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THE DYNAMICS OF TRAVELLATORS IN UNDERGROUND SPACE

John Zacharias[1]

Abstract: Travellators, also known as moving walkways, are typically installed to move people quickly and over extended distances in large facilities. They are commonly used in airport terminals and in underground corridors between metro stations, and are generally believed to enable moving larger numbers of people more quickly from point to point than can be achieved without the facility. Utility from the user perspective includes perceived time and kinetic energy savings, while management aims to increase throughput where there is heavy demand. An empirical study is necessary to evaluate how such facilities are actually used and to what extent these utility goals are achieved. Variables in resulting throughput, measured as speed, include 1) standees on the moving travellator, 2) moving pedestrians on the travellator, 3) pedestrians walking on the ground, 4) total pedestrian volume 5) incline of the walking surface. The case study is in the MTR system of Hong Kong, which has several examples of travellators. The heavily used corridors between Central Station and Hong Kong Station provided the test case of four travellators and related open floor areas. Counts were extracted from video capture. The travellator improved efficiency by about 17% during non-saturated flow conditions. Those walking on the travellator walked more slowly than those on firm ground but travelled faster overall because of the travellator motion. The travellator serves to organize the traffic streams, offers an alternate experience of displacement and a place for screen-related activities.

Keywords: travellator, moving walkway, pedestrians, underground network, Hong Kong

1. INTRODUCTION

Travellators or moving walkways, are installed in many underground walking systems to achieve certain desired improvements in the displacement of people from one place to another. A review of the commercial websites of travellator suppliers provides an overview of the presumed benefits of their inclusion in underground facilities. Travellators are said to be needed “where there is a high volume of pedestrian traffic and a need to move people quickly and efficiently over short to medium distances” [1]. In theory, higher pedestrian speed increases throughput in limited channel space. The promised higher speeds for pedestrians is accomplished with their safety in mind [2], in recognition of boarding and exiting difficulties for some passengers [3]. The higher speeds and channelling of movement are seen as the means to reduce congestion in busy transport terminals [4]. Because travellators are unidirectional, they gather pedestrians moving in a single direction from heterogeneous flows that often have conflicting trajectories.

The engineering and behavioural principles constituting the theory of travellators has been elaborated to some extent, as explained in the literature review below. There are, however, very few empirical studies of their operation in practice, in particular to assess the announced benefits in terms of mobility, accessibility and efficiency. Most of the published literature is concerned with travellator applications in airport terminals, the results of which must be taken with caution when considering their implementation in transport facilities and underground walkway systems. Possible reasons for differences in airports is that most pedestrians are managing luggage or luggage carts, and it is more likely that they are not overly familiar with the facility. As a result, they tend to move more slowly than in systems dominated by commuters and shoppers [5]. Nevertheless, some of the findings are of interest for the general application of travellators in underground walkway systems, as discussed

[1] Zacharias, John, PhD, urban planner, Chair Professor, College of Architecture and Landscape, Peking University, Beijing, PRC 1100871. johnzacharias@pku.edu.cn

below. The main purpose of the present work, then, is to assess improved efficiency in terms of travel speed in the presence of the travellator facility, and to assess to what extent that improved efficiency is conditioned by pedestrian volume, standing firm behaviour of some users and walking surface incline. Regardless the expected efficiencies delivered by walking on a travellator, the recommended procedure for using a travellator with safety in mind is to board and stand firm. The conditions in which people stand firm and are transported also needs understanding, since standing behaviour has a major effect on the theoretical efficiency of the system, as does a dense pedestrian flow.

The present study is an analysis of observations taken from the travellators installed in the Hong Kong MTR. Mean pedestrian speed is the dependent variable, with simultaneous counts of pedestrians standing on the travellator, walking on the travellator, walking on the bypass route, and degree of incline as independent variables. The numbers were derived from 38 video records on 4 travellators, with a total of 3,322 observations. Details of the field protocols and analysis will be found in the Methods section of this paper that follows consideration of the literature below.

The literature can be considered in three main categories, as follows: The planning and engineering of the travellator facilities, human responses to the operations of the mechanical system, and the range of walking behaviours that interface with the travellator.

Travellators will be implemented typically where there is a perceived long distance between hubs, activity centres and transport stations. They tend to be located where there are no incipient activities along the route that might induce a diversion, and are typically associated with major generators of movement, like metro and rail stations. An exchange space is needed where there is a cross-flow or where there are emergency exits to the ground level. It remains uncertain how length of travellator is related to use rate, but the length is often constrained by the needs of the larger facility. For example, [6] propose an analytical procedure for determining the placement and length of the travellator so as to minimize travel distance to exits and destinations along the route. Their case is the airport terminal with serially placed gates parallel to the moving walkway, although the model could be adapted to underground commercial facilities. A more extensive network of such travellators requires consideration of existing pedestrian flows. For example, in Tokyo at the Shinjuku JR station there are underground travellators taking pedestrians toward the Shinjuku CBD from the JR Station but without return movement, based on the principle that the start of the working day is more time-constrained than the end of the day. The Mid-Levels Escalator in Hong Kong, which is actually a travellator over much of its length, moves downward at the beginning of the working day but upward for the rest of the day. In this way it offers energy saving to users needing to climb to the Mid-Levels, but has also generated renewal and investment in those higher elevation areas [7]. As with all other people movers, the travellator may expand the activity space for individuals. Travellators have been installed in several locations in the Hong Kong MTR system, between Tsim Sha Tsui (TST) and TST East stations, at Sai Ying Pun station, among others.

It is argued that in reducing travel time and energy consumption, that travellers will be induced to travel longer distances. Following this reasoning, patronage of the MTR could be promoted through these labour and time-saving features. It is also argued that the travellator accommodates those with mobility constraints although users must be able to stand and move on their own [8][9]. In close proximity, the movement of all individuals is constrained by the behaviours of others and prompts various coping behaviours [10]. That increased proximity on the travellator may also be a factor in the decision to use it rather than to walk in the less constrained by-pass route. The tendency to use a labour-saving movement device is highly dependent on the location of the device. In the case of escalators in underground space, it was found that 71% of the variance in choice was attributable to the distance between the escalator and stairway [11].

As metro systems expand and greater connectivity is needed between lines, there are more long, undifferentiated corridors to take pedestrians from one station to another. The design of these corridors needs to take into consideration capacity, to account for sudden bursts in the flow of disembarking passengers. As metro systems develop and have more connectivity, there may be shifts in patronage among lines, placing more or less demand on fixed, underground corridors. A single travellator in one direction on such a corridor disturbs the usual right-left self-assignment of flow in conditions of high pedestrian volume. A corridor with travellators in both directions also induces uncertainty: should one walk on the bypass corridor next to the travellator moving in the same direction, regardless of the prevailing left-right bias in the local environment? Many systems, including Hong Kong's MTR, have tried to resolve conflicting flows by providing directional arrows on the floor. Cross-flows are, however, inevitable given all the pre-existing structures.

Travellators have been implemented with different operating speeds. The higher the speed, the more difficulty some pedestrians have in boarding and exiting, such that audible warnings are included in the facility, particularly for the exit condition. Hawkins & Atha (1976) found that 44% of individuals boarding used a half-step to board, which involves slowing slightly. Only 22% of individuals walked onto the travellator without a gait change. Their interpretation of the video record suggests that 31% of boarding individuals had balance problems which might lead to avoidance in using the facility. Ironically, the mobility aims of the travellator for those individuals with reduced mobility are thus thwarted by the mechanical action of the facility.

Other problems arise in the spaces upon exiting and boarding with the greater likelihood of cross-movements and sudden crowd formation in the exit area, with slow-moving crowds in the boarding area when the flow is very heavy [8]. There are risks involved in a crowded and fast-moving situation with the mechanical accelerator of flow rate and locations where falls are more likely. Underground space planning will aim to ensure adequate exchange space between travellator facilities, access to emergency exits, generous ceiling height, optimized legibility and the avoidance of blind corners. But ultimately, the great majority of passengers will trapped on the travellator in the case of an emergency necessitating evacuation.

The accelerated travellator, or accelerated moving walkway (AMW) has been implemented in a few facilities such as Schiphol airport, Amsterdam and Lester Pearson airport in Toronto. Boarding speed is the same as for the usual travellator but then accelerates using moving plates to achieve speeds much higher than normal walking speed. In the context of imagining it augmenting local mobility, there remains significant problems in the network [12][13]. Higher mechanical speeds appear to induce slower pedestrian pace, in an apparent desire for a certain level of comfort or familiarity. Such behaviour, if evidenced, would reduce theoretical efficiency. There is limited empirical evidence to support this theory, however, so it is important to collect speeds in all the conditions of the study case.

While this paper is primarily concerned with the efficiency argument for travellators, individuals and their choices remain the core of the question. Individuals are sensitive to instrumental aspects of facility use – usability and usefulness, social-spatial interaction, aesthetics, sense of control and multi-tasking being notable among them [14]. There is no obvious link between these ways of experiencing the travellator and the measured efficiency of the system, although both may inform decisions to build. But the election to use is a gauge of preference [15]. We might not learn the specifics of that response but still it lends insight into the world of transport and comfort. The latter is a fast-emerging field of enquiry into the hedonic and instrumental motivators for choice that appear to explain a significant part of choice behaviour [16]. Thus, it is important to pay attention to the intensity of use of the options.

In theory, humans will optimize energy expenditure while moving. However, on a moving walkway, this would mean standing firm. Some do stand firm, others walk. Observations in airports [9] showed that walking speed on travellators is lower than by-pass walking speed. However, airports may be particular situations because passengers are transporting luggage and may or may not be time-constrained. A second theory is that visual flow will result in humans reconciling the movement of their legs with their apparent movement from visual flow [17]. This should result in faster than by-pass walking speed on the travellator but less than the addition of normal walking speed and travellator speed. In addition, the presence of others on the travellator may then influence both the decision to walk and the decision to enter the travellator. It is also observed that perceived higher speed – what one can see of the environment surrounding the travellator facility – results in a shorter gait [18]. These new variables require consideration with an empirical study in a case more typical of movement and exchange networks underground. The goal is to identify the co-factors in the functioning of these systems in their daily use, as a guide to their planning. Also, it is useful to be able to understand the contribution of aids to movement such as this one in relation to other needs in the movement system.

2. MATERIAL AND METHODS

A broader introductory study of travellator installations revealed certain salient social features of people-moving devices, which were then validated in the Hong Kong case. The travellators observed in this study are located in the underground concourses between Hong Kong Station and Central MTR station. There are four travellators, one ascending, one descending, and two at level, parallel to a divided or undivided by-pass channel. The flows vary markedly over the day, largely as a result of the concentration of commuting movement within two main peak periods. Samples are taken to cover all the but the highest level flows, but still representing sufficient variation on all variables to work in regression analysis.

At the extreme ends of the joined travellator sets are station exchange spaces – Central Station and Hong Kong Station – with complex movement among several lines and corridor commercial space (figure 1). Space allocation for by-pass walks is critical at the point of choice and a requirement for this study was for such by-pass space to exceed requirement. In this case, the corridors were near saturation – slowed speed, shorter steps for the great majority of individuals – only once in our observations. The total travel time between Central Station and Hong Kong Station is as little as 3 minutes while walking on the travellators.

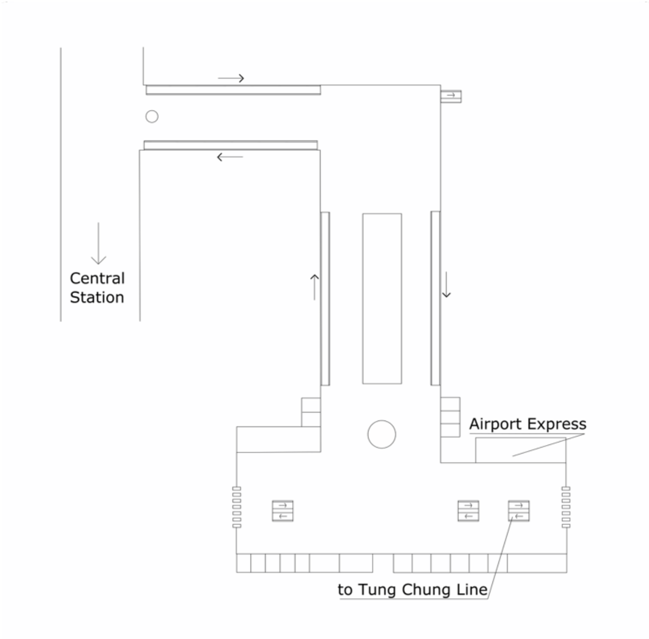

***Figure 1**. The layout of the travellators between Central Station and Hong Kong Station*

Group behaviour, including mimicking those surrounding one, may enter into the decisions to stand, walk or by-pass. To examine this issue, standees were considered for their group characteristics. Modest increases in overall pedestrian volume results in greater increases in density on the travellator, which might then induce the decision to by-pass or to stand firm.

Video segments from an oblique angular view of the facility enabled subsequent extraction of traversal time and stance – in our case, the binary standing firm and walking. The vast majority of observed individuals did one or the other exclusively. There were 37 samples from 36 s to 99 s in duration, where 3.342 individuals were coded as walking on the travellator, standing firm on the travellator or walking on the by-pass and the generated walking speed derived from the time taken to go from end to end of the travellator, standing or walking. A database for the coded individuals is created with these data.

A bivariate analysis seeks out the basic relationships between the variables in the behavioural outcome of the travellators. A regression analysis with the resulting mean speed of individuals passing through the channel will show the extent to which these variables are interacting. Speed is the indicator for efficiency understood as throughput. Inferences from the modelling of movement are drawn to illustrate features that deserve consideration in the design phase for the reasons of the behavioural outcomes. The final analysis is of revealed benefits in relation to the commitments in space and funds for such travellator projects.

3. RESULTS

Flow rates varied from 0,33 to 6,02 persons/sec. with a mean of 1,89 (SD = 1,34). While average speed of all pedestrians declined slightly as pedestrian volume rose (-,11), the decline was not significant. This is in keeping with our observation that there were nearly no cases of saturated and impeded flow. The numbers of standees had an expected negative effect on walking speed for those on the travellator (-,29; p=0,79), in keeping with the observation that moving pedestrians must pass the standee usually on the left but will tend to do so at slightly reduced speed. The number of standees also had a significant negative effect on overall walking speed (-,61; p=,000) but not because they represent an increasing proportion of the total flow. With increasing numbers of walkers on the travellator, average speed of those walking on the facility declined (-,48; p=,003), although the number of those walking on the travellator had no significant effect on average speed overall. At the higher volumes of walkers on the travellator, it is seen that reduced spacing also reduces stride length. The number of standees had a strong positive relationship with the number walking on the by-pass route (,64; p=,000), in all likelihood indicating that individuals tended to choose walking on the ground when they saw larger numbers of standees on the travellator. They would perhaps anticipate that their progress would be limited by the standees.

Overall, those walking on the travellator move faster on average (1,91m/s; SD=0,19) than those walking on the floor (1,42m/s; SD=0,22), because the travellator is moving at 0.79m/s. Without the mechanical assist, they would be walking at 1,12m/s. Overall walking speed (1,66m/s) is increased through the use of the travellator over the walking speed on the ground by 17%. This includes those standing on the travellator (figure 2).

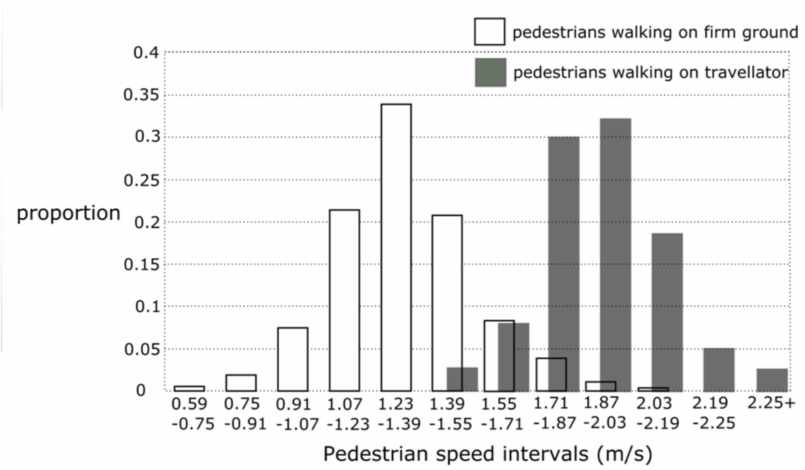

Figure 2*. The frequency distribution of moving speeds on firm ground and on the travellators.*

The incline or its absence had no significant impact on speeds or the distribution of standees and those walking. Accordingly, this variable is eliminated from the regression analysis.

At the highest volume flows, there is bunching and stasis at the entrance to the travellator that might persist for several seconds per individual, that is not factored in the flows on the travellator or beside it. This occurs again before the end of the track since disembarking pedestrians slow their pace and often make a half-step to exit the facility. At higher pedestrian flow, i.e. >5 p/s, the stopped queue at the end of the track may persist for several seconds. The exchange spaces adds complexity where some individuals must find their way around others moving across the vector of movement.

A linear regression model examines the variable effects of each of the movement components on the resulting speed (table 1). The presentation is hierarchical, to enable detection of the contribution of individual variables. Evidently, standing behaviour on the travellator is the biggest factor in transit speed in the corridor, even if this variable is weakly related to the others. In this model, 44% of the variance can be explained by 4 independent variables. Although the direction of this model is clear, with the direction of effect of individual variables fitting with theory, further interpretation is limited by data availability.

Table 1. *Linear regression for overall transit speed as a function of four predictor variables***.**

Regression Variable	Regression Coefficient	t-value	SEE	Standard. B	ANOVA R^2	F-value
Standing	-,011	-4,500***	0,150	-5,872	,37	20,252***
Standing	-,008	-2,55**	0,148	-4,271	,41	11,640***
Walking	-,002	-1,512		-0,498	,41	11,640***
Standing	-,007	-2,240**	0,145	-3,737	,42	7,865***
Walking	-,003	-1,686*		-0,746		
Walking/WW	-,001	0,790		-0,101		
Standing	-,008	-2,314**	0,150	-4,271	,42	5,903***
Walking	-,002	-0,1032		-0,497		
Walking/WW	,001	0,879		0,101		
Flow	-,040	-0,653		-153,610		

*p<,10; **p<,05; ***p<,01

Standing behaviour is a result of several factors but is not induced by total flow on the travellator or the total pedestrian volume. Individual standees (n=43), more than 1 m from any other individual, are typically concentrating on their cellphones. Others are in conversation with one or more others. There is also a tendency to fall into the line of standees when the line is already long. Thus, standing behaviour is a result of individual behaviours and response to others' behaviours (figure 2).

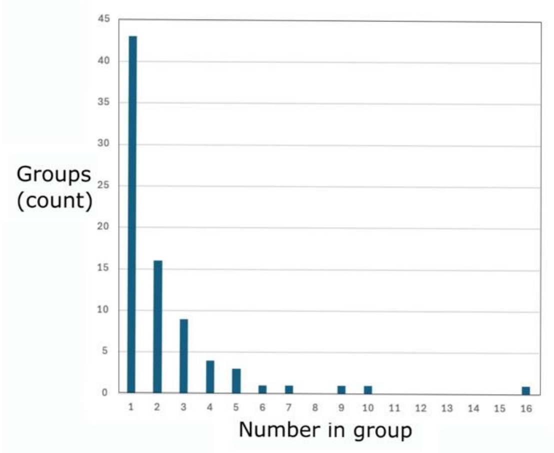

***Figure 2**. The frequency distribution of grouped standing behaviour.*

4. DISCUSSION

The theoretical and laboratory-based predictions that pedestrians will slow their voluntary walking speed when on a track moving in the direction of their walk [17][18] are borne out in the present empirical study. This is a novel finding because it derives from the real world of actual, unguided human behaviour and also is supportive of the psychological theory from a behavioural perspective. There are many other, uncontrolled factors that could have weighed on the walking pace, including momentary distractions, pauses, anchor points, the space itself and the dynamics of others, footwear, preceding physical activity, etc. While these remain tantalizingly beyond the scope of the present investigation, what remains is the clear identification of the dynamics of movement on and beside the travellator and their relation with the desired aims of efficiency.

Following this result of differential speeds, the faster the track is moving, the slower the pace of the transported pedestrians, as evidenced in the observed behaviours on the AMWs at L.B. Pearson International Airport and Schiphol International Airport. Overall, as the present case demonstrates, average speed of displacement on the travellator is slightly increased over observed walking speed on the parallel way, the effect of which is attenuated by slightly slower walking speed. The point is that behaviour enters into a symbiosis with the infrastructure, using the infrastructure for a variety of purposes. The behaviours themselves appear to seek some kind of balance among a variety of issues including utility, energy consumption, cognitive load, thought. The infrastructure variations on the experience of travel in the underground also offers clear time savings for a small minority of athletic-minded users.

While metro systems continue to develop worldwide and introduce more underground space and movement systems, there is also the opportunity to make corridors that are not purely transport linkages. The TST tunnel that also offers access to the K-11 Art Mall in Hong Kong is a case in point where two major bi-directional travellators also offer faster and more direct routes between the stations. The new underground 430 m-long concourse at Shinjuku, Tokyo, between the Takashimaya department store and the Isetan store is meant to bring these two commercial powerhouses closer together, using an underground, climate-controlled pathway without stops. The wider urban plans for development of travellator systems envisioned by Scarinci et al (2017a) are likely to garner more attention as underground networks develop.

To consider such movement systems as generalized infrastructure introduces the question of how we want to control the channel containing the travellator since the travellator is essentially a closed system without access to the spaces to either side. A possible solution is a multi-scalar approach to the movement system, to retain ground-based movement that is more distributed while longer and dedicated trajectories are handled on travellators, and then even longer trips on underground rail. That was the promise of the earliest urban application of the travellator at the 1900 Exposition Universelle in Paris, where the Rue de L'Avenir consisted of two parallel tracks that carried passengers for up to 3,5 km at 1,17 m/s and 2,36 m/s next to a fixed walkway. The 3,5 km distance with nine intervening stations could be accomplished in 26 minutes. If the passengers on the faster track had been walking at the usual pace, the entire trip could be done in 15 minutes. These distances and times are already optimal among the available other choices. While such an implementation is now more difficult on the ground with so many competing interests, it is much more feasible underground. Not surprisingly, the longest and most heavily used travellators are in underground space.

While speed delivers the desired efficiency, higher entry speeds are related to mishap rates. It may be that experience and training could reduce these events but it remains a novel experience to step onto a moving walkway for most people [19]. Mishaps on travellators occur and are perhaps less risky than those on escalators but nevertheless may involve falls. More work is needed to solve the entry and exit speed differential problem.

The more general policy issue concerns whether this is a good investment in underground space when larger distances are to be traversed. In the present case, there was a 17% increase in speed and thus in throughput with the travellator, but only in off-peak periods. Whether this efficiency boost alone is sufficient for the infrastructure and its maintenance is a question when considering where else the money could be spent. The results of this study do not support the implementation of travellators for the purposes of increasing throughput at peak travel times.

One could make an argument for the qualitative aspects of the facility. From a practical standpoint, the travellator organizes some proportion of the movement, inducing movement cohorts and reducing movement conflicts. The travellator offers a respite to those wanting to focus on their cellphones while continuing their progress and offering accelerated movement to those wanting to save time. The footprint is relatively small, while contributing to the demarcation of the movement space, something that is traditionally achieved through a colonnades or a line of bollards.

5. CONCLUSION

This study evaluated the efficiency claims for travellators by examining a real case of several travellators in a busy underground transport corridor.

The research revealed in quantitative terms the contribution of a travellator in a movement corridor to overall movement efficiency measured in time and throughput. Users walk at lower speed than when they are walking on firm ground, but are moving at overall faster speed than those on the ground. The use of the travellator for sedentary activity is notable, with 12,1% of those transiting the space remaining stationary on the travellator, to stand, rest, engage in a chat or review some feeds on an electronic device. The standing space is consistently on the righthand side of the moving track in the Hong Kong case, allowing a single person to pass. Those who choose to walk on the parallel ground are 20,2% of the total in the present sample, but at peak time this figure rises to over 80%. The travellator notably does not deliver added efficiency at the peak travel times in the morning and early evening. At those points, the wider walking corridor can accommodate a rank of pedestrians if all are travelling in the same direction, while the crowded travellator may be subject to congestion, slow speeds or no personal locomotion around the entry point and on the track nearer the exit. This means that at peak times, movement on the travellator is slower than on the ground. On average and at non-peak times, the travellator delivers efficiencies but not at peak times.

The promise of such systems in underground space is to link two locations more closely than can otherwise be achieved on the surface. In certain applications, the travellator can deliver efficiencies and help organize the movement while in other instances it is likely to be neither necessary nor cost-efficient. From the present study, we can conclude that distance alone is not a good foundation for going ahead with implementation.

The strength of this article is the validation of theory regarding behaviour with empirical observation. It is not known whether such observed behaviours are universals. Ideally, one would have access to a long video record from CCTV cameras, which was not available in this case. This would allow the inclusion of highest volume-flow and variations by time of the day and day of the week.

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