ISSN: 2513-2512

R4TLI Conference Proceedings 2017
Paper Reference: *R4TL (17) - A11*

Understanding the Fundamentals of Macroscopic Pedestrian Flow Modelling in Sri Lanka

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1. Introduction

Objective of transport planning is to determine the necessary infrastructure required for future transport demand estimations aligned to the policies which are in place to cater to the management of mobility needs of the public. Smooth vehicular flow and pedestrian flow are two key dimensions that are pivotal to ensuring satisfactory mobility [1]. Though several studies have modelled vehicular flow [2], there has been limited study of pedestrian flow [3] internationally. In Sri Lanka, such studies are non-existent. This research aims at understanding the fundamentals of macroscopic pedestrian flow modelling in the Sri Lankan context.

Pedestrian flow becomes complex due to the complexity inherent to human behaviour which depends on many personal attributes such as trip purpose, safety concerns, physical capabilities, proximity to other pedestrians, age, attitude, cultural aspects etc. [4]. Analysing and predicting pedestrian behaviour considering each of the above attributes is known as microscopic modelling, whereas considering the pedestrian flow system as a whole is referred to as macroscopic modelling [5]. This research focuses on the latter starting with the possibility of extending a suitable traffic flow model applied for understanding vehicle flow to determine macroscopic pedestrian flow in the Sri Lankan context.

2. Methodology

The methodology consisting of three phases was developed with the aim of modelling pedestrian flow.

- Phase 1 - Selecting Greenshield's traffic flow model [5] as the most suitable generalised traffic model to test the modelling of pedestrian flow.
- Phase 2 - Selecting six characteristically different locations in and around Colombo to study pedestrian movement based on literature review using convenience sampling due to time and resource constraints. Data was collected through videos captured in each location as described in table 3.1.

Photographs of the six locations labelled as L1 to L6 are depicted in Appendix A.

- Phase 3 **-** The study of the relationship between flow measured as pedestrians per metre width and the space measured as the mean speed of pedestrians to travel a given length at each location in order to establish their relationship and to identify location specific deviations. Consequently, all data across different locations was pooled and analysed to calibrate a Macroscopic Pedestrian Flow Model for Sri Lanka.[1]

3. Results

The results of the analysis pertaining to each location, highlighting the key features identified can be summarised as under following sections.

3.1. Summary of Findings from L1 - L5

The following macroscopic impacts on pedestrian flow conditions were identified and named.

- **Push Effect -** Where individual pedestrians align their speed to the majority of the pedestrians in order not to get pushed from behind. This can be observed at locations such as exits from railway stations, sports stadia and cinema halls etc. This means that unlike in vehicle flow, where slow moving vehicles in front can slow down other vehicles, in pedestrian flow, a large number of faster moving pedestrians can push pedestrians intending to travel slower to move faster.
- **Stimulus Effect -** This is a deviation of speed in a given location based on pedestrian mix with time, where speed varies with trip purpose. For example, commuters would walk briskly while visitors would walk more leisurely often allowing the pedestrians desiring to walk faster to go on ahead. This can happen when a train arrives or office workers get out and then try to out-walk others to get to a waiting bus.
- **Space Effect -** Pedestrian speed varies with space availability where the pedestrian flow and the width availability has an impact on speed. This was observed at entrances and gates of traffic generators and attractors such as a railway station or and university. When width reduces the pedestrian formation of single file is observed where pedestrians tend to subconsciously form single file queues to avoid congestion.

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[1] The analysis was conducted using the Minitab 17 statistical software toolkit.

- **Stay Back Effect -** It was observed that when facilities get congested such as in single file movements, pedestrians prefer to step away to avoid being pushed from behind by a heavy flow of pedestrians who intend to walk much faster than they desire, defined earlier as the Push Effect.

Summary of the best fit of the regression modelling of speed and flow observed for each location is given in table 3.1 where

V_S - Space Mean Speed (m/s) q - Flow (ped/min/m)

Table 3.1: Summary of Findings from Locations L1-L5

Location	Features	Nature of the Sample Collected	Equation Obtained	R-Sq. Value	Observed Macroscopic Flow Conditions
Panadura Pedestrian Bridge - L2	BDC /CS[2]	263 pedestrians observed at 10 min time intervals for 3 hours	$V_s = 0.9748 - 0.01930\,q + 0.001028\,q^2 - 0.000016\,q^3$	31.5%	Push Effect, Stimulus Effect, Space Effect
Panadura Pedestrian Corridor - L3	BDC/CS	306 pedestrians observed at 10 min time intervals for 1 hour	$V_s = 0.9705 - 0.04612\,q + 0.002724\,q^2 - 0.000056\,q^3$	51.7%	Push Effect, Stimulus Effect, Space Effect
Moratuwa Railway Station - L5	UDC/CS	1,152 pedestrians captured continuously following 6 trains	$V_s = 0.5266 - 0.0333\,q + 0.001099\,q^2 - 0.000004\,q^3$	53.4%	Push Effect, Stimulus Effect, Space Effect, Stay Back Effect
University of Moratuwa - L1	UDC/ UCS	578 pedestrians observed at 15 min time intervals for 1.5 hours	$V_s = 0.8331 - 0.00720\,q + 0.000476\,q^2 - 0.000007\,q^3$	64.8%	Push Effect, Stimulus Effect
Savoy Cinema - L4	UDC/CS	347 pedestrians captured continuously for 1 hour	$Vs = -329.5 + 37.62\,q - 1.422\,q^2 + 0.01783\,q^3$	30.0%	Push Effect, Space Effect, Stay Back Effect

3.2. Bellanvila Leisure Park - L6

This location was used to determine the free flow speed where the pedestrian movement was classified under free flow and purpose-driven movement as mentioned in table 3.2. A total of 78 pedestrians were observed during a period of one hour.

[2] BDC – Bidirectional Flow UDC – Unidirectional flow CS – Constrained UCS - Unconstrained

Table 3.2 Key Findings from the Bellanvila Leisure Park

Movement Type	Maximum Individual Speed	Average Speed	Std. Deviation
Leisure Walk	1.01 m/s	0.86 m/s	0.085 m/s
Brisk walk	1.82 m/s	1.59 m/s	0.115 m/s
Jogging/Running	3.01 m/s	2.72 m/s	0.419 m/s

3.3. Macroscopic Pedestrian Flow model

Locations L2, L3 and L5 were selected for formulating the aggregate model as the locations L1 and L4 were identified to have specific behavioural attributes. It can be seen that while the Leisure Walking Speed is 0.86 m/s, in the calibrated Macroscopic Pedestrian Flow model given in Figure 3.1, the speed at low-flow conditions of less than 15 pedestrians/min/metre width is found at times to be higher than the leisure speed due to the Push Effect. The equation of the Macroscopic Pedestrian Flow model which returns an R square of 56% can be expressed as,

$$V_s = 0.8260 + 0.00998\ q + 0.000723\ q^2 - 0.000008\ q^3$$

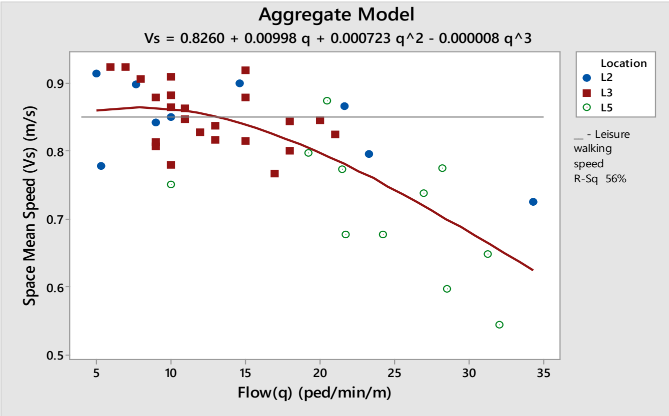

Figure 3.1: Generalised Model

4. Conclusion/Recommendation

This research having considered several locations in Colombo, Sri Lanka arrives at a Macroscopic Pedestrian Flow Model to explain pedestrian speed variation with flow and other attributes.

The research identifies that macroscopic pedestrian flow is affected by the (a) Push effect, (b) Stimulus effect, (c) Space effect and the (d) Stay Back effect which results in deviations to the pedestrian flow when comparing to vehicular flow. The time of the day has an effect on the flow yet the analysis was limited on this aspect as the data was collected covering only a specific time period. These effects result at times combines to increase in speed above the leisure or free flow speed, with increase in flow until the activation of space effect which begins after a flow rate of 15 pedestrians/min/metre after which speed begins to reduce with flow oppose to the Greenshields's Traffic Flow model to a certain extent.

It can be concluded that the Macroscopic Pedestrian Flow model formulated in this research can be used to determine the pedestrian flow only after studying the nature of the effects identified in this research for a given location or facility. This would enable researchers to customise the pedestrian facility pertaining to the user characteristics which results in delivering maximum mobility to the users which has been rarely addressed in urban planning mechanisms which exists in present context. Further research is required to determine the impact of each of the factors to improve the basic Macroscopic Pedestrian Flow model to predict the travel speed of pedestrians more accurately. In addition, microscopic analysis can be conducted to establish other models such as speed-density, speed-space and flow-space relationships in extensive nature.

5. References

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Keywords: *pedestrian flow, space mean speed, Greenshields's model*

Appendix A

Figure A.1: University of Moratuwa - L1

Figure A.2: Panadura Pedestrian Bridge - L2

Figure A.3: Panadura Pedestrian Corridor - L3

Figure A.4: Savoy Cinema - Entrance/Exit - L4

Figure A.5: Moratuwa Railway Station-L5

Figure A.6: Bellanviala Leisure Park-L6