A model to simulate passenger flow congestion in airport environment

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Abstract

The global air transport industry is expanding rapidly. New approaches to airport management are required to ensure that ever-increasing consumer demand is met with adequate developments of ground operational and processing facilities; particularly those related to effective and safe processing of passenger flows. The solution to this problem requires, development of a new generation of fast, reliable, decision-making tools to quickly mobilise the human and technical resources available at modern airports. Operational research aimed at developing novel airport optimization simulations to empower efficient management decisions is therefore a rapidly advancing field. The research conducted in this study highlighted the improvements to be made for better passenger flow modelling in airport environment. These models can be classified as either ‘analytical’, ‘simulation’, or ‘hybrid’ models, giving decision support capabilities at all levels of detail: from macroscopic, through mesoscopic, to microscopic. However, despite the current developments in understanding passenger flow, the literature suggests that an aggregate model, integrating both outbound and inbound processes, is still needed. The main aim of this research is to develop a generic, holistic simulation model that can optimise passenger flow that can be adopted in any airport environment. Included in this are major outbound and inbound processes such as check-in, security screening, and immigration. The model supports what-if and trade-off analyses by inclusion of a problem-oriented approach.

Keywords: Passenger Flow; Airport Operational Planning; Airport Modelling; Simulation; Discrete Event Simulation.

1. Introduction

In 2017, the number of airline travellers exceeded 4 billion globally, an increase in global air transport demand of about 8.1% from 2016 [1], a number that will continue to increase and predicts to exceed 7.1 billion by 2035 International Air Transport Association (IATA). Airport management and airlines have discussed the possibility of changing and updating several policies related to flight schedule, staff allocation and other operational policies to accommodate future demand growth, and to provide better quality of services and security. An international airport terminal is a large and complex system, since it involves inbound and outbound passenger flow processes, each with unique operations. Some airports have a slightly different process and new airports designed in the future may require further changes to the standard process in light of new security concerns being faced in our modern world.

Safety concerns in recent times have caused many changes to security screening procedures which affect passenger throughput times. After September 11, 2001, when terrorists brought down the twin towers in New York by using passenger planes, airport security has become more critical. Another problem facing modern airports is the limited infrastructure and staffing capacity, such as numbers of common check-in counters and numbers of personnel available, to deal with increasing passenger numbers.

This paper introduces a generic framework for an integrated simulation model of an international airport. It focuses on the standard outbound processes, such as check-in, security, immigration, and boarding, and the standard inbound processes, including disembarking, baggage claim, immigration, and quarantine. The main objective of this research was to develop a model that can accurately identify bottlenecks and improve operational efficiency. This model can also evaluate the effect of an increasing number of passengers on the terminal facilities, a factor that has made airport systems much more complicated. As a result of this rapid growth in the number of air travelers and the complexity involved, numerous regulations and new technologies are being applied to airport operations [2]. For example, flight schedules are frequently changed due to irregular demand. Therefore, a simulation has been selected as the desirable approach to fully understand the complex system of an airport. In addition, a wide range of what-if scenarios can be explored throughout the model to assist in more effective decision-making during airport terminal operations’ planning, design, and management.

2. Related work

This section reviews past research that has focused on the current problems associated with airports’ operational performance and the challenges of planning. A wide range set of parameters are used to characterise passenger flow, including flight schedules,
service rates and resources, and the facilitation process and associ- 
as passenger characteristics (e.g. nationality, as it influences which Customs lane the passenger can use). To start with, Ma et al. [2] and [3] investigated the uncertainty factors that can impact the route choice decision making of pas- 
sengers, as well as the complex behaviours outside the required processes. Furthermore, passenger flow in new terminals, as studied by Beck [4], was demonstrated using simulation model of the passenger flow in the new terminal of Heathrow Airport. This model sought to understand the system before the terminal opened. Yamada, Ohori [5], undertook their study to explain links be- 
tween passenger behaviour and facilities and finds out numerous kinds of probable congestion circumstances. Safety concerns in recent times have caused many changes to security screening pro- 
cedures and this impacts passenger throughput times. For example, van Boekhold, Faghri [6] evaluated the performance of the pas- 
senger processing system, and provided an acceptable waiting

The simulation results show that the flight schedule influences passenger flow and suggest that integrated flight schedule creation and passenger-flow modelling can help address the issues of pas- 
senger flow within an international terminal. Additionally, in Alodhaibi et al.[11], the same approach had been used to investigate how the arrival pattern of passengers affects international terminal operations concentrating on outbound pro- 
cesses.

3. Airport simulation model

In this section, a generic framework for modelling the flow of passengers through the airport terminal processes where each sys- 

tem has its own particular flow and each system requires a differ- 
ent infrastructure and services. The development of a model for an airport comprises the following tasks. The first is the development of a general international terminal system for the outbound traffic system. The second task is the evaluation of the demand and sup- 

ply of an airport terminal. In this step, the entities of the general international terminal system are established and the characteris- 
tics and capabilities of the model are also evaluated. The required information in this step are flight schedules, the structure of the terminal, and implementation information. The third task compris- 
es the development of an algorithm approaches for managing the resources of the airport system and the fourth task involves vali- 
dating and checking this model. The models require validation to ensure their consistency and credibility and both factors are equal- 


![Airport System Model](image)

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ly important for any model. The fifth and final task is the applica-
tion of the model to various scenarios for further analysis. The model can be successfully applied to different scenarios and cases related to an airport terminal, such as arrival distributions [10], processing time distributions, and the different internal and external structures of an international airport terminal. During the fifth step, Key Performance Indicators (KPIs) are monitored as part of the application of the above scenarios. The KPIs for this model include the average waiting time, maximum waiting time, average queue length, and maximum queue length.

As mentioned above, airport systems are extremely complex, therefore, a multi-disciplinary approach was utilised to understand all the flows and features associated them. The application of simulation techniques is highly beneficial for airport operations management. To obtain a unique model, the simulation of the system must be constructed according to the specifications of the specific model that is being studied (see Fig 1). The proposed model can determine bottlenecks in the system and alternative procedures can then be attempted to optimise the system without negatively impacting it.

4. Development of logical model

In this section, the logic of development a holistic model of an international airport, will be explained with a level of adequate detail including outbound and inbound flow processes.

In order to simplify the complexity of such system, the models were built based on a series of hierarchical structure. The workstations and queuing in different airport facilities (including between operational sections) were implemented using the simulation software package of ExtendSim.

4.1. Outbound extendsim module

The structure of the model is built around the basis of a hierarchi-
cal model structure. In this context, the proposed model is organised into two hierarchical levels:

1) The first level of the hierarchy reflects the airport departure system broken down into a set of the main departure procedures, including check-in, security, immigration, and boarding.

2) The second level describes the intricate details of the different sub-processes in the airport terminal. Specifically, the
5. Simulation and experimental results

The developed model was used to investigate and analysed the best possible techniques and policies for operating international airports efficiently. Our model was constructed to fitting the characteristics of Australian international airport in regards to the physical layout of the terminal the processing of passengers in both sides outbound and inbound.

To demonstrate the approach capability, a set of experiments using “what if” scenarios were conducted considering various policies in regard to adding/removing staff. These experiments can demonstrate how the developed models improve the performance of the system and how it can be optimally operated under different operational policies. This investigation can provide a deeper understanding of best strategy to enhance system performance.

Different policies have been used to evaluate the best policy for adding and removing employees at check-in. This experiment started with initial operational policies, for example, to add more staff at business and economy counters when the queue threshold is 5 and 10 passengers, respectively, and to remove one staff when queue length becomes 2 for business and 10 for economy passengers.

Hence, scenarios are combinations of the following sets of policies:

i) Sets of adding one staff at business check-in if queue length
   \[ \{1, 2, 3, 45, 6, 7, 8\} \]
ii) Sets of removing one staff at business check-in if queue length
    \[ \{0.1, 2, 3, 4, 5, 6, 7\} \]
iii) Sets of adding one staff at economy check-in if queue length
     \[ \{10, 20, 30, 40, 50, 60, 70, 80\} \]
iv) Sets of removing one staff at economy check-in if queue length
    \[ \{5, 10, 15, 20, 25, 30, 35, 40\} \]

According to Kazda and Caves [12], the satisfactory length of queue time at economy check-in is 12 minutes and 3 minutes for business class. Kirk (2013) observed that 50 of the 71 passengers observed spent the longest amount of time at check-in with an average time of 17 minutes. Individual times ranged from 2 to 54 minutes. Figure 3 shows that the satisfactory level can be reached in the first three scenarios with the rule of adding one economy staff if the queue threshold is 10, 20 and 30, and the policy of queue threshold of other terminal domains is fixed with the initial operational policies.

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     \[ \{10, 20, 30, 40, 50, 60, 70, 80\} \]
iv) Sets of removing one staff at economy check-in if queue length
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![Fig. 1: Impacts of Adding and Removing Staffing Policies on Check-In Process.](image-url)
Staff will be shared between the two sides with priority for outbound immigration. The criteria for selecting the best policy is based on Kirk [13]; the author found that the average time spent in the immigration domain is between 6 and 7 minutes. Thus, any policy within this range or lower is acceptable. From Figure 6-19, it is clear to see that the average waiting time for outbound immigration is in the range of 5 to 7 minutes for the first 16 scenarios and the last nine scenarios.

Fig. 3: Impacts of Allocating and Reallocating Staffing Policies on Immigration Process.

Results suggest that to decrease the number of passengers waiting in the queue, the number of staff hours is increased. Waiting times for both sides exhibit similar behaviour for the first nine scenarios including maximum and average waiting time. From scenario 11 there was a sharp rise in the maximum waiting time until it reached peak waiting time in scenario 41. The swapping policy of scenario 41 is that if the number of passengers waiting at outbound immigration is greater than 100 and the number of passengers waiting at the inbound domain is less than 50, staff are moved from inbound to outbound processing. If the number of outbound passengers is 20 or less, staff are moved from outbound to inbound processing.

6. Conclusion

This paper has discussed a holistic model for passenger flow congestion in airport environment. This model is a decision support tool for airport operators to make well-versed decisions for efficient airport operation. Application of the model facilitates the operational planning of integrated inbound and outbound flow processes and determines the impacts on passenger flow and congestion. The developed approach is significant because it can be used to manage entire airport system and provide better results. It also can be significantly influenced by queue threshold values in regard to adding/removing staff and sharing staff between integrated processes. The following future research direction is recommended.

Determine the influence of arrival patterns on resource-allocation management including both outbound and inbound systems of an international terminal. This can be done by considering different distributions functions to determine the primary inputs of departing passenger arrival profiles. This is likely to provide significant new outcomes about the expected impacts of such inputs on the effective allocation of resources. Ultimately, the efficiency of all airport terminal operations can be improved.

References