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A Bottleneck Investigation at Escalator Entry at the Brisbane Central Train Station

Fatma Al-Widyan[1], Nathan Kirchner[1], Ahmed Al-Ani[2], Michelle Zeibots[3]

[1]Centre for Autonomous Systems, University of Technology Sydney, Australia

[2]Faculty of Engineering & IT, University of Technology Sydney, Australia

[3]Institute of Sustainable Futures, University of Technology Sydney, Australia

Email for correspondence: fatma.alwidyan@student.uts.edu.au

Abstract

Escalators are an essential for passenger's movements through multi-level rail station concourse environments. Despite the access benefits that escalators provide, they can make travel time longer and pose some challenges when bottlenecks appear at entry.

Studying the passenger behaviour of bottlenecks at escalator entrances is essential for planning, designing and control of engineering transportation systems. In this paper we investigate passenger route choice behaviour while approaching an escalator-stair infrastructure set at Brisbane Central train station. A model of an escalator entry bottleneck is formulated. The developed model can explain the queuing characteristics of the bottlenecks and can be readily used to predict congested state occurrence at escalator entry bottleneck.

Accurate prediction of bottlenecks occurring around escalators and the estimation of escalator capacity are obtained based on real field data collected from Brisbane Central train station. Results have provided significant insights and computational tools for understanding many features of escalator bottlenecks. Remarkably, escalator capacity at bottleneck points affects the duration and severity of the congested period.

Keywords – Escalator Entry Bottleneck, Pedestrian Queuing*, Congestion, Bottleneck Model.*

1. Introduction

Predicting the passenger flow is a requirement for planning and design of the public transport facilities. In major cities, most of the efficiency loss due to congestion occurs when traffic is congested. Despite the high usage and prevalence of escalators, little research has been conducted on the escalator entry bottleneck and its associated capacity.

In modern world, the facility of using escalators at train station reduces the passengers walking time, particularly when the area is congested. There is a bottleneck on the escalator entry with a fixed capacity or service rate, and if the arrival rate of pedestrian at the escalator entry exceeds the capacity a queue develops. Congestion that happen in the entry of an escalator is termed escalator entry bottleneck (Fixed Bottleneck) which corresponds to passengers jam and gridlock (Kauffmann & Kikuchi 2013, Voskamp 2012).

In a previous research study (Al-widyan et al. 2015), the authors reported on pedestrian behaviour in the congested environments, based on the principle of least effort. This paper is an extension of the research work reported therein. The focus of this work is on passenger route selection behaviour at escalator entry bottleneck, observations in the real field have been carried out for understanding passenger behaviour. Moreover, here we present a model evaluated to the passenger route selection behaviour on the escalator entry from real data. The proposed model considerers the escalator entry capacity and queue growth on the base of the escalator.

The remainder of this paper is organised as follows: Section 2 describes the bottleneck and queuing problem. Section 3 presents the formulation and model. In section 4, experimental results are presented and analyzed. Finally, Section 5 concludes the paper.

2. Bottleneck and Queuing

In designing transport facility, it is important to predict passenger selection behaviour, since it is one of the key factors affecting the passenger flows between entrance and exits points (platforms, train gates etc). Typically these stations are designed with the intention of limiting passenger's route choices where information systems are usually present to direct egress. A number of simulation tools have been developed to predict passenger flows in walking facilities, SimPed (Daamen & Hoogendoorn 2003), NOMAD (Hoogendoorn & Bovy 2004), and Legion (Still 2000). On the other hand very little research has been devoted to escalator entry bottleneck.

Congestion has been studied extensively by transportation researchers that occur when passenger's traffic demand exceeds the infrastructure capacity (Bandini et al. 2014, Tajima et al. 2001, Tabuchi 1993). Bottleneck capacity is determined by a number of factors, such as a width of the bottleneck, wall surface, and interaction behaviour of passengers passing the bottleneck (Hoogendoorn & Daamen 2005). Bottlenecks impose a wide range of problems for passengers especially at escalator entry in train stations, like delay in travel time, rescheduling train timings, and unhappy experiences for passengers mainly because of pushing and shoving (Palma & Lindsey 2001). Many situations exist in which influencing passengers flow in congested train stations would be useful. The ability to influence the movement of people could reduce collisions on blind corners, or increase the efficiency of passenger flow through bottlenecks such as passageways, stairs and escalator (Kirchner et al. 2015).

Capacity is certainly important in the design of the area around the escalator and has a significant impact on the escalator performance. Lower passenger densities are desirable in uncongested environments so that passengers may manoeuvre and pass each other in order to maintain their desired speed (Kauffmann & Kikuchi 2013). Conversely, in congested environments, it is important to provide adequate queuing space under crush loading conditions like train arrivals or emergency evacuations so that passenger safety is assured. Queues are developed when the arrival rate of passengers the escalator entry exceeds its capacity (Kauffmann & Kikuchi 2013). For that, we need to improve our knowledge on escalator entry bottleneck influencing passenger selection behaviour.

Permanent bottlenecks will occur at escalator entry, for short time periods. The capacity of an escalator is generally thought to depend on the speed at which the bottleneck moves (Laval & Daganzo 2006). Some empirical studies have been carried out on bottlenecks and focused on the behaviour of passengers in a narrow bottleneck experiment (Shiwakoti1 et al. 2015, Cepolina & Tyler 2005, Fosgerau & de Palma 2012, Davis & Dutta 2002, Kinsey et al. 2014, Arnott et al. 1990). However, none of these empirical studies provides any data about the escalator entry bottleneck phenomena, which is the focus of this paper.

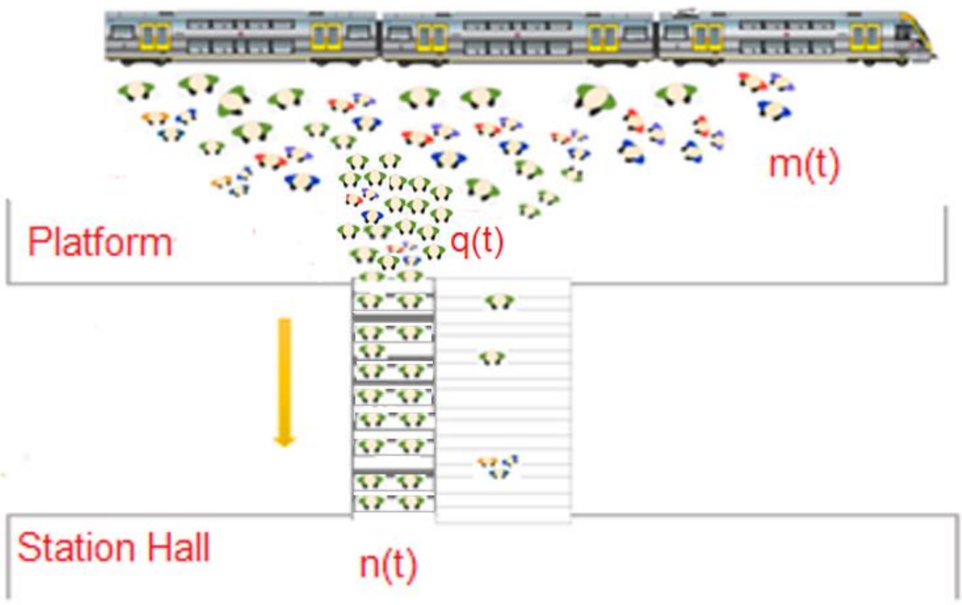
Most available research focuses on the relation between the bottlenecks and its capacity. This is important in any passenger environment to understand and monitor for passenger traffic management (Seyfried et al. 2009), where there is a change in size which might give rise to a change in capacity, and involve congestion with the influence on passenger route choice, In instance train stations and emergency exits (Braid 1989, Fosgerau & de Palma 2012, Yang & Hai-Jun 1997, Still 2000, Hoogendoorn & Daamen 2005). Such research efforts are inherently limited in that they focus on passenger selection behaviour in case of bottlenecks. Meanwhile (Voskamp 2012) argued that fixed bottlenecks could be found at escalator entry while moving bottlenecks might occur in the overtaking process on an escalator (Voskamp 2012). Furthermore, the core of this research is to create a model of passenger behaviour on escalator entry bottleneck.

3. Model Formulation

Generally, the passenger must first access the escalator, and to do that, the passengers must walk into an escalator entry bottleneck. The rigid fenders that line the sides of escalator constrict the passengers flow into a narrow stream no more than one metre wide. The most common escalator step width is 1 metre (Hoogendoorn & Daamen 2005). In our approach, the capacity of an escalator entry is first determined based on an assumed maximum step capacity, typically two passengers per step.

Consider a simplified infrastructure as the one depicted in Figure 1, which shows an escalator entry bottleneck. The bottleneck, whose capacity is finite, is subject to congestion. The crowd starts developing when the arrival rate of passengers at the escalator entry exceeds its capacity. The explicit analytical solutions can help us understand the queuing characteristics of the bottlenecks.

Figure 1: Train Station Layout



Let the number of passengers in the queue be denoted by q (t), the passenger rate departing from train at a time t be m(t), and the rate of passengers existing from bottleneck denoted by n (t) which can be expressed,

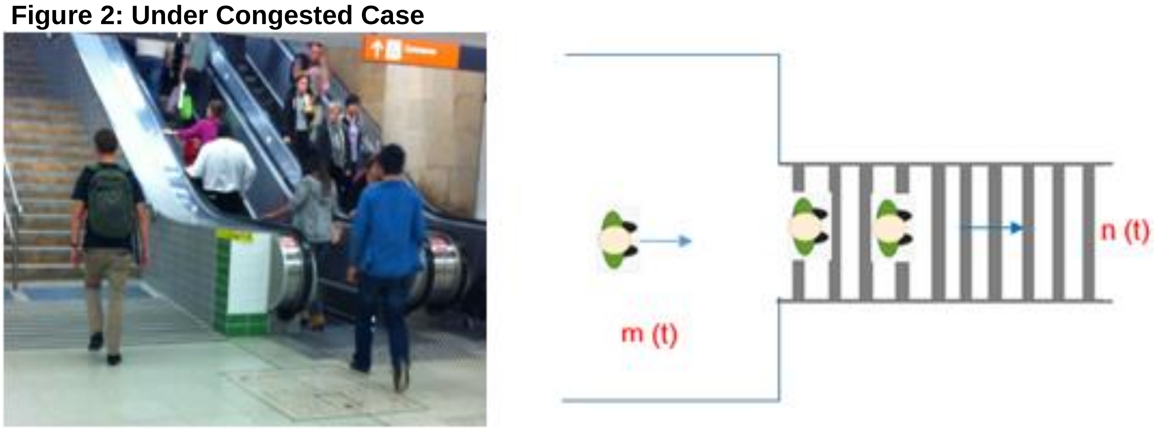
$$n(t) = \begin{cases} m(t), \text{if} \quad q(t) = 0 \quad \text{and} \quad m(t) < C \\ C\,, \ \text{if} \quad q(t) > 0 \quad \text{or} \quad m(t) > C \end{cases}$$

Where, C is the escalator capacity (maximum number of passenger rate that can pass the entrance of the escalator at a time t). This scenario is illustrated in Figure 1.
We can realize the following three cases:

1) Under Congested: $q(t) = 0$, and $m(t) < C$

This case represents no congestion; if the passenger travels from platforms to station hall at a time, he/she will pass the escalator entry bottleneck easily as shown in Figure 2.

Figure 2: Under Congested Case

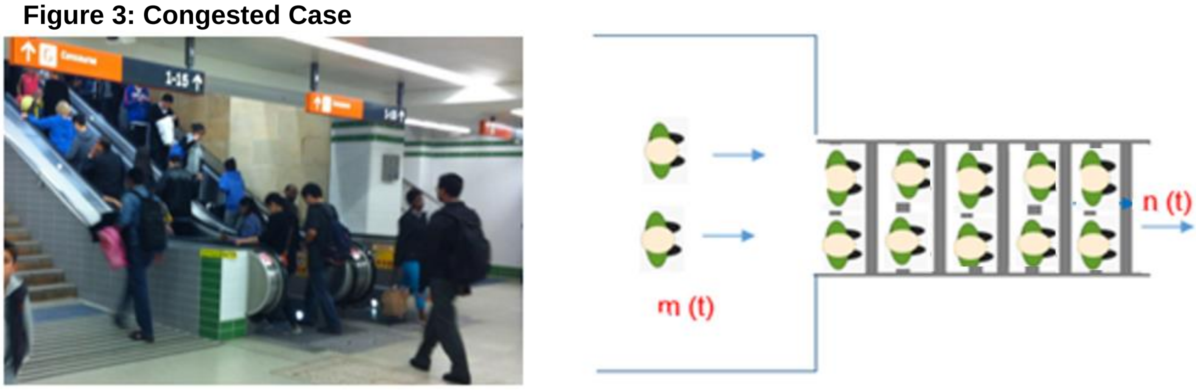


a) The flow commences (Real -time scenario) **a) Overview of experiment**

2) Congested: $q(t) = 0$, and $m(t) = C$

In this case the number of passengers travelling over an escalator equal escalator capacity, as shown in Figure 3.

Figure 3: Congested Case



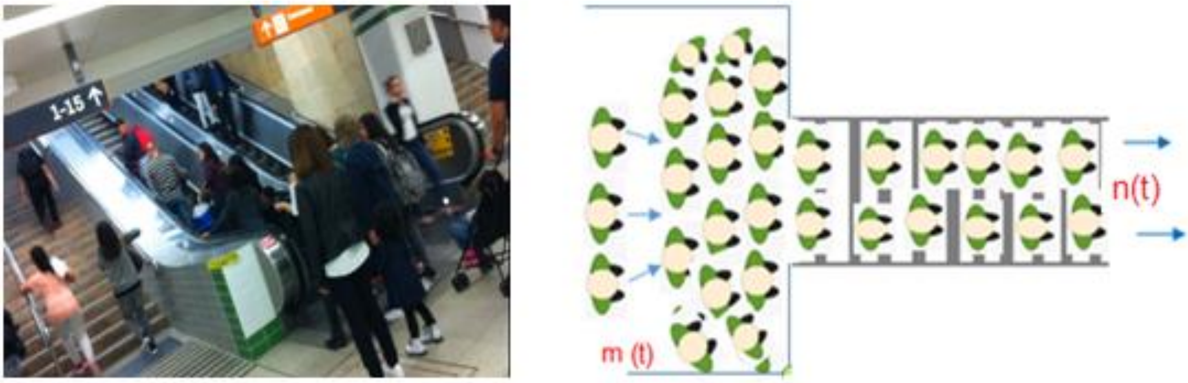
a) The flow increases towards the maximum (Real -time scenario) **b) Overview of experiment**

3) Over Congested: $m(t) > C$

This case describes the authority's reaction when high- level congestion occurs, if the numbers of passengers, travelling from platforms to station hall, are more than escalator capacity the queue commencing as shown in Figure 4.

Queues are known to form when a bottleneck is over congested. Queuing is the most organized form that occurs for instance in front of escalators entry, Passengers do not always maintain a large distance between each other when queuing. In contrast to queue formation, queues are typically organized in the form of bulk (Fruin 1971). When passengers are queuing, their desire to move grows. As a result passengers stand closer to each other over time, which can be observed by decrease in queue length and increase in density (Helbing D., P. Molnár 2001).

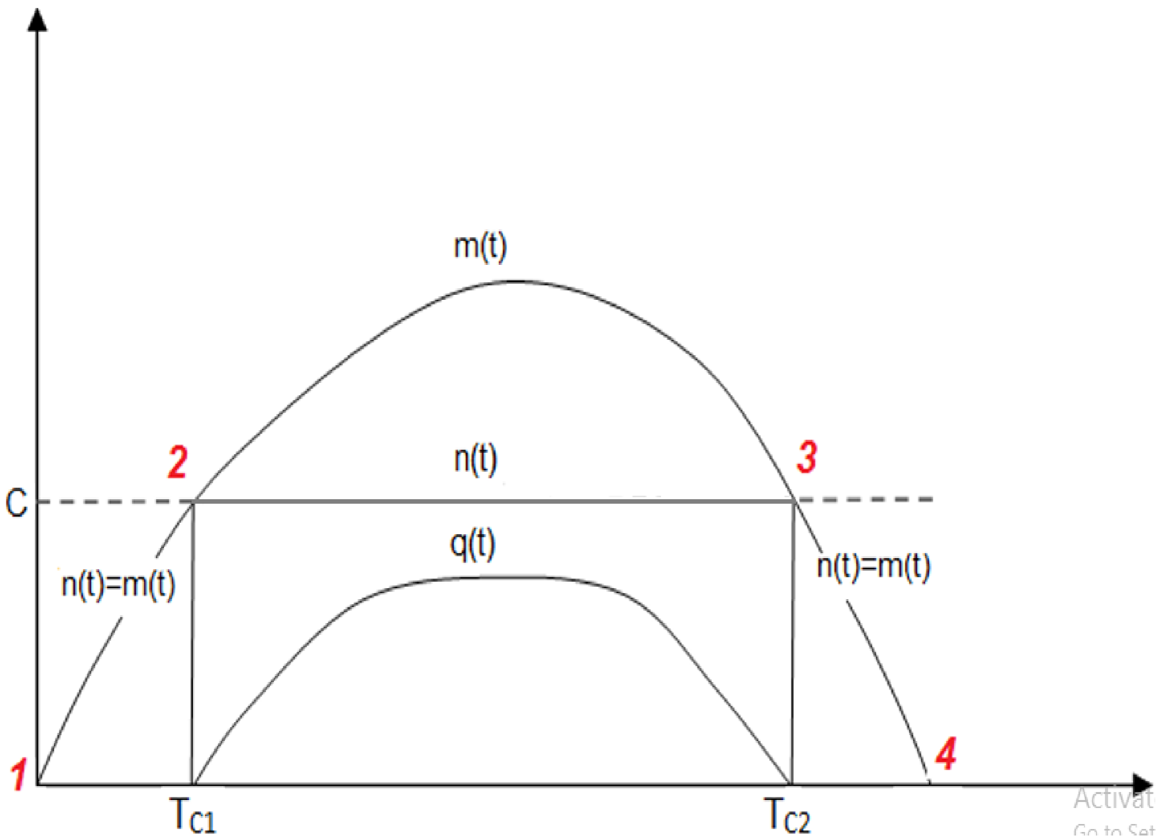
Figure 4: Over Congested Case



a) The point of maximum accumulation of pedestrians. **b) Overview of experiment**

Figure 5 illustrates a typical pattern of the passenger rates m(t), and n (t) and the passenger queue length q(t). Apparently the difference between n(t) and m(t) leads to congestion occurrence with a queue taking place at the escalator entry, as shown in the curve from point 2 to point 3, which is the over congested case. From points 1 to 2, and points 3 to 4, the number of passengers traveling from platforms to station hall is less than the escalator entry capacity, which is the case of under congestion.

Figure 5: Typical example of the passenger rates m(t), n(t) and q(t)

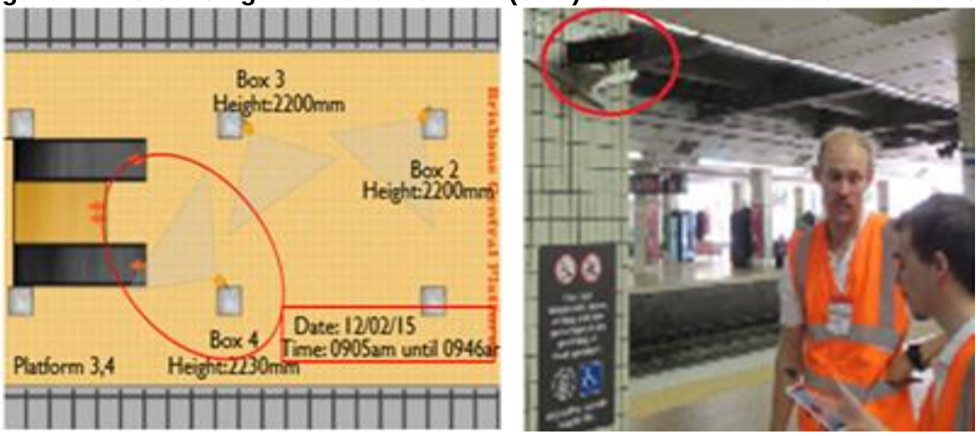


4. Experimental Results

Experimental evaluation was conducted at the central Brisbane train station and performed various tests to validate the model developed in the previous section based on the Escalator entry bottleneck and congestion occurrence. Our Sensing Hardware Platform (SHP), shown in the right image of Figure 6, which has demonstrated capability of robust person detection and tracking in situ in public train stations and used to produce a real-data or individual passengers movements (Kirchner et al. 2014, Virgona et al. 2015, Collart et al. 2015).

Data was collected to monitor the selection behaviour of passenger at the escalator entry from (9:05 am- 9:46am) on a weekday. An asus Xtion camera, 3D Sensor was mounted at the column of the platforms at a height of 2.30 m observing an area of approximately 3 m by 5.5 m and angle 15^o. A wide lens was used, enabling the camera to view the entire walking area, as shown in Figure 6 (left).

Figure 6: The Sensing Hardware Platform (SHP) located at Brisbane train station

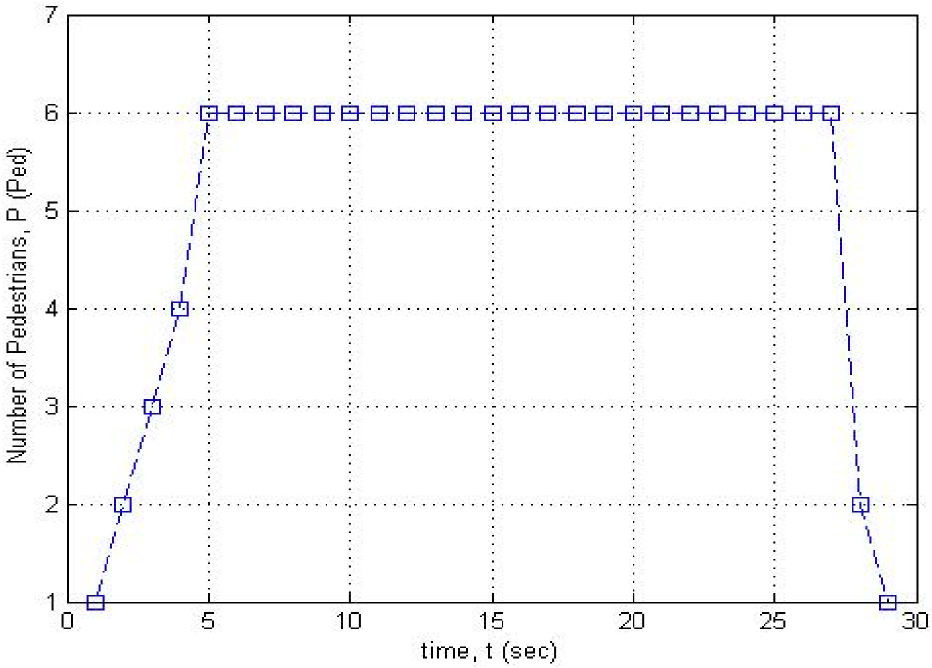


During the peak hour period, the platforms at the central Brisbane Train Station are densely populated. When the trains arrive, the formation of queues at the escalators entry is a common practice. In total, 328 passengers were recorded from (9:05 am- 9:46 am).Queuing at the base of escalator entry varied with each batch and during the time that the patch passed through the escalator. The bottleneck is only observed at the escalator entry for a limited time. The severity of bottleneck is assessed from the waiting times and the number of passengers on queue derived from our SHP Data.

Analysis of origin-destination relations shows that the bottleneck on escalator entry has a significantly different influence on selection behaviour. The frequency of escalator and stairs users appeared to vary with the queue of passenger at the base of the escalator. To facilitate a consistent method of measuring the bottlenecks at the base of the escalator, a region observing approximately (3 m by 6 m and angel 15^o) in the base of escalator was defined by our SHP, with which depth images for the 49-minute video (data extraction was carried out manually by playing the video recordings on a computer screen). The number of passengers in the region of the station platform was counted manually to determine the escalator entry bottleneck within the region.

Figure 7 shows passenger rate versus time when queue occurs. It is apparent that the passenger rate exceeds the capacity in this case, which matches case C, that in section 3. We conclude that the escalator has a capacity C = 6.

Figure 7: Bottlenecks in a peak hour situation at a Brisbane station.



5. Conclusions

The research work presented in this paper focuses on pedestrian behaviour at bottleneck of escalator entry. Experiments and observation have been carried out. The process variables considered are the capacity, the number of passengers in the queue, the passenger rate departing from train, and the rate of passengers existing from bottleneck. The actual value of capacity is essential for understanding pedestrian route choice behaviour and for planning and designing of transportation systems. Three cases of escalator entry bottleneck have been underlined: under congested, congested, and over congested.

To study the escalator entry bottleneck and their effect on selection behaviour, an asus Xtion camera, 3D Sensor was mounted at the column of the platforms. A wide lens was used, enabling the camera to view the entire walking area, in total, 328 passengers were recorded from (9:05 am- 9:46 am).

The escalator entry bottleneck on route selection has a cost in real world (using real data from a field study) and that passenger route selection models can exploit this to describe behaviour.

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