evening and in the night, at 17:40 to18:35p.m. and 9:20p.m. to 23:50p.m. respectively. This information can be used to assist airport operational managers to schedule staff within the terminal and its facilities. It can also be used to determine the walking time required for the passenger from each transport station at which they arrived to the entry of the terminal.

4.2. The impact on terminal facilities

As far as the efficiency of the operational processes at airport terminal is concerned, Fig. 4 & Fig. 5 show what simulation outcomes occur in the security screening and immigration processes.
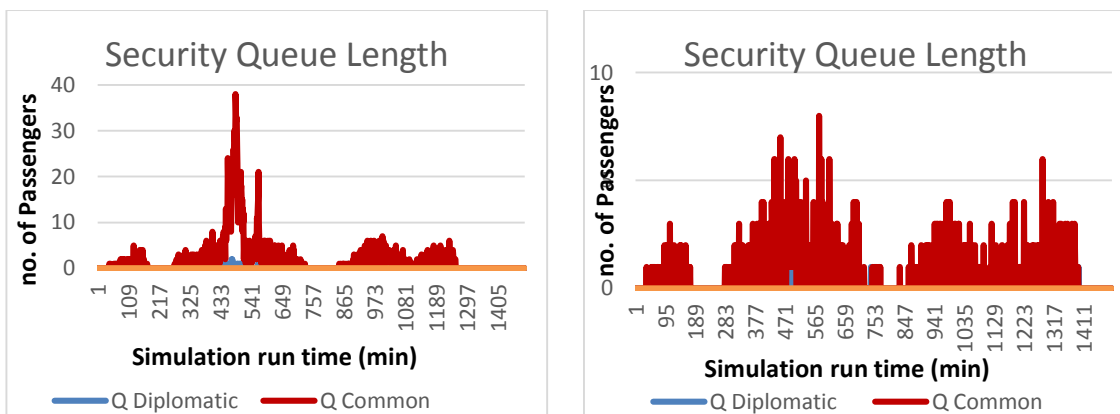

Figure 4: Security queue length 100% flights full; (b) Security queue length 50% flights full.
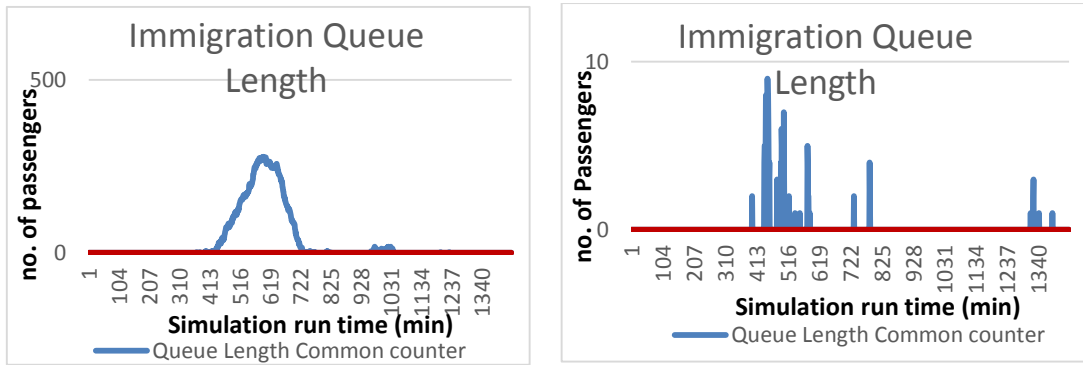
Figure 5: Immigration queue length 100% flights full; (b) Immigration queue length 50% flights full

What-if scenarios have been performed to analyse the queue length for the two facilities. It is clear to see that the queue length of security screening can be decreased more than four times if the capacity of the flight is 50% full. For the same condition the queue length of immigration is sharply decreased from 275 to 8 passengers. In addition, the above figures clearly demonstrate that there is a severe bottleneck occurring at security screening and immigration during the day, occurring around 11:30am – 4:30 p.m. thus, it is believe that the results of model are quite accurate because they align with the arrival pattern shown in Figure 2 and 3.

Conclusion

Simulation has been used to understand and evaluate the flow of passengers through the departure processes of an airport. Our approach can assess and predict the efficiency of airport operations. The model can be used to support airport operational management, in order to determine system bottlenecks, with respect to flight schedule planning problems. The simulation can also provide accurate information about the impacts of infrastructure and operational changes. In this study, different load factors of different flight schedules have been evaluated. The simulation results demonstrate that the flight schedule has a very large and influential effect on passenger flows. The proposed simulation framework and model can be used to predict ahead of time the effect of different flight schedules and may be used as a feedback mechanism to improve it before implementation. Taken together, these results suggest that integrated flight schedule creation and passenger simulation analysis may be an avenue to address some issues of passenger flow within airport terminals especially, at two most affected processes, namely security screening and immigration.

In future research we plan to address the following:

- The analysis of different statistical functions for the different activity durations.
- The extension of the simulation model for inbound passenger processes within the terminal
- Investigate the relationship between variables using Linear Regression and other mathematical or statistical methods.
- Include advanced resource management techniques to improve passenger flow outcomes. These techniques will regulate the interactions between outbound and inbound processes.

References

[1] Barnhart, C., Fearing, D., Odoni, A., & Vaze, V. (2012). Demand and capacity management in air transportation. *EURO Journal on Transportation and Logistics, 1*(1-2), 135-155.

[2] De Neufville, R., Odoni, A., Belobaba, P., & Reynolds, T. (2013). *Airport systems: planning, design and management*.

[3] Dorton, S. L., & Liu, D. (2015). Effects of Baggage Volume and Alarm Rate on Airport Security Screening Checkpoint Efficiency using Queuing Networks and Discrete Event Simulation. *Human Factors and Ergonomics in Manufacturing & Service Industries*.

[4] Guizzi, G., Murino, T., & Romano, E. (2009). A discrete event simulation to model passenger flow in the airport terminal. In *Proceedings of the 11th WSEAS International Conference on Mathematical Methods and Computational Techniques in Electrical Engineering (MMACTEE'09)* (pp. 427-434).

[5] International Air Transport Association. (2014). News brief: tracking airline industry performance in 2013 - world air transport statistics released. Retrieved 4 May 2015, from http://www.iata.org/pressroom/pr/Pages/2014-08-12-01.aspx

[6] Kamyszek, K. (2014). Modeling of the departure process at Poznań-Ławica Airport. *Journal of Mechanical and Transport Engineering, 66*.

[7] Ma, W., Fookes, C., Kleinschmidt, T., & Yarlagadda, P. (2012). Modelling passenger flow at airport terminals: individual agent decision model for stochastic passenger behaviour. In *2nd International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2012)* (pp. 109-113).

[8] Ma, W., Kleinschmidt, T., Fookes, C., & Yarlagadda, P. K. (2011). Check-in processing: simulation of passengers with advanced traits. In *Proceedings of the Winter Simulation Conference* (pp. 1783-1794): Winter Simulation Conference.

[9] Manataki, I. E., & Zografos, K. G. (2009). A generic system dynamics based tool for airport terminal performance analysis. *Transportation Research Part C: Emerging Technologies, 17*(4), 428-443. Retrieved from http://www.sciencedirect.com/science/article/pii/S0968090X09000229. doi:http://dx.doi.org/10.1016/j.trc.2009.02.001

[10] Novrisal, D., Wahyuni, N., Hamani, N., Elmhamedi, A., & Soemardi, T. (2013). Simulation of departure terminal in Soekarno-Hatta International Airport. In *Industrial Engineering and Engineering Management (IEEM), 2013 IEEE International Conference* (pp. 600-604): IEEE.

[11] Olaru, D., & Emery, S. (2007). Simulation and GA-optimisation for modeling the operation of airport passenger terminals. In *The 29th Conference of Australian Institutes of Transport Research (CAITR)*.

[12] Pitchforth, J., Wu, P., Fookes, C., & Mengersen, K. (2015). Processing passengers efficiently: An analysis of airport processing times for international passengers. *Journal of Air Transport Management, 49*, 35-45.

[13] Rauch, R., & Kljajić, M. (2006). Discrete event passenger flow simulation model for an airport terminal capacity analysis. *Organizacija, 39*(10). Retrieved from http://organizacija.fov.uni-mb.si/index.php/organizacija/article/view/158.

[14] Takakuwa, S., & Oyama, T. (2003). *Modeling people flow: simulation analysis of international-departure passenger flows in an airport terminal*. Paper presented at Proceedings of the 35th Conference on Winter Simulation: Driving Innovation, New Orleans, Louisiana.

[15] Verbraeck, A., & Valentin, E. (2002). *Transportation applications of simulation: simulation building blocks for airport terminal modeling*. Paper presented at Proceedings of the 34th Conference on Winter Simulation: Exploring New Frontiers, San Diego, California.

[16] Wu, P. P.-Y., & Mengersen, K. (2013). A review of models and model usage scenarios for an airport complex system. *Transportation Research Part A: Policy and Practice, 47*, 124-140.

[17] Zografos, K. G., & Madas, M. A. (2006). Development and demonstration of an integrated decision support system for airport performance analysis. *Transportation Research Part C: Emerging Technologies, 14*(1), 1-17.