Development of an iterative pedestrian route choice behaviour model using Floyd Warshall algorithm

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ABSTRACT

Walking is by far the most adaptable and accessible form of transportation. Though there are other more complex, sophisticated modes of transportation that are readily available, walking is the only mode by which otherwise remote areas are made readily accessible. This can be observed in the case of platform-to-platform travel in a railway station, accessing bus stop from home, and several other such cases. Walking thus plays a crucial part in the everyday life of commuters.

A thorough and comprehensive understanding is hence required for planning and designing pedestrian facilities such as overhead passes. The route choice of the pedestrian has a huge effect on the pedestrian flow, and thus it also plays a decisive role in determining the LOS (level of service) of a facility. The LOS incorporates various aspects, such as, efficiency, safety, evacuation time and comfort. The need for understanding pedestrian motion is more necessary in countries like India where population is increasing in the large cities at a very higher rate. Understanding this motion and developing a model, though, can be a tedious and yet indispensable task, the lack of which can lead to disastrous incidents. These incidents are more conspicuous during emergency situations, when sudden rush due of the pedestrian through a limited and ill-conceived exit can lead to a stampede. The proper knowledge of pedestrian flow is thus not only desirable but also warranted. In these study pedestrian behaviour is modelled using iterative Floyd Warshall algorithm. It is a dynamic programme that has been validated using some real life data.

Keywords: Pedestrian decision based model, Pedestran route choice behaviour, Floyd Warshall algorithm

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1. INTRODUCTION

Modelling of pedestrian behaviour can be a complex process. It can either be macroscopic modelling or microscopic modelling.

Macroscopic modelling gives fundamental flow parameters like speed, flow, and density and the inter-relationships between such parameters. Macroscopic models, on the other hand, depict individual pedestrian movement and are generally based on fundamental diagrams, fluid dynamics, well- defined observations.

Microscopic modelling can exhibit the pedestrians' decision making isolating individuals and their interactions. Microscopic modelling can either be force based or decision based.

i. **Force based models** are similar to force models as used in physical sciences, working on the assumption that pedestrian motion is governed by several attractive (towards destination) and repulsive (towards destination) forces. Social force model, magnetic force model and centrifugal force models are some well-known models that can be classified as force-based models.

ii. **Decision based models** use space and time as discrete quantities. These models utilizes set of rules to govern the flow of pedestrians. Examples include cellular automata models.

In this research work, a decision based model is implemented focusing on route choice behaviour of pedestrians.

Several studies were conducted to understand interrelations of speed-flow-density and fundamental diagrams of pedestrian motion. These include Hankin and Wright (1958), Older (1968), Navin and Wheeler (1969), Fruin (1971), Mori and Tsukaguchi (1987), Seyfried et al. (2005), Helbing et al. (2007).

Henderson and Lyons (1972) noticed alterations in the distribution of speed between male and female pedestrians when subjected to the same homogeneous flow.

Likewise, Polus et al. (1983) established that speed of female pedestrians is less when compared to male pedestrians.

Similarly, many studies have been conducted on Empirical studies of pedestrian flow on stairways.

Fruin et al. (1987) studied the impact of demographic and anthropometric factors such as age, direction of flow, gender, and physical dimensions of stair on average walking speed on stairways. Stairway is a critical element in areas like railway stations compared to straight walkways because the generally narrow size and undivided pedestrian flow reduces the capacity which develops more profound follow-on effect in average walking speed of pedestrian.

Yang et al. (2012) reported variation of speed and density when studied under both normal condition and emergency conditions. Average speed ranges from 24-42 m/min for density less than 1 ped/m^2, which is lower than average walking speed and density measured under emergency situations.

Lee (2005) found that the direction of flow in the stairs affects free speed of the pedestrians and reported higher free speed on downstairs (0.771 m/s) compared to (0.68 m/s) on upstairs.

Yao et al. (2012) demonstrated weaving phenomena of crowd to avoid conflict during transfer process provided minimum space was available to them at transport terminal.

Wen et al. (2007) conducted speed-flow-space study at Shanghai Metro station and established LOS based on their researches. They found that space requirement were also influenced by the physical size of the pedestrian . The deduced that as the Chinese pedestrian has on average, a smaller physical dimension, and hence less space is required. Interestingly, average walking speed on stairways in the upward direction at LOS B was observed to be more than that at LOS A, probably due to some pushing force on up- even as space available reduced at LOS B compared to LOS A.

As discussed earlier, microscopic models can be either force-based models or rule-based model. Both such models are discussed below.

Force based models deals with interactions between passengers. These include *Social force model, Magnetic force model* and *Centrifugal force model.* These models have been developed by several researchers.

Rule Based models considers both space and time as discrete quantities.

2. EXPERIMENTAL

2.1 Data Collection

For this study, pedestrian data was collected using high resolution video camera. This video graphic survey was conducted in Tatanagar and Kazipeta railway stations. The study was conducted at different densities. Male and female data was separately analysed for speeds and compared. Also speed on stairways and foot over bridges were compared. A typical diagram exhibiting camera setup and data collection process is exhibited below.

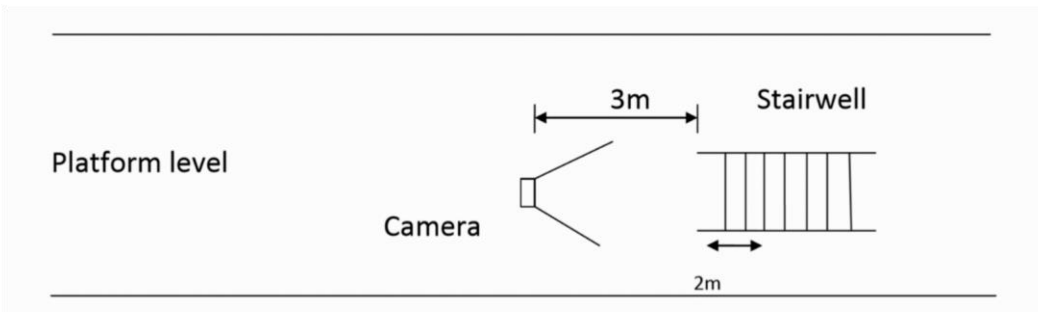


Fig 1. Typical sketch for data collection methodology on stairway

2.2 Data analysis

Statistical analysis was performed for the data collected at different facilities. ANOVA test was conducted for various facilities and it was found that mean speeds on stairways of Tatanagar and Kazipet railway stations are same whereas mean speeds on foot over bridges of Tata nagar and Kazipet railway stations are different. The ANOVA test was conducted using MS Excel.

It was concluded that mean speed on stairways of Tata Nagar and Kazipet are significantly same.

It was also concluded that mean speeds are different.

A study on level of service was also conducted. In addition to speed data some other attributes were also considered. HCM 2010 was considered to give a note on the serviceability conditions of the studied facilities. Density, flow rate and average pedestrian space were taken into account.

There are different definitions of the six levels of service criteria. Understanding level of service helps one to understand the capacity and existing service conditions of the existing pedestrian facilities and also encourage to provide some measures of change or modify them to attain favourable conditions for pedestrian usage. ‘A’ level of service is the most desirable one as it encourages smooth pedestrian motion without any decrease of speed. It also provides ample pedestrian space to each pedestrian for unrestrained pedestrian motion. Level of service ‘F’ impedes pedestrian motion providing very less space for each individual. As motion is severely restricted, ‘F’ level of service is the most unwanted.

Table 1 Level of service of foot over bridge in terms of v/c ratio

Location	Section	Sample size	V/C ratio	LOS
TATANAGAR	FOB 1	271	0.501852	D
	FOB 2	734	0.447561	D
	FOB 3	380	0.399793	C
KAZIPET	FOB	299	0.204375	A

Table 2 Level of service of foot over bridge in terms of average space.

Location	Section	Sample size	Average space (m^2/ped)	LOS
TATANAGAR	FOB 1	271	10	A
	FOB 2	734	12	A
	FOB 3	380	15	A
KAZIPET	FOB	299	8	A

LOS of staircases in terms of V/C ratio and average speed is provided below

Table 3 Level of service of stairways in terms of v/c ratio.

Location	Section	Sample size	V/C ratio	LOS
TATANAGAR	Stairway 1	315	0.277824	A
	Stairway 2	325	0.219314	A
	Stairway 3	334	0.247040	A
KAZIPET	Stairway 1	159	0.297196	A
	Stairway 2	229	0.209707	A
	Stairway 3	185	0.144757	A

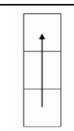
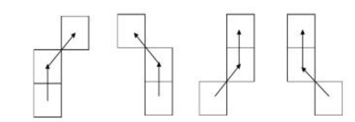
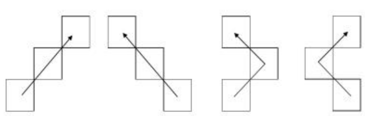
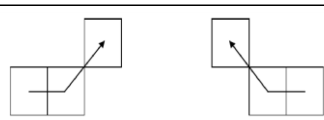
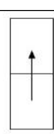
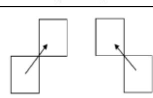
Table 4 Level of service of stairways in terms of average space.

Location	Section	Sample size	Average space (m^2/ped)	LOS
TATANAGAR	Stairway 1	315	10	A
	Stairway 2	325	5	A
	Stairway 3	334	12	A
KAZIPET	Stairway 1	159	4	A
	Stairway 2	229	4	A
	Stairway 3	185	8	A

2.3 Proposed model

This study focuses on developing a model which is a self-intelligent system. Pedestrians always try to move through shortest paths, which has a close relationship with Floyd Warshall algorithm that provides shortest routes between start and destination node in an iterative process. In this study a self-controlling system for pedestrians was developed. The number of possibilities that can be achieved is shown. The figures are arranged in order of their priority.

Table 5 Priority order of possibilities of pedestrian movement

Priority order	Diagram	Description
1		Two steps straight movement and two step progress
2		One step straight and one step diagonal and two step progress
3		Two step diagonal and two step progress
4		One step straight and one step diagonal and one step progress
5		One step straight and one step progress
		One step diagonal and one step progress

The above figures also shows the priority in which pedestrians will move given the neighbouring conditions. The flow space is designed as a rectangular grid with each time step taking 1 sec. and the size of each grid is taken as 0.4 m × 0.4 m. Weightage of 1 and 2 is given for straight and diagonal steps respectively.

2.4 Floyd Warshall Algorithm

Floyd Warshall algorithm can be explained by following equation.

$$D^{k}_{i,j} = \min \{d^{k-1}_{i,j}, d^{k-1}_{i,k} + d^{k-1}_{k,j}\}$$

Here k denotes intermediate nodes and i, j denotes the position of the pedestrians in the flow space. As it can be seen from the above figures two step progress is preferred to one step progress, two iterations are to be made. This implies that the generation of D' matrix is always dependent on D^0 matrix.

An example of the route choice behaviour of the pedestrians in the model is shown in figure 6. As per figure 6, pedestrian enters into the flow space at 33 position and finds two steps progress possible by taking two possible routes shown in two different colours. The cross signs shows other pedestrians moving forward in the same direction. Since, both these paths have the same priority, the pedestrian follows the path shown in green depending on his/her instantaneous decision making capability which is a random process. If two pedestrians in motion compete over a particular cell in the flow space, one with a greater confidence (i.e., lesser reaction time) succeeds occupying the cell. According to Floyd Warshall algorithm shortest route is followed by pedestrians in accordance with the minimum weightage computed which can be deduced from D^0 and D^1 matrix. These matrices show the weights (cost of path) from one node to another. Figure 7 and figure 8 show the D^0 and D^1 matrices in the first iteration (first time step).

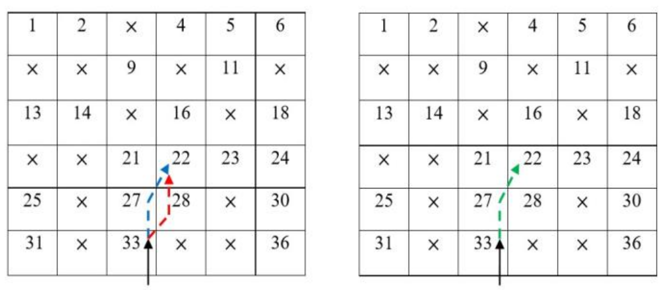


Figure 6 (a): Possible paths (b): Chosen path in the flow space

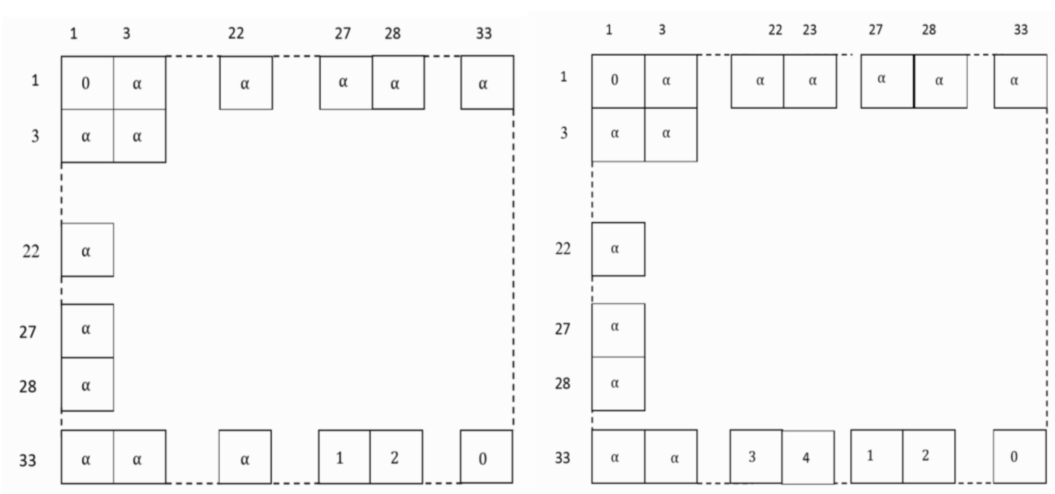


Figure 7 (a) D^0 Matrix without any intermediate node (b) D^1 Matrix without any intermediate node

According to figure 7 the intersection of 33 (position of pedestrian entry) and 27 (a vacant space) provides a path cost of value 1. Again, movement to 28 provides a path cost of value 2. So according to Floyd Warshall algorithm movement to 27 is justified. In spite of this the generation of D^1 matrix in figure 4.4 illustrates upgraded values of path cost at the points of intersection of 33 with 22 and 23 which had infinite path cost in D^0 matrix. In D^1 matrix it is evident that the path costs from 33th position to 22 is minimum with the best possible progress (2 rows upward) in the forward direction.

Same process is repeated in the consequent iterations the pedestrian moves forward inside the flow space. Each iteration (each time step) generates newer D^0 and D^1 matrices according to the newer positions of the pedestrian and positions of the other pedestrians in the vicinity. The complete path is shown in figure 8 .

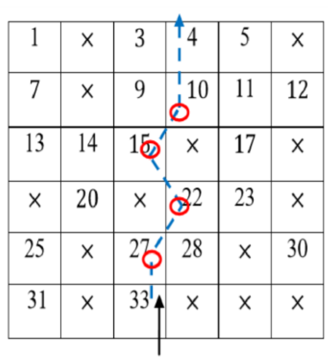


Figure 8 Complete path of the pedestrian entered in 33th position at the last time step

2.5 Flow Space

Flow space is the one where pedestrian move. In this study is required to have the following properties

- It is considered as a dynamical system
- It is discrete in time
- It is discrete in space
- Only local interactions are possible
- Entire flow space is divided in regular grid (rectangular, triangular, hexagonal etc.) of lattice cells.
- At each time step each cell is either empty or occupied.
- The state of each cell at time step t+1 is a function of some of its surrounding cells (the neighbours) at time step t.

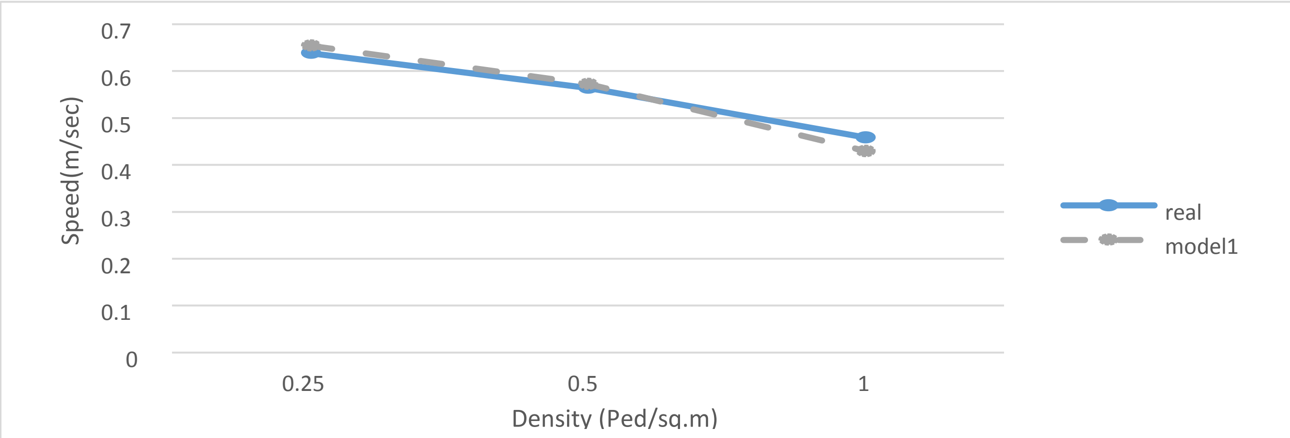
4. RESULTS AND VALIDATION

Results of simulated model are presented in this chapter. Model is simulated using Microsoft Visual C++. For simulating the model some parameters such as like user-defined flow space are considered like size of the cell, time, speed and no. of intermediate points in Floyd Warshall algorithm. Speed of pedestrian is influenced by position of pedestrians in his near proximity.

In graphical method, speeds at different densities i.e. at 0.25 ped/m^2, 0.5 ped/m^2, and 1 ped/m^2 are compared for real life data set and results from the simulated data. The graph for comparison is shown below.

The graph below shows that there is no significant difference between observed and simulated average speeds. Owing to which, model can be validated.

Fig 10 Graphical comparison of real data and model data



Besides graphical method, a model can be validated through conducting statistical studies like t-test and ANOVA test. Observed and simulated data are compared for speeds at different densities.

These tests are done using Microsoft Excel. The results are as follows

Table 6 T-test at different densities

S.No	Density(ped/m^2)	Result
1	0.25	No significant difference
2	0.5	No significant difference
3	1.0	No significant difference

The ANOVA test results at different densities are as follows -

Table 7 ANOVA Test for density = 0.25 ped/m^2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.006198	1	0.006198	0.242548	0.623132	3.907782
Within Groups	3.628561	142	0.025553			
Total	3.634759	143				

Table 8 ANOVA Test for density = 0.5 ped/m^2

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.009798	1	0.009798	2.474068	0.119947	3.968471
Within Groups	0.297006	75	0.00396			
Total	0.306804	76				

Table 9 ANOVA Test for density = 1.0 ped/m^2

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.007679	1	0.007679	2.962832	0.090623	4.009868
Within Groups	0.147722	57	0.002592			
Total	0.1554	58				

As F is less than F-critical and p-value is less than alpha value = 0.05, hence it can be said that no significant difference is present between real and stimulated data.

5. SUMMARY AND CONCLUSIONS

In this study, a huge amount of pedestrian data for different facilities were collected. Empirical studies was conducted on the collected data. Modelling was done to explain some parameters. Models were validated with the collected data. Major highlights of this thesis include

- A huge collection of pedestrian data of Indian railway stations.
- Assessment of Level of Service of these facilities.
- Development of model.

Major conclusions are included below

- Speed of pedestrians is different for different facilities.
- Diagonal change in direction of pedestrians observed when encountered with an obstacle.
- Speed of male pedestrians is greater than female pedestrians.
- Model can be validated with real life data.

ACKNOWLEDGEMENTS

We acknowledge the support of Science and Engineering Research Board, Department of Science and Technology, Government of India (Project Sanction No: SB/S3/CEE/008/2014).

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