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A Hybrid Queue-based Bayesian Network framework for passenger facilitation modelling

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ABSTRACT

This paper presents a novel framework for the modelling of passenger facilitation in a complex environment. The research is motivated by the challenges in the airport complex system, where there are multiple stakeholders, differing operational objectives and complex interactions and interdependencies between different parts of the airport system. Traditional methods for airport terminal modelling do not explicitly address the need for understanding causal relationships in a dynamic environment. Additionally, existing Bayesian Network (BN) models, which provide a means for capturing causal relationships, only present a static snapshot of a system.

A method to integrate a BN complex systems model with stochastic queuing theory is developed based on the properties of the Poisson and exponential distributions. The resultant Hybrid Queue-based Bayesian Network (HQBN) framework enables the simulation of arbitrary factors, their relationships, and their effects on passenger flow and vice versa.

A case study implementation of the framework is demonstrated on the inbound passenger facilitation process at Brisbane International Airport. The predicted outputs of the model, in terms of cumulative passenger flow at intermediary and end points in the inbound process, are found to have an R^2 goodness of fit of 0.9994 and 0.9982 respectively over a 10 h test period. The utility of the framework is demonstrated on a number of usage scenarios including causal analysis and 'what-if' analysis. This framework provides the ability to analyse and simulate a dynamic complex system, and can be applied to other socio-technical systems such as hospitals.

1. Introduction

Modern airports face a number of challenges including growing passenger traffic and its effects on capacity and congestion as well as regulatory and market changes such as the proliferation of Low Cost Carriers (LCC) (de Neufville and Odoni, 2003; Nombela et al., 2004). In addition, there is a significant time and monetary cost associated with the construction or renovation of infrastructure needed for airport operations (Odoni and de Neufville, 1992). The challenges are further compounded by the fact that the airport is a complex system. There are multiple stakeholders who at times have conflicting objectives (Eilon and Mathewson, 1973; Schultz and Fricke, 2011). Additionally, there are complex interactions and interdependencies between stakeholders and between different parts of the airport system (Zografos and Madas, 2006; Manataki

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and Zografos, 2009). Finally, the system itself is highly dynamic and there is significant uncertainty on its performance (Manataki and Zografos, 2009; Lui et al., 1972).

From an operational perspective, a model can integrate the diverse elements of the airport complex system to help the user understand how the airport is likely to perform under different operational scenarios. This can be invaluable in supporting capacity planning, operational planning and design, and airport performance review (Wu and Mengersen, 2013). Examples of this in the past include the application of stock and flow modelling to ascertain whether the terminal infrastructure was sufficient to handle the increased traffic related to the Athens Olympic Games (Zografos and Madas, 2006). Additionally, Jim and Chang (1998) discuss how simulation modelling can specifically assist the final design stage of terminal development. Brunetta et al. (1999) describe another example of how modelling is used to assist capacity estimation at Milan Linate and Malpensa 2000 airports.

The efficient flow of passengers and/or aircraft is a key goal in the operations management of an airport (de Neufville and Odoni, 2003). However, this is a challenging task because the cause of long queues and other problems affecting flow are not necessarily obvious due to complex interactions and interdependencies within the airport complex system. A number of models have been presented that provide a means to indirectly determine the cause of flow performance through simulation, such as (Manataki and Zografos, 2009; Wilson et al., 2006; Eilon and Mathewson, 1973). This paper proposes a modelling framework that can explicitly capture the flow of passengers and its relationship to the different factors affecting its performance, thus enabling decision makers to focus on the root cause of performance issues. The work is demonstrated on a case study application, which is the inbound passenger facilitation process.

1.1. The Passenger facilitation modelling problem

Consider the passenger terminal, which is one of the key subsystems within the airport environment (de Neufville and Odoni, 2003). This paper seeks to address the challenges of modelling the inbound passenger facilitation process as defined by the Passenger Facilitation Taskforce (2009) to provide decision support. Annex 9 of the Convention on International Civil Aviation provides standards and recommended practices for passenger facilitation, which is the process that "assists the free flow of passengers and goods across the border whilst upholding border integrity and/or sovereignty" (International Civil Aviation Organisation and July, 2005). The selected case study focuses on arriving passengers (i.e. inbound passengers) and was undertaken as part of the Airports of the Future (AotF) project and involved government and industry partners, including the Australian Customs and Border Protection Service (Customs and Border Protection), Brisbane Airport Corporation, and the Department of Agriculture, Fisheries and Forestry (DAFF) Biosecurity.

The work was initially motivated by the requirements of the National Passenger Facilitation Committee (NPFC) performance framework initiative, which sought to establish standardised levels of facilitation performance such as in terms of passenger wait time, congestion and throughput across Australian international airports. Note that these are all measures of passenger flow, which underpin the passenger facilitation process. Therefore a model of inbound passenger facilitation must capture **passenger flow** explicitly. Note also that the spatial aspect of passenger movement and the spatial constraints of the enviornment also play a role in passenger flow, hence **space** and/or the effects of space also need to be captured.

However, engagement with stakeholders revealed that there were other operational factors and objectives such as border security and biosecurity that also needed to be met. Passenger flow can affect the performance of factors such as border risk and biosecurity risk and vice versa; for example, increased security procedures lead to lower risk but increased queuing times (Wilson et al., 2006).

The stakeholders also indicated a need for explicit, quantitative causal analysis; i.e. the ability to quantitatively characterise the relationship between factors such as congestion, passenger demographics (e.g. age, nationality), and 'performance' factors such as passenger processing time and throughput. Eilon and Mathewson (1973) for example use a regression submodel within an simulation model to mathematically capture the relationship between congestion (number of passengers) and passenger delay time. Such a sub-model enables decision makers to better understand how one factor affects another, and hence ascertain the root cause of performance issues. As a result, the model also needs to be **extensible to other factors** and also enable **explicit, quantitative causal analysis**.

In addition, due to the variability in day-to-day operations, such as due to weather, flight delays or equipment malfunction, the stakeholders require the capability to simulate **'what-if'** scenarios. Note that the implementation of any model requires a means for updating or learning model parameters. This is especially the case for an airport as it is a constantly changing environment (de Neufville and Odoni, 2003). In summary, the main modelling requirements are: (i) to capture passenger flow, (ii) incorporate the effects of space, (iii) be extensible to other factors, (iv) enable explicit, quantitative causal analysis, and (v) enable 'what-if' analysis.

1.2. Summary

This paper presents a novel Hybrid Queue-based Bayesian Network (HQBN) framework for modelling passenger facilitation. The framework integrates a Bayesian Network (BN) model of the passenger facilitation system with a stochastic queuing model of passenger flow based on the Poisson process. Using the proposed framework, it is possible to leverage the inherent explicit, quantitative causal analytic capabilities of the BN to capture the relationships between passenger flow and the various factors that make up the airport terminal system. A review of the existing literature by Wu and Mengersen