A Comprehensive Study of the Techniques and Challenges of Passenger Movement Simulation in an Airport Terminal

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Abstract - *The optimal functioning of a nation's air transport system plays a significant role in its economic growth. As air travel has become much cheaper nowadays, there is an increase in the number of passengers, so concerns are increasing for both airlines and airports as to whether the existing infrastructure would be able to handle the increase in passenger traffic and ensure smooth operation of the airport. So in order to be better prepared in the future, airport authorities make use of multiple passenger simulation tools. Additional information is obtained from simulations which help authorities make informed decisions. The use cases are evaluated and potential failures are prevented. Simulations help authorities control passenger flow within the terminal dynamically. In this paper, we try to analyze various studies on simulation of airport passenger's movement to bridge the gap between the concepts described in these studies and the current requirements for airport authorities. It will help the authorities streamline the future designs of airports and optimize the allocation of resources. This will allow airports to provide passengers with a seamless experience throughout their voyage.*

Key Words: Agent-based model, Passenger traffic flow, Airport model, Pedestrian model, Optimization, Bayesian networks.

1. INTRODUCTION

There has never been a greater need for productivity at airports, with protection and labor costs continuing to rise every year. Airport authorities need to ensure understanding and optimization of the costs associated with staff, facilities and new technologies in order to be successful. Airport and passenger simulation is the representation of any real-world operation involving an airport, based on a computer. Simulation enables companies to evaluate and experiment in a virtual setting with their systems, thereby reducing the time and cost constraints associated with physical testing. Simulations enable airports to decide how best to make maximum use of their resources.

A Good simulation software enables authorities to make and test changes to the distribution network and production line without any risks to the systems. A good simulation software will forecast the consequences of the change reliably so bad decisions are avoided.

In order to help authorities develop and design new airports, there are several airport terminal passenger simulation tools used to model all possible scenarios and include a report on parameters such as the length of the queue at check-in desks, the time taken to push the queue at the security counters and the total time taken by a passenger to reach the boarding gate. These tools help assess the bottlenecks present at each of the checkpoints.

In this paper, we conduct a literature review on the previous airport simulation studies based on passenger behaviour in the airport terminal (Section 2). In Section 3, we discuss the simulation models in greater detail and note down the pros and cons of each model. Section 4 proposes some future areas of research and in section 5, we summarize our major findings.

2. LITERATURE REVIEW

The paper **Check-in Processing: Simulation of Passengers with Advanced Traits** by Wenbo Ma and Tristan Kleinschmidt talks about the use of agent-based models in the understanding of movement of passengers in a complicated environment like the airport. This paper talks about the shortcomings of prior research done. Previously, most of the research was focused on building a macroscopic simulation tool which does not address the behaviour of passengers at a microscopic level. Macroscopic tools deals with mandatory passenger processing steps such as check-in, security, immigration and boarding gates.

Microscopic tools develop realistic passenger movement simulations as they include discretionary activities. Unfortunately, Passengers spend most of the time in the airport on discretionary activities after completing the mandatory ones. Thus, designing an agent based model with these considerations is of the essence. Each agent is assigned with both basic and advanced traits. Basic traits are the characteristics that can be easily quantified such as age, nationality, travel class, etc. Advanced traits ensure that a passenger is someone who can adapt and respond to their surroundings. Advanced traits are dynamic in nature such as level of hunger, level of comfort, desire to pre check-in, etc. To build the ABM, four decision points are considered. Decision point A requires the passenger to choose between proceeding to check-in or perform a discretionary activity instead. Decision point B requires the passenger to proceed to either travel class check-in (Business or Economy), baggage drop if they have completed the check-in prior to arriving at the terminal or make use of Self Service Kiosks. Decision point C is present to ensure that passengers who use the Self Service Kiosks proceed to the next step efficiently. Decision point D controls passenger movement. After completing check-in, the passengers can move towards the security or perform more discretionary activities. Thus, in order to build a more effective and realistic simulation model, the problem has to be viewed both macroscopically and microscopically.

In the paper **Modelling Passengers Flow at Airport Terminals Individual Agent Decision Model for Stochastic Passenger Behaviour** by Wenbo Ma and Clinton Fookes, the solution was obtained in a similar way as [1] by looking at the problem microscopically. The dynamics of the passengers are stochastic and complex. The mathematical tool used in the paper is Bayesian belief networks. The agent decision depends on simulation based components and passenger traits. Simulation based components are split into planned time (Remaining time before boarding procedure begins) and Endurable walking distance (Longest distance a passenger can walk). Passenger traits as discussed in [1] are divided into basic and advanced traits. The advanced traits of each agent are inferred by the use of Bayesian networks. The approach taken in this paper is different to [1] but reiterates the fact that in order to build a realistic simulation tool, discretionary activities need to be considered.

Analysis of Passenger Group Behaviour and Its Impact on Passenger Flow using an Agent-based Model by Lin Cheng, Clinton Fookes, Vikas Reddy talks about the behaviour of passengers in a group and how it affects the ABM. Approximately 50% of the passengers travel in groups and speed of the passengers is greatly affected by the group size. The advanced traits of an agent are determined with the help of basic traits using bayesian networks, as discussed in [2]. Five rules for passenger group interaction are also defined:

1. Passengers in a group generally move towards the same destination.

2. Passengers in a group tend to maintain a uniform speed while walking.

3. If some members in a group fall behind due to some reason, other members will wait for them to catch up.

4. Passengers who finish their mandatory activities quickly need to wait for the other members to finish their activities before moving on.

5. The members in a group generally undertake the same discretionary activity if some time is left before boarding procedure begins.

The simulations were run using three different scenarios. The scenarios were passengers travelling a) alone; b) in a group; c) in a group with wavers (Companions who do not board the flight but accompany passengers to the airport). These scenarios may cause potential flight delays and provide a poor experience to the passengers. They may also result in less time available for undertaking discretionary activities which is not favourable for airport authorities and retail operators.

The airport does not only suffer the consequences of the growth, but also has to cope with many social and political changes that have an impact on the passenger handling. The major features of listed in paper **Analysis and Simulation of Passenger Flows in an Airport Terminal** by Michel R. Gatersleben Simon W. van der Weij are:

1. Identification of logistic impediments in the treatment of passengers within 5 years.

2. To have systematic solutions to these impasse.

Two models were developed: The static model offers future management planning and shows if the system management and the planned facilities are sufficient to ensure the passengers are treated qualitatively.

Passenger flow analyses through the terminal building and the use of non-assignable facilities were performed using dynamic simulation models. Through designing scenarios for several combinations of future developments, it is possible to establish circumstances with minimum, maximum and planned passenger traffic and the subsequent occupancy of accommodations. First of all, insight was gained into current and future circumstances, and solutions for bottlenecks were judged on their simulated performance improvement. These insights allow proactive steps to avoid potential bottlenecks. The experts concerned have learned about their own and dependent methods, as they are all part of the larger handling chain.

As the movement of passengers is very random, the paper **A Discrete Event Simulation to Model Passenger Flow in the Airport Terminal** by Guizzi G., Murino T., and Romano E discusses the development of a simulation using "Discrete Event Theory" which becomes vital in predicting the delay and in enabling a pragmatic management of various checkpoints within the airport. Here the airport has been split up into three major functional areas. They are access interface, process and flight interface [1]. The results from the simulation provide in queue average length, average waiting time and also the percentage of resource allocated with respect to time. Later an objective function is used to optimize and find the best combination of check-in desks and security check points.

As the checkpoints and paths taken by the passengers are complex, the paper **A Model to Simulate Passenger Flow Congestion in Airport Environment** by Sultan Alodhaibi, Robert L.Burdett talks about development of a comprehensive model in a hierarchical fashion [2]. This helps in breaking down of complex procedures at the airport into different levels on the basis of consumption of time and importance. Simulations have been conducted for the both the arrival and departure of passengers.

The detailed movement of passengers inside the airport gives more accurate results. The software AnyLogic can be used to run airport passenger movement simulations where we can add specific characters to individual entities, in this case the passengers. The paper **Modeling and Simulation of Passenger Traffic in a National Airport** by J. Enciso, M.Sc.1, J. Vargas, Ing. (c), and P. Martinez, proposed splitting passenger behaviour into Microscopic, Macroscopic, and Mesoscopic models [3] to provide the same passenger with characteristics of different types [3] for a more realistic simulation. This paper also generalizes this approach to people's movements in buildings or other form of infrastructure.

3. RELATED WORK

3.1. COMPLEX MODEL WITH ADVANCED TRAITS FOR CHECK-IN USING AGENT-BASED MODEL

From the moment they reach the entrance, not all passengers follow the same route inside an airport terminal before they board the plane. There are some basic characteristics that are common to all passengers. But, there are some features not all passengers share including using the washroom, heading to a duty-free store, etc. An advanced agent-based model that has these two traits can be developed. The first is the basic traits like age, gender, baggage, frequency of travel and travel group size. The second is advanced traits like the need to make a call, prefers pre check-in, hunger level and ease with which the technology is used. It should also be kept in mind that some advanced traits like the level of hunger changes dynamically in the terminal over the span of time.

But the downside of this model is that there is no incorporation of randomness into passenger movement inside the terminal from point A to point B. Also, this does not take into account the effect passenger baggage has on passenger travel through the airport. Baggage affects the overall productivity of terminal operations, whether it is check-in or carry-on. For the luggage to be checked at different security points, such as large screening areas (for check-in baggage), and X-ray areas with portable bags, a considerable amount with time is used.

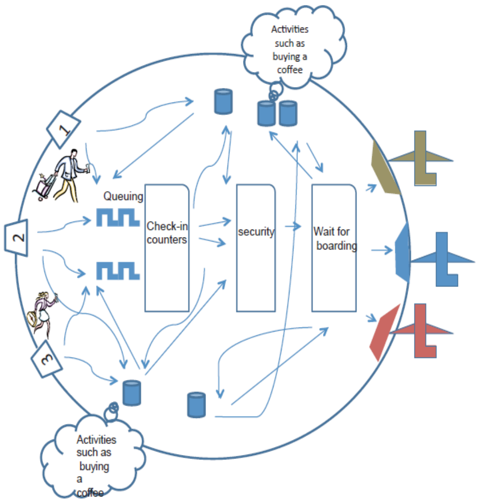

Fig -1: Passengers participating in discretionary activities outside of mandatory ones

3.2. MODELING THE MOVEMENT OF A PASSENGER USING BAYESIAN NETWORKS

All passenger behaviour within the airport terminal primarily depends on two important factors. The scheduled departure time and the endurable distance each passenger will walk from the entrance gate before departure. An average passenger walks inside the terminal from somewhere between 400 m and 800 m on average [reference paper 2]. These two components can be used as boundary conditions to restrict the passenger movement inside the terminal. Now, with the basic and advanced traits used in the previous method, the basic traits can be used to predict the likelihood of a person indulging in any of the advanced traits. For example, for a passenger coming to the airport for the first time and is relatively young, then the probability of that passenger heading to a duty-free shop and to an information kiosk would be very high. Therefore, by integrating the simulation model constraint factors with the Bayesian networks, the dynamic movement of passengers inside the airport can be simulated. One of the major drawbacks of this model is that the departure time is constant and hence the scenarios were flight delays occur are not induced. This model also does not talk about the passengers moving in a group.

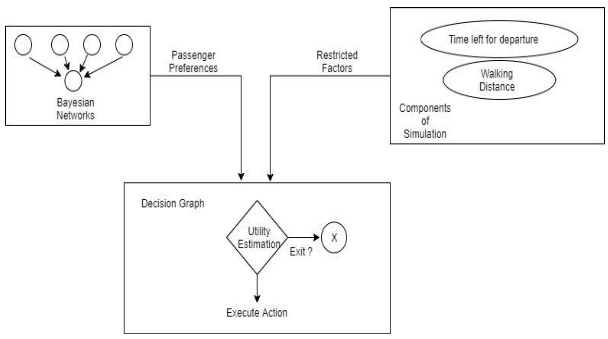

Fig -2: Agent-Based Model

3.3. USING SUB MODELS FOR SIMULATION OF PASSENGER MOVEMENT IN AIRPORT AND RESOURCE ALLOCATION

The type of model developed depends entirely on the type of data present. More comprehensive data contributes to developing the type of model required for simulation. The simulation model can be modularized when there is adequate detail in the data. There are three sub-modules that reflect the entire airport system: passenger generation, check-in and security checks. This model addresses mainly resource allocation. If there are n counters at the check-in, n-1 are dedicated for tourists and one is generally used by the passengers in the business class. This will allow passengers to have attributes attached to them. People who fly business class are generally by themselves but in most cases people travel in groups of 3 or more. The people can engage in other activities, depending on the time left before departure, before going to the security counter. Each passenger is viewed as a single entity at the security counter and takes approximately the same amount of time to get through the security, so all passengers have the same attribute. Hence, a single queue is created in front of common security desks to make the system simpler. If the desk is free then the value is 1 and the desk state is 0 if it is occupied. These types of models majorly identify the relation between the airport's existing resources and how it can be used to manage the passenger flow. The downside of this strategy is that certain situations are pre-assumed thereby leaving less space for randomness.

3.4. PEDESTRIAN MODEL

Pedestrian modelling is used for evaluating and optimizing locations in which crowds move [16]. Modelling enables for the collection of data on a given area of pedestrian traffic, ensuring appropriate rates of performance for service points with a hypothetical load, calculating how long pedestrians can remain in different areas, and detecting possible issues that may cause interior changes such as the addition or removal of obstacles or service points. Pedestrian model is commonly used to simulate crowd movement within a building, as well as any structures relevant to architecture such as malls, stadiums and airports.

These studies will help designers refine structural designs, facility owners analyze future structural and operational improvements, engineers test scenarios to improve capacity utilization and civil authorities model possible emergency evacuation routes. Since pedestrian flows can be complex, an extremely detailed simulation is needed. The actions of pedestrians follows simple rules defined by statistical studies: they travel at predetermined rates, avoid physical obstacles such as walls, furniture and others, and use information about the crowds around them to change their movements (word-of-mouth effects). The findings have been demonstrated several times in field experiments and client applications [15]. This pedestrian model can be used by agent-based model to attach properties to each individual passenger before starting the simulation.

3.5. USING FLUID DYNAMICS

Modeling the actions of a passenger can be achieved using mathematical approaches. The approach allows one to understand complicated circumstances. A related mathematical model may be developed to simulate the conduct of passenger movement at the airport, depending on the issue and the area of operation. For this model, the fluid dynamics are used to simulate passenger movement. This simplification is enough to explain common-person behaviour under some conditions; however, it is not possible to replicate complex motion patterns and self-organization effects [17]. The dynamic human behaviour is due to random decisions, which are classified to be short-range and long-range. The short range decisions are whether to take a left, right or go straight. These are basic movements of any passenger in the crowd. The tactical decision are more long-term and there might be more than one decision that has to be made. For example the path chosen by the passenger to reach the flight from the check-in desk is a tactical decision. Individual self-organization is yet another important aspect of human behaviour [7]. Self-organization is a systemic mechanism that is triggered by sub-system cooperative activity and results in complex structures. Human modeling (agents) and their unique experiences with crowds play a major role in the design of the agent-based model. The developed model of human behaviour is based on a probabilistic method for managing unexpected actions and individual route deviations. The simulation model built here is based on an approach to stochastic probability, similar to a cellular automata. A cellular automaton is a series of "colored" cells on a grid of specified shape that evolves according to a set of rules based on neighbouring cell states through a number of discrete time steps. Simple grid layout is used. Like the cellular automata, the creation of a new model is based on a fundamental paradigm change:

The agent does not change the cell based on the state of the neighbouring cells. The agents will move across the structure and may join certain other cells not occupied by other agents. The movements are entirely independent of other agents in the simulation.

Table -1: Summary of the Models

Name of model	Advantages	Disadvantages
Complex model with advanced traits for check-in using agent-based model	Supports both general and specific traits of a passenger.	It does not incorporate the randomness in movement of passenger. It does not take information about baggage.
Modeling the movement of a passenger using	It induces randomness in passenger	Some constraints such as flight schedule is fixed without any delay,

Bayesian networks	movement inside given constraints.	hence leaving out certain scenarios during simulation.
Using sub models for simulation of passenger movement in airport and resource allocation	It majorly addresses the idea of optimized use of resources currently present in the airport.	Many things are pre-assumed before running the simulation, hence randomness is absent.
Pedestrian model	It will help designers refine structural designs, facility owners analyze future structural and operational improvement	This model is not specific to airport simulation, hence it does not give details regarding the resource utilization.
Using fluid dynamics	Supports complete random behavior of a passenger inside the airport with mathematical models.	It is an intensive process. This model talks only about passenger movement and does not consider other parameters such as baggage and resource utilization.

4. CONCLUSION & FUTURE SCOPE

A number of studies have developed simulation models inside an airport terminal for passenger movement. Traditionally, all of the above-mentioned models concentrate mainly on the compulsory check-in, security, immigration, and boarding gates process. But in reality, a passenger spends a significant amount of time outside of such facilities.

As shown in Table-I, there are some features that each model lacks when it comes to the simulation. The current models assume a lot of parameters before running a simulation and hence results produced lack edge case scenarios.

Future research should enable the simulation models to take in any airport design as input and be able to detect the check-in counters, carousels, security counters and dwell areas automatically. Provision should be made for the inclusion of scenarios where flight delays occur. The simulation speed should also be regulated in real time, in the sense that there should be provision to adjust the simulation speed while the model is running. But most importantly, passenger movement should be made more realistic. The realistic model should give control over to the user on how the passengers move in different areas inside the airport. Generally in check-in queues, the passengers move in a specific manner and when they move from check-in to security, randomness should be induced, i.e. the randomness is characterized the number of people traveling with the passenger, by the contact with the crowd while walking and the number of different detours that the passenger takes before heading to the security counter.

Having these things in mind, when the simulation is finished, it will be useful for the airport authorities to coordinate and handle the tools at their disposal to provide better customer service and also prepare for the future.

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