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Evaluating the effects of bus design on passenger flow: Is agent-based simulation a feasible approach?

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ABSTRACT

In this paper, we propose an agent-based simulation approach that is capable of simulating the flow of passengers on board buses and at bus stops. The intention is that it will be applied during vehicle development to analyze how vehicle design affects passenger flow, and thus also how it affects system performance such as dwell time. In turn, this could aid the developers in making design decisions early in the development process. Besides introducing the simulation tool itself, the paper explores the realism of the data generated by the tool. A number of passenger flow experiments featuring a full-scale bus mockup and 50 participants were carried out. The setup of these experiments mirrored a number of 'bus journeys' (regarding vehicle design, number of passengers boarding/alighting at each stop and so on) that had previously been simulated using the simulation tool. When the data from the simulations were compared with the data from the passenger flow experiments, it could be concluded that the tool is indeed able to generate realistic passenger flows, although with some errors when a large number of passengers board/alight. The simulated dwell times were rationally affected by the tested bus layout aspects. It was concluded that the tool makes it possible to evaluate how variations in bus layouts affect passenger flow, providing data of sufficiently high quality to be useful in early phases of vehicle design.

1. Introduction

Public transport (PT) is put forward as being safer, less spatially demanding and more environmentally sound than car use (Skoglund, 2012). Therefore, society's interest in making more people choose PT is increasing. The design of buses has a major role in making PT more attractive, as the bus is a key component in numerous PT systems. The bus's design has a direct influence on a passenger's experience of a PT journey but it also affects the service system (for instance capacity and efficiency) and the behaviour of other passengers, both of which in turn heavily influence the experience. A central aspect related to this is how a bus design affects the way passengers move when boarding/alighting the bus, i.e. the *passenger flow*. Passenger flow affects the passengers' experiences (for instance due to crowdedness) and has a major impact on the efficiency of the PT service system. Being able to predict how a bus design affects passenger flow would consequently be highly valuable during bus development.

There are methods available to developers aiming at predicting future product use. In the automotive industry, practical field tests (for instance test drives) are regularly used in the later phases of the development process, but in the earlier phases one is generally dependent on less powerful methods such as checklists and expert judgements (Bhise, 2011).

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Manufacturers' knowledge of the performance of a new vehicle concept relies heavily on experiences with vehicles already in service and statistical data about passengers (e.g. age, disabilities, and anthropometry). Direct experimentation during the development process is often difficult or impossible due to financial, material and time constraints (Meignan et al., 2007). Furthermore, many of the use-centred methods in early development phases rely on demonstrations of solutions commented upon by potential users. While bus passengers may be able to comment on the looks of a bus presented for example in a sketch, they will not be able to predict how it may affect the performance of the bus system or how this in turn will affect their experience of the bus journey. In addition, many use-centred methods (for instance usability tests, cognitive task analysis) focus on how a single user interacts with a product, and not dozens of users as in the case of buses.

There is thus a need to find methods that, during the development process, can help bus designers to evaluate the complex situation that a bus in use constitutes. A method that is ideal for evaluating the use of PT vehicles from a passenger flow perspective should fulfil two requirements: (1) it should be applicable early in the development process, when no physical representation of the vehicle exists as yet and (2) it should evaluate the bus's performance when it is used by a large number of passengers concurrently. Computer simulations are one approach that might fulfil these requirements.

Computer simulation has been widely applied in PT. Many previous works have evaluated different policy aspects regarding the entire bus network, for example DRACULA – dynamic traffic network model for evaluation of real-time management strategies (Liu, 2005; Liu et al., 2006). Wang et al. (2008) studied the Cybernetic Transport System (CTS) and demonstrated that an algorithm based on agents is more effective than traditional centralized planning algorithms. Meignan et al. (2007) presented a user-centred bus network simulation tool which allows analysis and evaluation of a bus network in diverse space and time scales.

Other efforts have focused on the behaviour of passengers at stops. Lee et al. (2001) investigated the behaviour of pedestrians in Hong Kong's Mass Transit Railway stations during peak hours using the PEDROUTE simulation model (Halcrow Fox and Associates). Daamen and Hoogendoorn (2004) studied pedestrian traffic flow on a platform and compared reported observations with the results of SimPed – a simulation tool designed to model pedestrian flows in transfer stations. There are also a few efforts to simulate passenger behaviour or performance inside the transport vehicles. For example Alam and Werth (2008) investigated the emergence of clusters in passengers' seating preferences, while Qi et al. (2008) applied a cellular automata-based model to study the boarding and alighting process in Beijing metro stations.

The effort that most closely resembles the work presented in this paper is that of Rudloff et al. (2011) who presented simulations of boarding and alighting processes on trains using the Social Force Paradigm. In their work, they showed that such a simulation tool, when calibrated on experimental data, can become a cost-effective way to predict how a vehicle design affects dwell time.

While simulation attempts aimed at accurately predicting bus system efficiency are an important area for public transport, a tool that can aid bus designers during early development does not have to fulfil the same requirements. The focus for the latter is not to accurately prognosticate capacity and operational costs of the bus in operation, instead it needs to generate information that enables designers to make sound design decisions early in the development to reduce costs and improve the products. This means that it must be sensitive enough to identify differences between design solutions. In the area of buses there has seemingly been no attempt at developing a simulation tool for this purpose.

2. Aim and research questions

In this paper, we propose an agent-based simulation approach that is capable of simulating the flow of passengers on board buses and at bus stops. The intention is that it should be used during vehicle development to analyze how a vehicle design affects passenger flow, thus showing how it affects system performance in terms of aspects such as dwell time. However, if the tool is to become useful in bus development work, the *quality* of the simulations needs to be sufficient to allow design decisions to be made based on the results. The aim of this study is therefore to evaluate the quality of the simulation tool in its current state (it is continuously being refined). The questions to be explored are:

1. Is it possible to generate realistic representations of bus passenger flow using agent-based simulation?
2. Is it possible to evaluate how variations in bus layouts affect passenger flow, using agent-based simulation?

The paper is divided as follows: Section 3 describes the simulation methodology. Section 4 presents the research method, in which a passenger flow experiment with a full-scale bus mockup was carried out in order to allow comparisons with the simulation tool. Section 5 presents and analyses simulation results and compares them with the result of the mockup experiment. Section 6 contains a discussion, and finally Section 7 presents the main conclusions of this work.

3. The simulation approach

A bus passenger simulation tool was created within AnyLogic, a Java-supported multi paradigm simulation framework (www.xjtek.com/anylogic/why_anylogic, 2012). (The design of the simulation tool is presented in detail in Schelenz et al. (2012).)