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Research paper



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. Opera-tional 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 exceeds 7.1billion 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,

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service rates and resources, and the facilitation process and associated 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 passengers, 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], undertaken their study to explain links between passenger behaveiour and facilities and finds out numerous kinds of probable congestion circumstances. Safety concerns in recent times have caused many changes to security screening procedures and this impacts passenger throughput times. For example, van Boekhold, Faghri [6] evaluated the performance of the passenger processing system, and provided an acceptable waiting time. In addition, Kierzkowski and Kisiel [7] investigated the impact of the behavioural characteristics of the operators and passengers on the reliability of the system. Another related work was conducted by Dorton and Liu [8] that investigated the main external factors influencing the security screening checkpoint's (SSCP) operational efficiency. This study took into account the system's dependent measures of throughput and cycle time. Furthermore, Chitty, Yang [9] stated that airports face pressures of reducing costs of waiting time at security lane zone by decreasing the working hours of the lane and maintaining passengers' service level. In this regard, evolutionary methods can reduce both objectives.

Recent research conducted by Alodhaibi et al [10] employed Discrete-Event Simulation (DES) models to identify potential bottlenecks occurring between kerbside and boarding procedures. The key input of the model is the flight schedule, which describes flight size, scheduled departure time, and the airline.

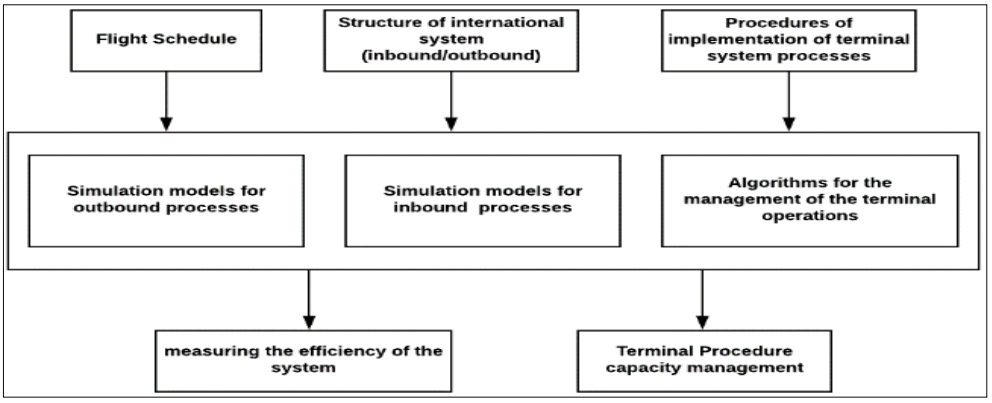


Fig. 1: Airport System Model.

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 passenger 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 processes.

3. Airport simulation model

In this section, a generic framework for modelling the flow of passengers through the airport terminal processes where each system has its own particular flow and each system requires a different 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 supply of an airport terminal. In this step, the entities of the general international terminal system are established and the characteristics 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 comprises the development of an algorithm approaches for managing the resources of the airport system and the fourth task involves validating and checking this model. The models require validation to ensure their consistency and credibility and both factors are equally important for any model. The fifth and final task is the application 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 andexternal 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 hierarchical 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

main departure procedures that the airport terminal model consists of are:

arrival characteristics, including the distribution of arrivals, method of arrival (car, bus, or train), number of bags, class of travel, and time of travel;

the check-in process, including the type of check-in, e.g. at the kiosk or online with a bag, business or economy, and the assignment of each flight to specific check-in counters;

security screening, including x-ray checks conducted in the common security screening line, x-ray checks for diplomats, and secondary screen checks (i.e. random checks);

immigration processing, including SmartGate services and the manned counter for passport control; and

boarding procedures, including boarding time, waiting time at the gate, boarding strategy, jetway capacity, and flight capacity.

4.2. Inbound extendsim module

The inbound simulation models can be organised into two hierarchical levels. The first level of the hierarchy reflects the inbound airport system broken down into a set of the main inbound procedures. The second level describes the intricate details of the different sub-processes in the airport terminal. Specifically, the main inbound procedures that the airport terminal model consists of are:

Passengers disembarking, including generating inbound passengers' attributes, such as SmartGate users, walking speed, number of bags etc.

Inbound security screening checkpoint for inbound passengers, assuming 15% of total transfer passengers failed in the first attempt. This module takes into consideration x-ray checks and secondary screen checks (i.e. random checks);

Inbound immigration processing points, including SmartGate services and the manned counter for passport control;

Quarantine processing checking points, including two separate queues to process arrival passengers: one for passengers who have something to declare, and another for passengers who have nothing to declare.

4.3. Resource management approach

This section discusses the developed algorithms for managing resources within international airports. The logic that has been followed to develop such algorithms is categorised into three options. The first option is adding staff to a particular workstation. That can be done by looping through across the queues of processing points and reading the status of the queue; if the queue length exceeds the threshold, check if there is available staff in the resource pool and add them to the first available spot. The second option is removing the staff from the processing point and shutting down the workstation. This can be done if the queue length is less than a given threshold. The last option is a more complicated one compared to the previous two because the staff need to be shared between related processes. This option is considered after loop through the staff resource pool 'global array' databases is done and then find that there is no available staff. Then, we need to share resources between areas based on the queue threshold for each process; for example, airline staff will be shared between economy and business counters with more priority to the business class queue. The purpose of developing such algorithms is to operate airport terminal processes at the optimum level.

Algorithms can be divided into two different levels:

Algorithms for managing staff that are working on one system (outbound/inbound) and can be shared with another process in the same system, such as airline staff responsible for operating check-in, and could share with boarding and quarantine;

Algorithms to control staff that work on a particular process that is located on both sides (outbound/inbound), such as immigration and security.

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 = $\{1, 2, 3, 4, 5, 6, 7, 8\}$
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. It occurred again for scenario 35 and above with the policy of adding and removing staff for business counters at thresholds of 8 and 0, respectively, and for economy thresholds of 30 and 5, respectively. The lowest economy maximum and average waiting times were 48.016 and 7.917 minutes, respectively, in the first scenario with the initial operational policies discussed earlier. The lowest maximum and average waiting time in business class was 1.78 and .012 minutes, respectively, for scenario 51 (adding and removing staff set at 1 and 0 for business class, respectively, and 10 and 40, respectively for economy). Hence, selection of the best policy are the set of rules that meet the acceptable waiting times for both business and economy counters.

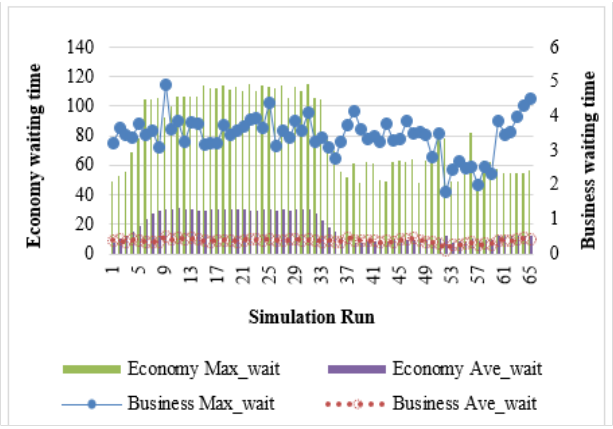


Fig. 1: Impacts of Adding and Removing Staffing Policies on Check-In Process.

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.

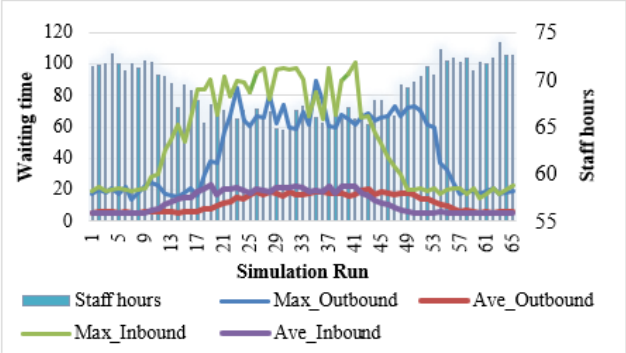


Fig. 3: Impacts of Allocating and Reallocating Staffing Policies on Immigration Process.

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.

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