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# **Gender-Based Variability in Pedestrian Flow Characteristics: An Experimental Investigation Using Fundamental Diagram Analysis**

**Ankita Sahu, Shiva Verma, Akhand Pratap Singh, Parmeshwar Sahu**

P.G. Student, Department of Civil Engineering, Shri Rawatpura Sarkar University, Raipur, India

Assistant Professor, Department of Civil Engineering, Shri Rawatpura Sarkar University, Raipur, India

Assistant Professor, Department of Civil Engineering, Shri Rawatpura Sarkar University, Raipur, India

Assistant Professor, Department of Civil Engineering, Shri Rawatpura Sarkar University, Raipur, India

**ABSTRACT:** Pedestrian movement can be studied in several ways, such as by observing people walking in real life, conducting experiments, or using controlled tests, and also by creating models that represent how people move. All these methods help build fundamental diagrams, which show how pedestrian flow changes under different conditions. One of the simplest ways to study this is by looking at how people move in a straight line within a closed space, like a narrow corridor. This helps us understand how various factors affect pedestrian movement and how we can improve spaces for better walking experiences. In this thesis, the focus is on how the mix of genders influences pedestrian behavior at different crowd levels. To explore this, the study uses fundamental diagrams and looks at how gender and mixed-gender groups impact movement. The experiment was done by having people walk in a single file along a line under controlled conditions, with five different gender mix scenarios. The results show that male pedestrians have a mean free flow speed of 1.27 meters per second, while female pedestrians have a speed of 1.24 meters per second. Women tend to be more aware of their personal space compared to men, which might be due to differences in how they organize themselves while moving. However, without using statistical analysis, we can't be sure if these differences are real. Through hypothesis testing, it was found that these differences are statistically significant, showing that gender and gender mix do have an effect on pedestrian behavior as seen in fundamental diagrams.

**KEYWORDS:** Pedestrian Dynamics; Gender Influence; Fundamental Diagram; Crowd Density; Pedestrian Flow Behaviour; Mixed-Gender Interaction; Free Flow Speed; Pedestrian Movement Analysis; Crowd Behaviour Modeling; Controlled Walking Experiment.

## **I. INTRODUCTION**

Walking is one of the most important, essential, and basic ways people move around the world. Almost everyone uses it, and it is often the first and last way people travel, connecting different parts of a place with other forms of transport. It's also good for health, cheap, and kind to the environment. According to the DEMOGRAPHIC OF INDIA from WIKIPEDIA (2014), India is the second most populous country with over 1.27 billion people, which is more than a sixth of the world's population. India is expected to become the most populous country by 2015, surpassing China. Therefore, India needs good pedestrian facilities to create better spaces for people to walk, encourage walking for various purposes, and support the physical, mental, and social needs of walkers. These facilities should keep people safe from overexertion, disturbances from others, and accidents. Because of this, research into how people walk has not received much attention in recent decades. Walking is a key part of the transportation system, and without it, movement and development would be very limited. Examples include reaching and leaving public transport, moving through city areas, shopping centers, and gathering places like movie theaters and sports stadiums, especially during celebrations.

In this thesis, an attempt is made to study the behavior of Indian pedestrians based on their gender. The movement of pedestrians can be studied through different experiments, such as single file movement, flow through open corridors, bottleneck experiments, and evacuations from a building.

1. In single file and bottleneck experiments, the effect of the space between people on walking speed can be observed.
2. In flow through open corridor experiments, changes in the density and speed of people can be studied based on different corridor shapes.
3. In evacuation experiments, the influence of goals and obstacles on how people move can be analyzed.

In this thesis, single file experiments are used to understand how the space between people affects walking speed. Knowing the impact of gender and mixed gender conditions is important for understanding the basic patterns of pedestrian movement. This helps in better understanding traffic flow phenomena, as speed, density, and volume are key indicators of traffic flow. These are simple to measure and understand. Previous studies on vehicle traffic have identified important relationships between these factors, which are useful for understanding traffic systems, managing them, and designing infrastructure. Many of these studies have looked at the link between speed and density, which was used as a starting point to study the effects of gender on pedestrian movement.

Empirical studies on pedestrian movement date back to 1937.

Even today, one of the main topics is the relationship between flow and density or speed. This is called the fundamental diagram and has been the focus of many studies from the beginning. It is used to assess models of pedestrian movement and to check if they can accurately describe how people move. In this thesis, the fundamental diagram is used to study the effects of gender and mixed gender conditions on pedestrian movement.

The relationship between the main factors of traffic flow – speed, volume, and density – is known as the fundamental relations of pedestrian traffic flow.

This relationship can be shown through curves that represent the links between speed and density, speed and flow, and flow and density. These are called fundamental diagrams and are based on observations.

The movement of pedestrians can be studied at different levels:

1. At the macroscopic level, we look at the general flow parameters of pedestrian movement.
2. At the microscopic level, we track the path of each individual walking through a space.
3. At the mesoscopic level, we look at how flow parameters change in space, both across and along the direction of movement.

In this thesis, data is gathered from experiments at both the macroscopic and mesoscopic levels to understand the relationship between speed and density, as well as the effect of gender on pedestrian movement.

These experiments help in designing pedestrian facilities, such as footpaths in city areas, shopping centers, and gathering spaces, to ensure they are safe and comfortable. By comparing basic pedestrian characteristics – speed, density, and headway – between different genders and gender mix conditions, we can identify differences that will help in designing pedestrian facilities that are suitable for the Indian context.

## **II. LITERATURE SURVEY**

Arunkumar Hankin et al. [1] studied the flow of passenger in subways including the effect of constrictions such as stairs and corners in order to assist in the design of new facilities. They introduced a non linear speed density graph. They found movement on stairs is markedly slower than in subways and stairs are therefore likely to form bottlenecks in passengers movement system operating under full load. When a subway becomes more crowded there is an unconscious slowing down due to the natural desire to avoid treading on the heels of the person in front. This results in flow reaching an effective manbeyond which increased crowding (and consequent discomfort) is compensated by reduced speed. The net effect is that for practical purpose no gain in flow is obtained.

Oeding et al. [2] conducted an experiment to understand the pedestrian behavior and characteristics under mixed traffic condition and represented the relationship of speed flow and density for different types of pedestrian i.e. shopper people going to or from work people going to a sport meeting etc.

Older et al. [3] Studied movement on pedestrian on front ways in shopping streets. A relationship was made between the speed and density of pedestrian walking on the footpath at the three different sites in shopping streets and he was

found that as expected that increasing in density reduced the speed of the fast pedestrians rather than that of the slower once and thus the range of speed available to pedestrian was reduced. He also considered the effect of the congestion and found that as the footway becomes crowded people are more likely to walk in the carriage way. He also found that the observed speed/density and flow/density relations are slightly different at these two sites. Site 1 where the footway is narrow has for the same densities speeds which are higher than site 2, where the footway is wider more efficient use is made by pedestrians of the narrow foot way than of the wider one.

A.Hoel [4] studied on pedestrians travel rates in central business distinct and found that pedestrians travel rates affected by the environmental factor such as time of the day, external influences and the temperature. He also found that the variations in rates of speed in between males and female pedestrians.

Francis Navin et al. [5] considered the pedestrians flow characteristics and they found that the two ways flow will reduce side walk capacity at higher concentration. The more orderly the walking pattern of the pedestrians the higher the flower per unit width as in the in the case of displayed matching formations. Mean speed observed on the test sections were significantly different from each other. The percentage of side works used by a traffic stream is proportional to the percentage of the stream relative to the total flow. They gave the conformation of the speed concentration relationship described by hankin and wright. With the increase in density and pedestrian traffic in opposite direction; they found decrease in flow rate and speed of pedestrian.

Fruin et al. [6] studied the basic vehicle flow relationship to pedestrians' volumes, average speed and density. A term modulus of square feet which it may stated as reciprocal of density was taken and the increase in modulus was described by taking a semi-parabolic curve. He found that pedestrian speeds tend to have less variability as increased crowd density restrict the ability to bypass slower moving pedestrians and to select a desired walking speed.

Polus et al. [7] studied pedestrian flow and level of distinct of traffic Israel using one and three regime linear speed-density regression model. They observed that the walking speeds of women are lower than men speeds. The both men and women speeds were inversely related to densities.

Tanaboriboon et al. [8] conducted a study to examine the characteristic of pedestrian in Singapore shows that the mean walking speed of Singapore was 74m/min. Singaporeans has a slower walking rate than his American counterpart. This speed is relatively slower than that of his American counterpart. However, the maximum flow rate obtained here is higher than that of the obtained in the western countries.

Mori and Tsukguchi [9] described two different methods to evaluate ordinary sidewalks in urban areas. One is an evaluation based on pedestrian behavior and the other is an evaluation based on the pedestrian opinion. The former method is recommended for all sidewalks, especially with the comparatively heavy pedestrian traffic and the later method is recommended for ones with pedestrian traffic.

Morrall et al. [10] found that flow pedestrian speeds for all groups in Asia countries are significantly lower than these observed its western counterpart. He found the differences in speeds between Asia and its western counterpart (Colombo and Calgary) may be physical and cultural (dress) differences and attraction (such as pavement hackers) located along sidewalks. He found that pedestrians planning technique for Asian countries should be based on the local pedestrian characteristics' rather than on pedestrian characteristics fro cities with dissimilar culture.

Tanaboriboon et al. [11] stated that walking rates on the pedestrian facilities in Bangkok were determined and compared with those of western standards as well as with findings obtain in other Asian countries. The findings of the study confirmed that Asian pedestrian's walk slower compared with their western counterpart. So local design standards are needed for pedestrian facilities in Asian countries.

### **III. EXPERIMENTAL OBSERVATION: EXPERIMENT, DATA COLLECTION AND DATA DECODING**

Exemplar Pedestrian activity is influenced by mental, physical, social, and environmental factors. When studying pedestrian movement, important factors include age, gender, health, how people interact with each other, and the design of the space they move through. In this study, five similar types of experiments were conducted. All of them

were carried out in Raipur to examine how the space between pedestrians in the direction they are moving affects their walking speed. From these experiments, a fundamental diagram connecting pedestrian speed with the linear density of movement was created.

In this chapter, Section 3.1 describes the experiment on single-file movement.

Section 3.2 explains how information is collected and analyzed from those experiments, especially where people walk in a single line. These single-file studies aim to understand the differences in speed and density among groups of different genders. The experiments were designed to see how different goals affect movement patterns. Five different conditions of gender mix were tested in these experiments. Section 3.3 covers the process of analyzing the data gathered from the single-file experiments.

### 3.1 SINGLE-FILE MOVEMENT EXPERIMENT

Normally, single-file experiments are used to understand how the space between people walking in the direction of movement affects their speed.

In this section, experiments are introduced to develop a fundamental diagram specific to Indian pedestrians. Similar studies were previously conducted to create such diagrams for German pedestrians by Seyfried et al. (2005), Chattaraj et al. (2009), and Manoj Biswal (2014) to set up the experiments and gather information. The following subsection explains the setup of the test, data collection, and data analysis.

#### 3.1.1 Experimental Setup for Single-File Movement

The experiment is carried out in a corridor surrounded by chairs and ropes.

The size and shape of the corridor are the same as described in Chattaraj et al. (2009) for similar experiments in India and Germany. A closed corridor of the size and shape shown in Figure 3.1 was built on a clear ground and used for this experiment. The analyses were conducted in the NIT Raipur Community Hall during the day in good weather. The length of the passage,  $l_p$ , is 17.3 meters. It should be noted that while people move through the corridor, data is collected only in the shaded area, called the observation section, as shown in Figure 3.1. The length of the observation section,  $l_o$ , is 2 meters. This section is formed by placing two marker poles at the start and end lines of the observation area. The camera was positioned 10 meters away from the observation area along the perpendicular bisector to reduce parallax error. The width of the path in the straight area is 0.8 meters, which is suitable for single-file walking but not for overtaking. In the curved section, the width is increased to a maximum of 1.2 meters using an elliptical curve. This is done because a width of 0.8 meters in a curved area could slow down pedestrians, which is not desired. The experiments were conducted on a clear ground. The participants were NIT Raipur students. They were told not to overtake or push others. To collect data at different densities, seven sets of experiments with varying numbers of participants  $N = 1, 6, 12, 18, 24, 30, 36$  were performed.

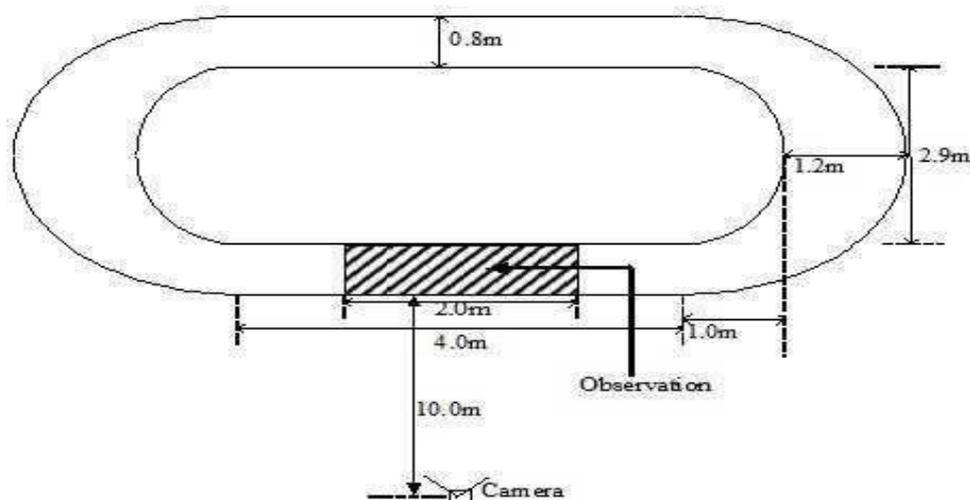


Figure 3.1: Sketch of the experimental setup for single file movement adapted from Chattaraj, Seyfried, and Chakroborty, 2009 [1]

For this experiment (excluding  $N = 1$ ), all participants in each trial were initially distributed evenly in the corridor in a steady line.

Then, each participant was given the direction to walk around the corridor three times. After that, an opening was created in the closed corridor through which participants could exit and continue walking a sufficient distance away from the corridor to avoid any backflow effect. The participants were male and female graduate students from NIT Raipur. The movement direction followed the standard Indian design, moving anticlockwise. To show different gender compositions, the experiments were conducted in five categories:

1. All boys.
2. Two boys and one girl alternately.
3. One boy and one girl alternately.
4. One boy and two girls alternately.
5. All girls.

Figures show snapshots from the experiments: 3.3, 3.4, 3.5, 3.6, and 3.7.

The experimental setup used in this study was adapted from Chattaraj, Seyfried, and Chakroborty (2009) and Chattaraj, U., Seyfried, A., Chakroborty, P., Biswal, M.K. (2013). All shapes and sizes of the experimental setup, including the length and width of the corridor, the position and measurements of the observation area, the direction of movement of the participants, and the method of data collection, are the same as in these previous studies. The direction of movement is the same, but there are differences in the composition of the participants.

#### **IV. EXPERIMENTAL RESULTS**

##### **Analysis of Empirical Data and Results**

In this section, the data is looked at and shown in a way that demonstrates how gender and mixed-gender groups affect pedestrian movement in India. The findings are split into five parts. The first and second parts show the basic connection between speed and density, and headway and speed for pedestrian movement. The third part looks at the free flow speed of pedestrians in India. The fourth part uses statistical methods like hypothesis testing. The fifth part uses an ANOVA test to show the differences between five groups of experiments.

##### **4.1 Speed-Density Relationship**

Figures 4.1, 4.2, 4.3, 4.4, and 4.5 show the relationship between speed and density for different groups. The speed-density relationship is a key part of the pedestrian fundamental diagram. The speed ( $u$ ) and density ( $k$ ) were measured in a closed corridor with five different groups of experiments:

1. All boys
2. Two boys and one girl taking turns
3. One boy and one girl taking turns
4. One boy and two girls taking turns
5. All girls

It was found that as density increases, speed decreases, and the opposite is also true.

This is clearly shown in the graphs, where the speed-density relationship is not straight but follows a curve.

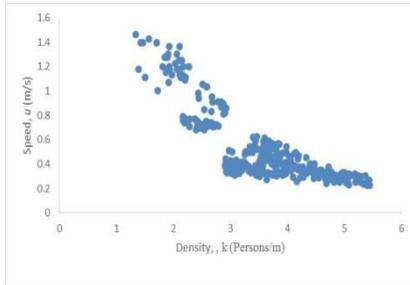
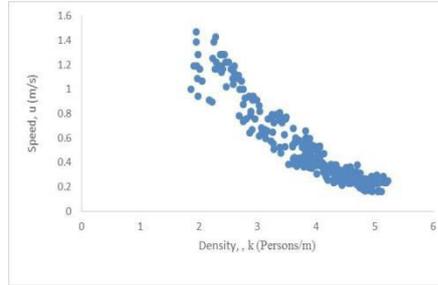
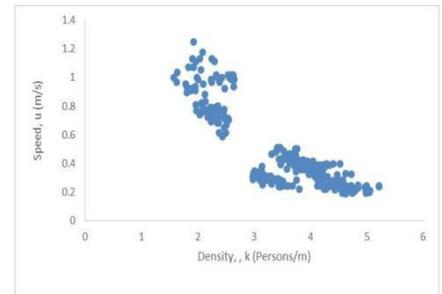


Figure 4.1: Speed-density plot for all boys



4.2: Speed-density plot for two boys and one girl alternatively



4.3: Speed-density for One boy and one girl

### 4.3 STUDY ON FREE FLOW SPEED

Free-flow speed is the speed of a pedestrian when pedestrian movement is not interfered by other pedestrian or interrupted by any other conditions. The linear headway–speed ( $h-v$ ) diagram of close corridor experiment can't give the free flow speed. However the information on free flow speed were gathered by making one and only individual move in the geometric corridor. From the above experiment it was found that the mean free flow speed of the boys is  $1.27\text{ms}^{-1}$ . Whereas the mean free flow speed of the girls are  $1.24\text{ms}^{-1}$ .

### 4.4 STATISTICAL ANALYSIS BY HYPOTHESIS TESTING

A Z-test is a statistical test for which the distribution of the test statistic under the null hypothesis can be approximated by a normal distribution. Because of the central limit theorem, many test statistics are approximately normally distributed for large samples. For each significance level, the Z-test has a single critical value which makes it more convenient than

the Student's t-test which has separate critical values for each sample size. Therefore, many statistical tests can be conveniently performed as approximate Z-tests if the sample size is large or the population variance known. Hypothesis test was done to show the statistical analysis. Hypothesis test

$$z = \frac{\bar{x}_1 - \bar{x}_2 - \Delta}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

Where,

$x$  = Standardized random variable  $\bar{x}$  = Mean of the data

$\sigma$  = Population standard deviation.

Null hypothesis:  $H_0: \mu_1 = \mu_2$

Or  $H_0: \mu_1 - \mu_2 = 0$

Alternative hypothesis:  $H_a: \mu_1 \neq \mu_2$

Statistical analysis can be done by different hypothesis test but in this experiment as the number of data points is more so, z-test is conducted between two different categories of experiment out of five different categories, to show the impacts of gender and gender mix condition. For statistical analysis by z- test, first slope and intercept of the fundamental diagram was studied. Tables 4.1, 4.2, 4.3, 4.4 shows the study of slope and intersection of fundamental diagram.

Table: 4.1 Study on intercept (a) and slope (b) of the fundamental

S. No	Data sets	Intercept (a)	Slope (b)	R2	Data points
1	All boys	0.143	0.315	0.801	339
2	Two boys and one girl	0.154	0.231	0.884	298
3	One boy and one girl	0.16	0.328	0.787	316
4	One boy and Two girl	0.16	0.240	0.81	309
5	All girls	0.107	0.361	0.729	306

Table 4.2: Z-test for intercept (a)

S. No	Data set	Z-observed	Z-critical	p-value	Result (Risk to reject null hypothesis)
1	(AB) and (2B and 1G)	1.111	1.960	0.266	Can't R.N.H (26.65%)
2	(AB) and (1B and 1G)	3.171	1.960	0.002	Reject NH (0.15%)
3	(AB) and (1B and 2G)	2.016	1.960	0.044	Reject NH (4.38%)
4	(AB) and (AG)	1.079	1.960	0.281	Can't R.N.H (28.06%)
5	(2B and 1G) and (1B and 1G)	1.813	1.960	0.070	Can't R.N.H (6.98%)
6	(2B and 1G) and (1B and 2G)	0.799	1.960	0.425	Can't R.N.H (42.41%)
7	(2B and 1G) and (AG)	0.081	1.960	0.935	Can't R.N.H (93.54%)
8	(1B and 1G) and (1B and 2G)	1.026	1.960	0.305	Can't R.N.H (30.48%)
9	(1B and 1G) and (AG)	1.995	1.960	0.046	Reject NH (4.61%)
10	(1B and 1G) and AG	0.921	1.960	0.357	Can't R.N.H (35.70%)

Here alpha is 5% (0.05) and the level of confidence is 95%. If alpha is more than p-value then the null hypothesis is rejected and the alternate hypothesis is accepted.

Table 4.3: Z-test for slope (b)

S. No	Dataset	Z-observed	Z-critical	p-value	Result (Risk to reject null hypothesis)
1	(AB) and (2B and 1G)	5.384	1.960	<0.001	Reject N.H 0.01%
2	(AB) and (1B and 1G)	2.423	1.960	0.032	Reject N.H 3.26%
3	(AB) and (1B and 2G)	4.622	1.960	<0.0001	Reject N.H 0.01%

4	(AB)and(AG)	2.113	1.960	0.005	Reject N.H	3.46%
5	(2B and 1G) and (1B and 1G)	5.861	1.960	<0.001	Reject N.H	0.01%
6	(2B and 1G) and (1B and 2G)	-0.862	1.960	0.389	can't R.N.H	38.85%
7	(2B and 1G) and(AG)	2.357	1.960	0.018	Reject N.H	1.84%
8	(1B and 1G) and (1B and 2G)	5.097	1.960	<0.001	Reject N.H	0.01%
9	(1B and 1G) and (AG)	-2.489	1.960	0.013	Reject N.H	1.28%
10	(1B and 1G) and	1.702	1.960	0.089	Can't RNH	8.88%

Table 4.4: Final Z-test results

S. No	Data sets	Slope	Result	Interce -pt	Result	Final result
1	(AB) and (2B and	Reject N.H	Gender impact exist	R.N.H	Gender impact doesn't exist	Gender impact exist
2	(AB) and (1B and1G)	Reject N.H	Gender impact exist	Reject N.H	Gender impact exist	Gender impact exist
3	(AB) and (1B and 1G)	Reject N.H	Gender impact exist	Reject N.H	Gender Impact exist	Gender impact exist
4	(AB) and (1B and 2G)	Reject N.H	Gender impact exist	Can't R.N.H	Gender Impact doesn't exist	Gender impact exist
5	(AB) and(AG)	Reject N.H	Gender impact exist	Can't R.N.H	Gender impact doesn't exist	Gender impact exist
6	(2B and 1G) and (1B and 1G)	Can't Reject N.H	Gender impact doesn't exist	Can't R.N.H	Gender impact doesn't exist	Gender Impact doesn't exist
7	(2B and 1G) and (1B and 2G)	R.N.H	Gender impact exist	Can't R.N.H	Gender impact doesn't exist	Gender impact exist
8	(2B and 1G) and (AG)	Reject N.H	Gender impact exist	Can't R.N.H	Gender impact doesn't exist	Gender impact exist

9	(1B and 1G) and (1B and 2G)	Reject N.H	Gender impact exist	Reject N.H	Gender impact exist	Gender impact exist
10	(1B and 1G) and (AG)	Can't Reject N.H	Gender impact doesn't exist	Can't R.N.H	Gender impact doesn't exist	Gender doesn't impact exist

### V. CONCLUSION

Experiments were done on how people walk in a closed space, focusing on how gender and mixed groups of males and females affect the basic patterns of pedestrian movement. The study aims to show how gender influences these movement patterns using different statistical tests. The results were checked using z-test and ANOVA. From the study, it was found that the average speed when people are moving freely is 1.27 meters per second for men and 1.24 meters per second for women. Women seem to be more aware of their personal space while walking than men. The idea of a "security distance" was used to explain this concept of personal space. The experiment shows that men are less concerned about their personal space, so they have a smaller security distance compared to women. It is clear that gender plays a role in how people move in groups, and especially in mixed groups, the presence of different genders affects the space between people walking together.

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