PEDESTRIAN FLOW BEHAVIOUR ALONG SIDEWALKS

A Thesis Submitted

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF TECHNOLOGY

IN

CIVIL ENGINEERING

[Specialization: Transportation Engineering]

by

Gandem Anil Kumar

213 CE 3079

Department of Civil Engineering

National Institute of Technology, Rourkela

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Under the guidance of

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Rourkela (India)

CERTIFICATE

This is to certify that the thesis entitled, **"Pedestrian Flow Behaviour along Sidewalks"** submitted by **Mr. Gandem Anil Kumar** in partial fulfilment of the requirements for the award of Master of Technology in Civil Engineering with "Transportation Engineering" Specialization during session 2014-2015 in the Department of Civil Engineering, National Institute of Technology, Rourkela.

It is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

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I express my special thanks to my friends for their help during the collection of data for the project. I also express my thanks to the staff members of Department of civil Engineering, NIT Rourkela for providing me the necessary facilities that is required to conduct the project and complete my thesis.

DATE: **GANDEM ANIL KUMAR**

ABSTRACT

Pedestrian walking is a major mode of transportation in Indian cities and also effective mode of transportation for short trips. In this study pedestrian sidewalk data was collected from three locations in Rourkela city in India. The obtaining three locations data was bi-directional flow unsteady data and also collect uni-directional flow data from L.A.Hall with in the NIT Rourkela campus. These data was analyzed for finding pedestrian characteristics like speed, flow and density as well as to draw the fundamental diagrams. Pedestrian fundamental diagrams and pedestrian characteristics are depends on gender of the pedestrian, age of pedestrian and type of facilities (sidewalks, wide sidewalks and prescient's). " pedestrian characteristics, fundamental diagrams for uni-directional flow as well as bi-directional flow, comparison of pedestrian fundamental diagrams between uni-directional and bi-directional flow, capacity and level of service (LOS) for above three sections" was done in this study. Hypothesis testing was conducted for compare the pedestrian speed between different sections and different combinations was done in this study.

Keywords: pedestrians, sidewalks, pedestrian characteristics (speed, flow and density), hypothesis testing, capacity and level of service.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

DESCRIPTION	SHORT FORM
Speed	u
Flow	q
Density	K
Mean of first sample	μ_1
Mean of second sample	μ_2
Null Hypothesis	H_0
Alternate Hypothesis	H_a
Level of significance	α
Length of section	l
Width of section	w
Pedestrian entry time	t_{in}
Pedestrian exit time	t_{out}
Number of pedestrian cross the section	n
Level of service	LOS
Volume to capacity ratio	V/C

CHAPTER 1

INTRODUCTION

Pedestrian walking is a mode of travel to a given destination on foot. In transportation this type of mode are effectively used for short trips. Walking is a major mode of transportation in middle and low class cities. In transportation many trips are originated and ended walking only. Developing country like India pedestrian walking is a major mode of transportation. The urban population in India was increased year by year; in 2001 the urban population was 27.81% after 10 years in 2011 this population reached to 31.16% because better facilities for pedestrians have been provided by us. One study told that Tiruchirapalli city 64.7% of the total trips are made on foot (arasan et al., 1994). Another study conducted in Mumbai they can told that all persons walk in a day irrespective of their income (Montgomery, 2006). Because better facilities have been provided for pedestrians are important criteria in urban areas. Now a day the local authorities are interested to provide good pedestrian facilities to encourage walking.

According to modal split study conducted in Mumbai in India told that out of nearly 2.85 million trips, 52.4% trips are walking trips (MMRDA 2008). African cities have more walking trips comparatively Asian and Latin-American cities. The average walking trips percentage of Africa, Asia and Latin-America cities are 57, 37and 22% respectively (Montgomery 2006).

Pedestrian movements are classified into two types they are pedestrian sidewalk and pedestrian crosswalk. In this report pedestrian sidewalk has been considered by me. The sidewalk facilities provided and improved was more important in urban areas. They

have different types of sidewalks in urban areas they are sidewalks, wide-sidewalks and precincts. In this report pedestrians capacity and level of service (LOS) will be considered. If we can consider capacity, "it means the maximum no of pedestrians passing through a point per unit of time". Level of service (LOS) is a quality measure for sidewalks in terms of speed, flow, comfort and convenience. Capacity and level of service of pedestrian sidewalk are depends on pedestrian speed, density and flow.

Pedestrian walking speed was depends on age of pedestrian, gender and type of facilities. Pedestrian walking speed is more on wide-sidewalk less on precincts. Male pedestrians walking speed is more compare to female pedestrians walking speed. Elder pedestrians speed is less compare to younger pedestrians speed.

The thesis has been divided into four chapters, in these four chapters introduction is first one. The second chapter considered past work done on pedestrian sidewalk characteristics, pedestrian dynamics, and models of pedestrian behaviour. It can be seen in literature review after this chapter. These literatures have been prepared by reading of many papers and reports of these topics.

In chapter 3, I have been describing, experimental set-up, data collection and data decoding in detailed. In this chapter experiments conducted on fundamental diagrams of pedestrian sidewalk and comparison between male and female pedestrians. And also use Z-test to compare between different sets of data collecting from three locations. Next, it concentrates how to affect fundamental diagrams on different pedestrian flows.

In chapter 4, presents the results obtained from above analysis and also have graphs obtained from above data analysis. These results are told that how to change pedestrian characteristics like flow, speed and density in different sidewalks and different conditions (age, gender and facilities). In this chapter results and conclusions have been considered by this topic.

1.1 Objectives of the study

- Understanding pedestrian speed, flow, density and their relationships (speed-flow, flow-density, speed-density relationships)
- Comparison of pedestrian characteristics with hypothesis test.
- To find the Pedestrian capacity and level of service study for providing better facilities for sidewalks.
- Comparison of fundamental diagrams between unidirectional and bidirectional pedestrian flows.

CHAPTER 2

LITERATURE REVIEW, MOTIVATION AND PROBLEM STATEMENT

In previous chapter is explained by me. Pedestrian characteristics like speed flow and densities especially important for design of any better facility related to pedestrians. Now a day's urban population growth rate was increased across the world, and more in India, pedestrian facilities was improved by conducting field survey in different places in different cities because we know the pedestrian characteristics. Crowd crushes also has been reduced by calculating future pedestrian growth rate. Pedestrian walking has been generated by many trips in developing countries like India. Pedestrian crushes will be occurred due to lake of pedestrian facilities

In this chapter pedestrian flow will be explained by past work on this pedestrian flow. After that, the interest behind this thesis work is followed by a problem statement.

2.1 LITERATURE REVIEW

The literature has been divided into 3 parts, the first one considered pedestrian characteristics; second part describes pedestrian dynamics and third part on different types of pedestrian streams.

2.1.1 Pedestrian characteristics

The pedestrian's characteristics and facilities study has very important for provided a successful pedestrian system. In before many studies have been conducted by many persons. Experiment on analyzed properties and characteristics of pedestrian flow on sidewalks will be conducted by Pouls (1983). Experiment on pedestrians of central business

district of Haifa, Israel has been conducted by him. In this paper pedestrian flow and level of service analysis has been explained by him. Increase in pedestrian density, there was a significant decrease in walking speed. Male pedestrian's speeds have more than female pedestrian's speeds. Experiment on pedestrian characteristics like speed, flow and density under mixed traffic condition have been explained by Oeding (1963), and also in 1968 he was done study on walking characteristics of Britain shoppers. Some researchers studied on comparison between different cultures and countries. Pedestrian speeds between Asian countries and Western countries have been studied by Morrall (1991), in this study speed of Asian countries pedestrians significantly lower than the western countries.

Pedestrian characteristics in Singapore have been studied by Tanaboriboon (1986). Average speed of Singapore pedestrians significantly lower than American pedestrians has been concluded by him. However, the maximum flow rate obtained here is more than western countries flow rates. Modelling of pedestrian walking speeds on sidewalks have been studied Robert Raeside (2007). Experiment in United Kingdom using slow motion video survey to collect pedestrian data to develop speed-flow-density relationships has been conducted by him. Experiment on Pedestrian's characteristics between two different cultures like India and German have been conducted by Chattaraj (2009). Density of pedestrians increases, German pedestrian speeds more influenced than Indian pedestrian speeds has been explained by him.

Design criteria for an urban sidewalk landscape considering emotional perception have been explained by Weiji Wang et al. (2009). This experiment conducted in Iksan inner city of Korea. The least sidewalk width is 1.5 m, and the least tree width is 1.5 m and the maximum widths for both are set as 6.0 m was explained by him. The results show that the sidewalk width of 3.50 m and the tree width of 3.52 m are optimal at the level of normal satisfaction. Experiments on pedestrian's perception of sidewalk facilities in Kuala

Lumpur's commercial areas have been conducted by Arshad, A. K (2012). In this study data was collected on-street questionnaires survey. In this research 50 number of pedestrians opinion was collected. In this 50 pedestrians 25 are age between 19- 49 remaining are age above 50 years old. The interviewer waits at the end of the sidewalk and aim at the selected pedestrian who walk from the beginning of the sidewalk towards the end. It is found that the elderly depends more on the facilities provided for them to travel whereas the younger pedestrian concern more on the safety.

2.1.2 Pedestrian dynamics

Methods of assessing pedestrian level of service for sidewalk have been studied by Bian Yang et al. (2007). In this research data was collected from 12 road way segment sidewalks. In this survey 725 questions are formed about level of service (LOS). After collecting data from pedestrians we can give score for each roadway segment. After giving the score give rank of LOS. Experiments on fundamental diagrams and pedestrian characteristics have been reported Hoong Chor et al. (1986), Daly et al. (1991), Daamen and Hoogendoom (2007), Ronald Jhon Galiza and Luis Ferreia (2013). These researchers studied on pedestrian speed, flow, density and their relations. Effect of gender on pedestrian speed, flow and density has been reported Pouls et al. (1983), Jaisung Choi et al (2013). Project on Modelling Pedestrian Walking Speeds on Sidewalks has been reported by Marwan Al-Azzawi (2007). In this study the researcher 38 h of data was collected in U.K. and total number of observations of 7,535 pedestrians. The procedure for abstracting the relevant data from the videos and identify pedestrian speed, flow, and densities. The concept involves marking out a rectangular box on the video monitor screen, set to approximate the dimensions of a virtual box on the ground of set breadth and length.

2.1.3 Types of pedestrian streams

Project on pedestrian crosswalk how to influence due to bidirectional pedestrian flow and its influences on the fundamental diagrams have been done by Seyfried (2012). In this study told that no significant difference in the fundamental diagrams for densities bellows 2.0 m^{-2} after that unidirectional flow have more flow and density comparatively bidirectional flow.

Project on empirical characteristics of different types of pedestrian streams have been done by Jun Zhang and Armin Seyfried (2012). In this study researcher compare fundamental diagrams of unidirectional and bidirectional flow with different studies.

2.2 MOTIVATION

Till now pedestrian sidewalk characteristics, pedestrian dynamics, pedestrian cultural differences and influence of fundamental diagrams in different pedestrian streams was studied by me. Many researchers' studies have been done on speed, density and their interrelationship. But, fundamental diagrams comparison between male and female pedestrians, capacity and level of service analysis of this sidewalk was motivated by me.

2.3 PROBLEM STATEMENT

From the literature review in this chapter till now more number of studies have been done on speed, density and their relationships. Comparison between male, female and combination of male and female pedestrian fundamental diagrams has been interested to take this concept by me. And also comparison between pedestrian fundamental diagrams for unidirectional flow and bidirectional flow has been interested. After fundamental diagrams I have found capacity and level of service for all locations. And also compare pedestrian characteristics have been done by Z-test

CHAPTER 3

METHODOLOGY

In this section trust that the principal factors that affected by pedestrian flow along sidewalks are the gender of pedestrian and direction of pedestrian flow. In this study two types of experiments are conducted. The first type of experiment has conducted the impact of gender on pedestrian characteristics like speed, flow, density and their relations along sidewalks. This study gives the fundamental diagrams between speed, flow, density and distance headway. Section 3.1 presents the experimental set-up and data collection.

In this chapter methodology for calculating pedestrian sidewalk characteristics like pedestrian speed, flow, density and their relations will be explained by me. Interest to study about this area will be more scope for further research purpose. Till now many researchers have been conducted many studies on this area but further more scope to research in this area. After choosing this study area, experiment will be conducted many places in Rourkela city. First of all select different places in Rourkela city after that choose which place have more pedestrian crowed. After found this area select a location for data collection. In this section 3.1 presents experimental set-up and data collection. Data collection will be conducted in working days only.

3.1 Experiments on impact of pedestrian gender on pedestrian characteristics

In this section, experiments conducted in Rourkela city and designed to develop fundamental diagrams for pedestrian flow along sidewalks. It may be mentioned here that similar experiments were conducted before this study to develop the fundamental diagrams for different places in India as well as different places in the world. The next subsection will be explained about experimental set-up and details on how data is collected.

3.1.1 Experimental set-up and data collection

The data collection section size and shape as shown in figure 3.1, 3.2 & 3.3 is considered on a paved sidewalks, these data will be bi-directional pedestrian flow data. Fig 3.4 shown the section is in the NIT Rourkela, this section will be collected pedestrian uni-directional flow data. After collecting those data some more places data will be collected for future work, the sections are Ambagan and sector2. Mainly the data has collected from three locations in Rourkela city, first location at daily market. The length of first section, l = 3.0 m and the width of first section w = 1.8 m. these proposed section will be used for data collection. The camera is set at a distance of 2.1 m from the inner edge of the observed section. The camera is fixed above the tripod at proper location, where is the place to cover all four corners of an observed section. The length of second section, l = 3.0 m and the width of second section w = 2.3 m. the length of third section, l = 2.5 m and the width of third section, w = 2.7 m. we select location and fix the experiment area by marking with chalk. The length of the section is 3m and width of section is same as width of sidewalk. Pedestrian speed will be vary less comparatively vehicle speed because data collection section have been taking vary small length. Width of section will be taken same as width of sidewalk. The video camera has rested on tripod, in before tripod will adjust horizontal levelling. After fixing the camera we can write-down the timing after that power on the video camera.

In this study data collection will be done with the help of digital camera (mode: HXR-NX30/NX30P, Make: Sony), Frame rate (25 frames/s) with resolution (640×480) is placed on side of the sidewalk where data collection was done. After data collection put off the video camera after that take data from this video camera.

Fig 3.1 location 1 at Daily market, Rourkela

Fig 3.2 location 2 at near Nala road, Rourkela

Fig 3.3 location3, Daily market, Rourkela

Fig 3.4 L.A.Hall, NIT Rourkela (uni-directional flow)

3.2 DATA DECODING

After completion of data collection data will be decoded by me.First calculate how many number of pedestrians cross the section after that note down pedestrian entering time and pedestrian exit time after that calculate each pedestrian speeds using bellow equation.

$$u_{\mathrm{p}} = \frac{l\mathrm{o}}{t\mathrm{in} - t\mathrm{out}}$$

Where

u_{p} = pedestrian speed, l_{o} = observation length of site, t_{in} =pedestrian entry time, t_{out} = pedestrian exit time, t_{in}-t_{out} = pedestrian crossing time.

Units of pedestrian speed = m/sec.

The above equation will be used to find all pedestrians speeds for these three locations. After calculating speeds in all three locations now calculate minute wise pedestrian flow in all three locations. Number of pedestrians cross the section in a particular time period is called pedestrian flow, now flow will be calculated minute wise in each section.

$$\text{Pedestrian flow, } q = \frac{n}{t}$$

Units of pedestrian flow = ped/sec (or) ped/min.

Flow have been calculating using the above equation. In the above equation n = no of pedestrians cross the section, t = time in minutes. The density has been calculating average number of pedestrians present in the observed section in a particular time. The section will consider length only, width will be considered one meter because pedestrian density will be calculated number of pedestrians present per length of observed section per unit of time.

$$\text{Pedestrian density, } k = \frac{n}{lo}$$

Units of pedestrian density = ped/m^2.

= ped/m for meter width.

Where n = number of pedestrians present in the section, l_o = length of observed section. The pedestrians' density has calculated another process that is using bellow equation.

$$q = u*k$$

Where q = pedestrian flow (ped/sec), u = pedestrian speed (m/sec), k = pedestrian density (ped/m). After calculating flow we can find density of sidewalk. It is the ratio of number of pedestrians present in a section per meter length is called density of that section like this we can find speed, flow and densities of all sections.

In this section next have been calculating pedestrian distance head way, this is the inverse of pedestrian density. The pedestrian distance head way or pedestrian space is known as the average space provided for each pedestrian with in the walk way section.

Distance head way $\propto$ 1/density

Units of distance headway/ pedestrian space = m^2/ped.

The pedestrians speed, flow, density and distance head way has calculated using above procedure after that using this information calculate pedestrian free flow speed; capacity, level of service of this walk way. Capacity is the maximum number of pedestrians cross the section in a unit of time after that flow will be decreased with increased density of pedestrian with in the walk way. In this study capacity has calculated using flow-density diagram, in this diagram consider peak of the curve after that take a corresponding value of flow, the corresponding flow is called the capacity of this section. These capacities will be calculated in different time intervals in the same section, number of capacity time intervals will increase accurate capacity will be got after that average the all capacities, at that time we got capacity of the entire section in the total time period.

Pedestrian level of service (LOS)have been calculating using the some pedestrian characteristics like pedestrian space, speed of pedestrian and volume to capacity ratio(V/C).

These pedestrian characteristics will be used to classify LOS of each section in various aspects like speed/average space/ (V/C).

In this section another test has conducted on pedestrian speeds (male/female/combination of male & female) in all three locations for compression of male & female speeds. The test is used in this study is called Z-test, also called as hypothesis testing. In this study two tailed Z-test will be used to compare the pedestrian speeds of different combinations. f1&f2; f2&f3; f3&f1; location1&location2; location2&location3; location3&location1; total male (all three locations M) &total female (F); m1&f1; m2&f2; m3&f3; m1&m2; m2&m3; m3&m1 these are the combinations will be checked to use Z- test.

The Z-test is a method in which we select samples to learn more about characteristics in a given population is called “hypothesis testing”. Hypothesis testing is really a systematic way to test claims or ideas about a group or population.

Four steps to hypothesis testing:

1. **State the hypothesis:** total pedestrians at any locations mean (μ_1) is equal to some sample mean (μ_2) at that same location ($\mu_1=\mu_2$) we can use null hypothesis (H_0), if null hypothesis is wrong at that time we can use alternative hypothesis (H_a/H_1). Alternative hypothesis (H_1) will come in these three cases there is $\mu_1\neq\mu_2$; $\mu_1>\mu_2$; $\mu_1<\mu_2$.
2. **Set the criteria for decision:** to state criteria for decision, we state the "level of significance" for a test. Probability of obtaining a statistic measured in a sample if the value stated in the null hypothesis were true. The criteria or level of significance is typically set at 5%. When the probability of obtaining a sample mean is less than 5% if the null hypothesis were true.
3. **Compute the test statistic:** test statistic is mathematical formulae it is using when the null hypothesis was true.
4. **Make a decision:** we can use the test statistic to make a decision about the null hypothesis. This is depending on probability of obtaining sample mean (%).

   Null hypothesis is true – probability of obtaining sample mean (<5%).

In this thesis hypothesis will be used for finding pedestrian speed comparison between different locations and same location also. In this study two tailed Z-test will be used.

3.3 Experiments on impact of pedestrian flow direction on pedestrian characteristics

This is the second experiment was conducted in this study; the study was how pedestrian characteristics will be changed in uni-directional and bi-directional pedestrian flow. In this

study first of all bi-directional flow data was already collected from three locations, two locations at daily market and one location at nala road in Rourkela city. Uni-directional flow data will be collected from NIT Rourkela campus. The data collection was done in the above places, bi-directional flow means pedestrian flow will be occurred left to right and right to left in two directions but in uni-directional flow, pedestrian flow will be occurred left to right/right to left. In bi-directional flow pedestrian flow will be in two directions because pedestrian interruption will be more comparatively uni-directional flow. In bi-directional flow pedestrian required sufficient place for to give the place who entering the opposite side in the same section. Pedestrian required more place in bi-directional flow comparatively uni-directional flow.

In this study after completed data collection have found pedestrian speed, flow, density and their relationships. After completion of pedestrian characteristics have been drawing fundamental diagrams between uni-directional flow and bi-directional flow, after that to find capacities of uni-directional flow as well as bidirectional flow. using the above data have found pedestrian distance head way after that draw the fundamental diagram between distance head way to speed, using this fundamental diagram have been calculated slope and intercept of these line.

CHAPTER 4

RESULT AND DISCUSSIONS

The results of this thesis have been dividing into four parts. In this first part results on free flow speed will be presented. In this second part the results on the fundamental relations of pedestrians will be presented. In the third part pedestrian capacity and level of service (LOS) will be presented. In the fourth part influence of pedestrian flow (uni-directional flow and bi-directional flow) on fundamental relations of pedestrian flow will be presented.

4.1 study on free flow speed

In this thesis pedestrian free flow speed will be calculated in different locations in Rourkela city. The free flow speeds will be

- mean speed of total pedestrians at **location 1 (daily market)** is 1.17m/s, mean speed of male pedestrians at location 1 is 1.24m/s and mean speed of female pedestrians is 1.09m/s.
- mean speed of total pedestrians at **location 2 (daily market)** is 1.24m/s, mean speed of male pedestrians at this location is 1.34m/s and mean speed of female pedestrians at this location is 1.14m/s.

The above two locations are in the same area but mean speeds of first location have very low comparatively second location. In the first location they have some obstruction are present because pedestrian speeds will be less. In the second section they have no obstruction because pedestrian speeds will be more.

- Mean speed of total pedestrians at **nala road** is 1.30m/s, mean speed of male pedestrians at this section is 1.40m/s; mean speed of female pedestrians at this location is 1.21m/s.
- Mean speed of total pedestrians at **Ambagan market** is 1.24m/s, mean speed of male pedestrians at this section is 1.27m/s, mean speed of female pedestrians at this location is 1.20m/s.
- Mean speed of total pedestrians at **near sector 2 circle** is 1.22m/s, mean speed of male pedestrians at this section is 1.26m/s; mean speed of female pedestrians at this location is 1.17m/s.

Pedestrian speed will be more in nala road after that daily market. In Rourkela maximum mean speed of total pedestrians is 1.30m/s minimum mean speed of total pedestrians is 1.17m/s. maximum mean speed of male pedestrian is 1.40m/s at nala road.

4.1.1 Study on comparison of pedestrian speeds by hypothesis testing

Hypothesis test was conducted to show the pedestrian speed comparisons between different combinations in above three locations in Rourkela. In this study first hypothesis test was done to illustrate the pedestrian speed difference between male and female in above all three sections. The combinations was male and female pedestrians at section1 (m1&f1), same as section2 and section3 (m2&f2; m3&f3), male pedestrian speeds between different sections (m1&m2; m2&m3; m3&m1), female pedestrian speeds between different sections (f1&f2; f2&f3; f3&f1), total male speeds in all three locations and total female speeds in all three locations (M&F), all pedestrian speeds between these three locations (section1&section2; section2&section3; section3&section1). In this study speed will be compared in above all combinations in the three sections. The results will be found after hypothesis testing is

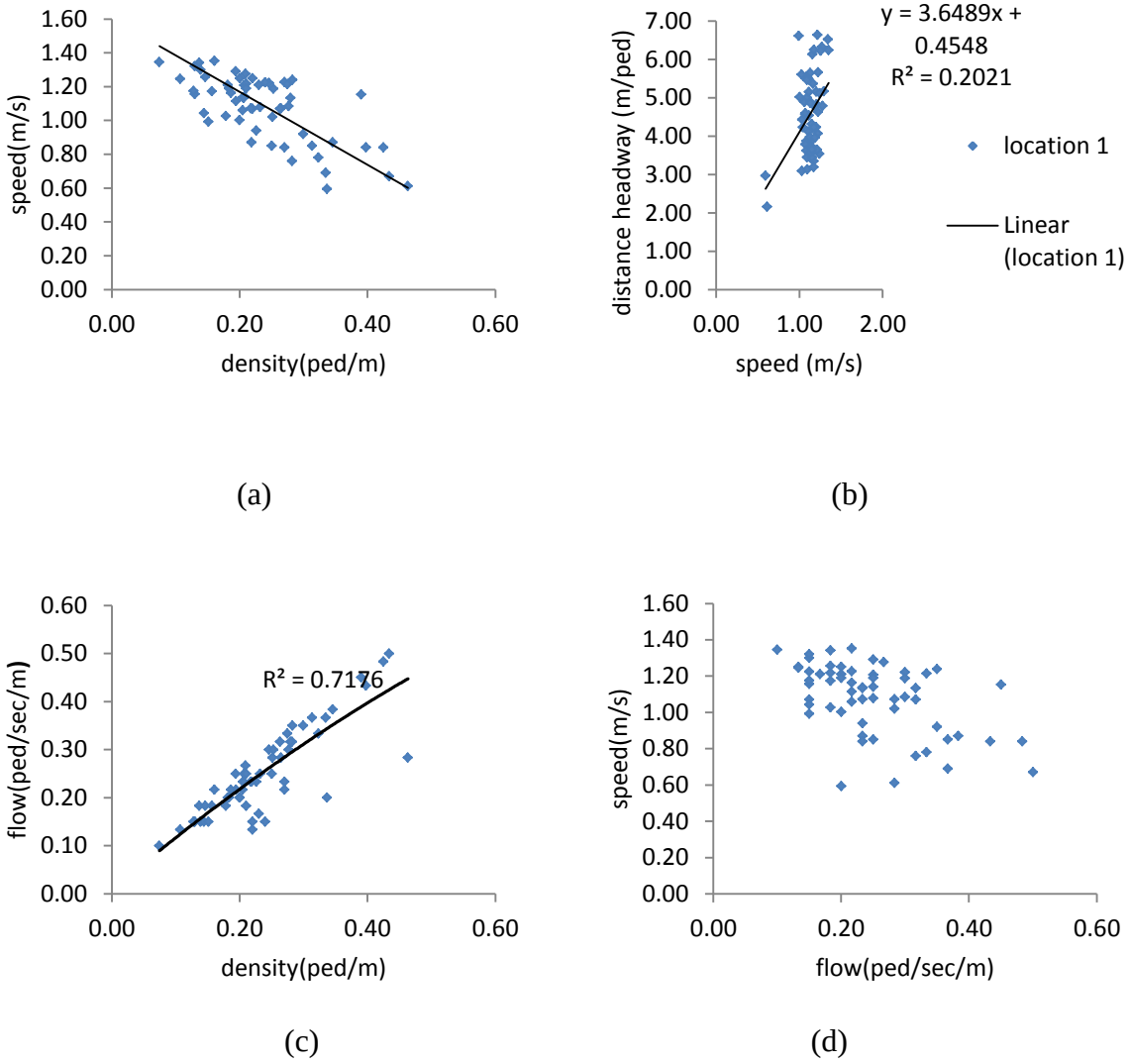
present in bellow tabular form. In the results m2&m3 combination was got $Z_{observed}$ value is less than $Z_{critical}$ value because cannot reject the null hypothesis H_0.

Z-test results for all combinations in above all three locations

combination	z(Observed value)	|z| (Critical value)	p-value(Two-tailed)	alpha
f1&f2	-2.128	1.96	0.033	0.05
f1&f3	-9.015	1.96	<0.0001	0.05
f2&f3	-3.89	1.96	0	0.05
m1&m2	-3.519	1.96	0	0.05
m1&m3	-7.104	1.96	<0.0001	0.05
m2&m3	-0.95	1.96	0.342	0.05
m1&f1	10.882	1.96	<0.0001	0.05
m2&f2	5.237	1.96	<0.0001	0.05
m3&f3	4.499	1.96	<0.0001	0.05
T1&T2	-3.329	1.96	0.001	0.05
T2&T3	-3.341	1.96	0.001	0.05
T1&T3	-10.431	1.96	<0.0001	0.05
M&F	11.622	1.96	<0.0001	0.05

4.2 Study on fundamental relations

The speed(u)-density(k), flow(q)-density(k), speed(u)-flow(q) curves will be plotted data obtaining from above three locations (fig 3.1, fig 3.2, fig 3.3).



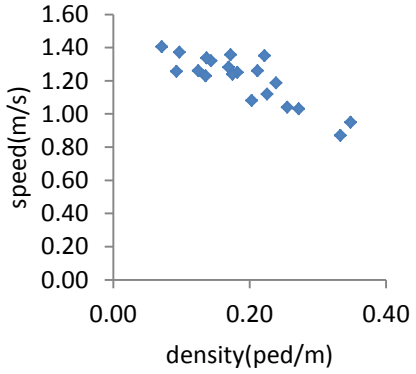
(a) (b)

(c) (d)

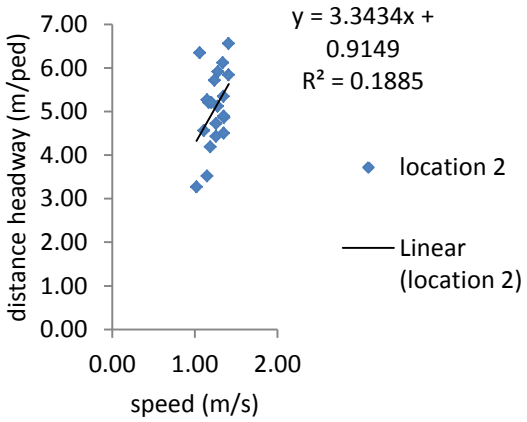
Figure 4.1: (a) speed-density (u-k) (b) speed-distance headway (u-h) (c) flow-density (q-k) (d) speed-flow (u-q) these fundamental diagrams are drawn data obtaining from location 1 at daily market in Rourkela.

As a flow versus density data, this plot is shown in figure 4.1 (c), a visual inspection of the flow versus density curve to give capacity of this section. In the diagram where curve reaches the peak point after reach the peak point curve will be fall down, that is the point give

capacity for this location 1. Using the above speed verses distance headway diagram we can calculate slope and intercept, the value of slope is 3.6489 and intercept is 0.4548m. The relationship of the form h = a+b*u is fitted to the data. The value of a and b obtained are 0.4548m and 3.6489, a represents the minimum personal space and b denotes the sensitivity of h to u. From the above fundamental diagram speed versus density curve represents density of pedestrian flow increase at the same time pedestrian speed will decrease, at which place pedestrian speed will be zero at that place density will be jam density (k_{jam}). In the same time where the density will minimum, at that place speed will maximum.



(a)



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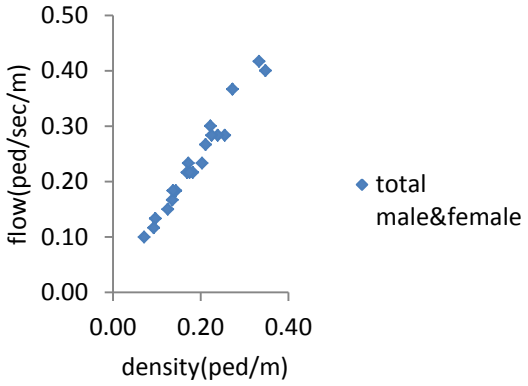
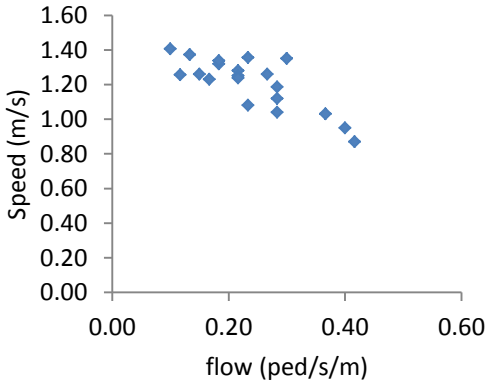


(c)



(d)

Figure 4.2: (a) speed-density (u-k), (b) speed-distance headway (u-1/k), (c) flow-density (q-k) and (d) speed-flow (u-q) curves data are obtaining from location 2 at daily market in Rourkela city.

From above flow versus density data as shown in figure 4.2 (c) have used to find capacity of the section. These capacity will be using in the construction of better pedestrian facility in Rourkela city. Speed versus distance headway data plot is shown in figure 4.2 (b). The plot has shown it is more suitable for description through a linear relationship. Relationship of the form h = a+b*u is fitted to the data. The value of a, b obtained are 3.3434m and 0.9149s.

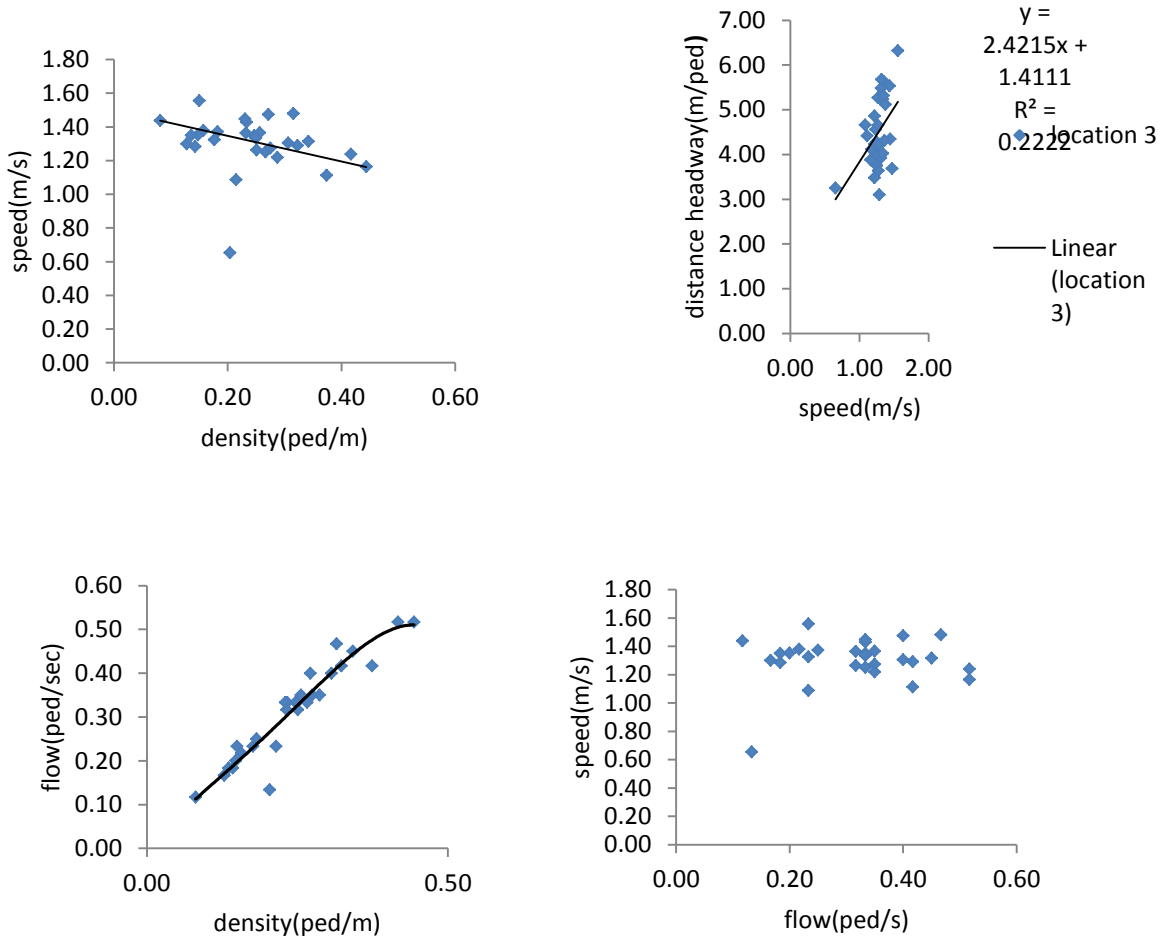


Figure 4.3: (a) speed-density (u-k), (b) speed-distance headway (u-1/k), (c) flow-density (q-k) and (d) speed-flow (u-q) curves data are obtaining from location 2 at daily market in Rourkela city.

From above flow versus density data as shown in figure 4.3 (c) have used to find capacity of the section. These capacity will be using in the construction of better pedestrian facility in Rourkela city. Speed versus distance headway data plot is shown in figure 4.3 (b). The plot has shown it is more suitable for description through a linear relationship. Relationship of the form h = a+b*u is fitted to the data. The value of a, b obtained are 2.4215m and 1.4111s.

The above all fundamental diagrams are representing to pedestrian characteristics in section 1, 2 and 3. Pedestrian speed has more at section 3 and speed has less at section 1, these points are concluded with using speed verses distance headway diagrams in above all three sections. From speed verses distance headway diagram intercept at section 1 is 3.6489m, at section 2 is 3.3434m and at section 3 is 1.4111m because intercept has been increased at that time pedestrian flow will be increased at that time pedestrian speed will be increased.

The bellow table was shown pedestrian characteristics (speed, flow and density), slope and intercept in above three sections.

Table 4.2 slopes and intercepts for three locations

location	Avg.speed (m/s)	Max.flow/capacity (ped/min)	Density (ped/m)	Slope	Intercept
1	1.17	24	0.42	3.6489	0.4548
2	1.24	26	0.36	3.34343	0.9149
3	1.30	30	0.44	2.4215	1.4111

4.3 Study on Capacity and Level of Service (LOS)

Pedestrian capacity and level of service have been explained by using above fundamental diagram. From the flow verses density diagram have been used to find capacity of pedestrian flow in these three locations represented above.

- Capacity of pedestrians at location 1 is **24ped/min**. maximum density at location 1 is 0.42ped/m.
- Capacity of pedestrians at location 2 is **26ped/min**. maximum density at location 2 is 0.36ped/m.
- Capacity of pedestrians at location is **30ped/min**. maximum density at location 3 is 0.44ped/m.

From above three locations capacity will be more in the third section and capacity will be less in the first section. After calculating capacity level of service is a main criterion for design of better facility, because have been calculating level of service in different aspects. Level of service have been calculating in terms of volume to capacity ratio (V/C), average space provide for each pedestrian and speed. V/C ratio has been calculating minute wise after that average the all data obtaining from each section.

4.3(a) Pedestrian level of service (LOS) score as for the HCM 2010

LOS	Average space(ft^2/ped)	Flow q (ped/min/ft)	Speed(ft/s)	V/C ratio
A	>60	≤5	>4.25	≤0.21
B	>40-60	>5-7	>4.17-4.25	>0.21-0.31
C	>24-40	>7-10	>4-4.17	>0.31-0.44
D	>15-24	>10-15	>3.75-4	>0.44-0.65
E	>8-15	>15-23	>2.5-3.75	>0.65-1.00
F	≤8	variable	≤2.5	variable

4.3(b) the level of service (LOS) as for the V/C ratio will be

section	Sample size	V/C	LOS
1	1010	0.62	D
2	285	0.55	D
3	565	0.63	D

4.3(c) Level of service (LOS) as for the average space

Section	Sample size	Average space (ft^2/ped)	LOS
1	1010	24.97	C
2	285	30	C
3	565	24.42	C

4.3(d) Level of service (LOS) as for the average speed of pedestrian

Section	Sample size	Average speed (ft/s)	LOS
1	1010	3.71	D
2	285	4.13	C
3	565	4.3	B

4.4 Study on Pedestrian Uni-Directional and Bi-Directional Flow

In this study how pedestrian fundamental diagram was influenced due to pedestrian uni-directional and bi-directional flow has been explained. In this study collect two different types of data sets, first data set have been taken above three locations data (bi-directional) next second data set have been taken L. A. Hall (NIT-Rourkela) data (uni-directional). After collecting data calculate pedestrian characteristics like speed, flow, and density after that fundamental diagrams also calculated individually for two types of data sets, after that these two fundamental diagrams are drawn in one sheet. In this study uni-directional flow has more capacity and pedestrian characteristics (speed, flow and density) comparatively bi-directional flow.

4.4.1 Comparison of pedestrian fundamental diagram between uni-directional and bi-directional flow at daily market (section 1).

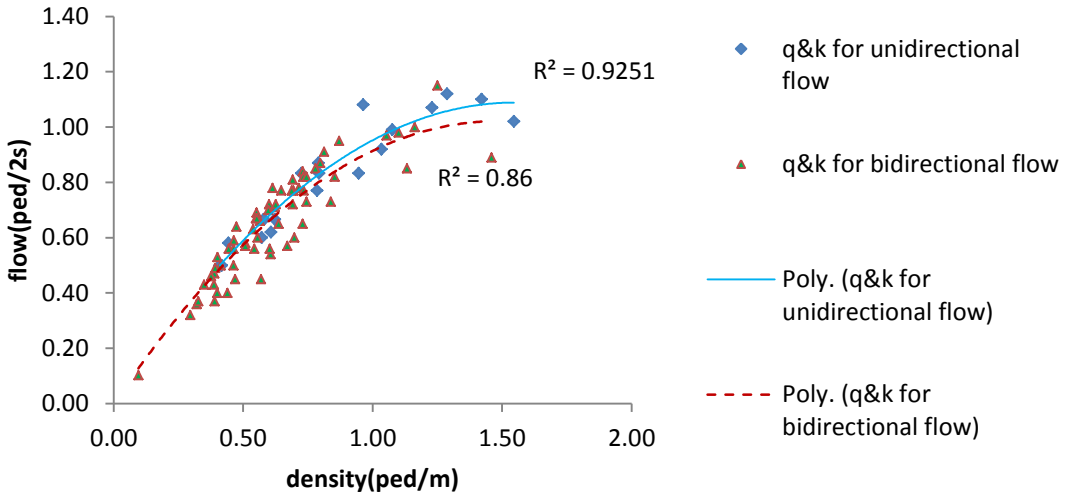


Fig 4.4.1 (a) flow versus density curve

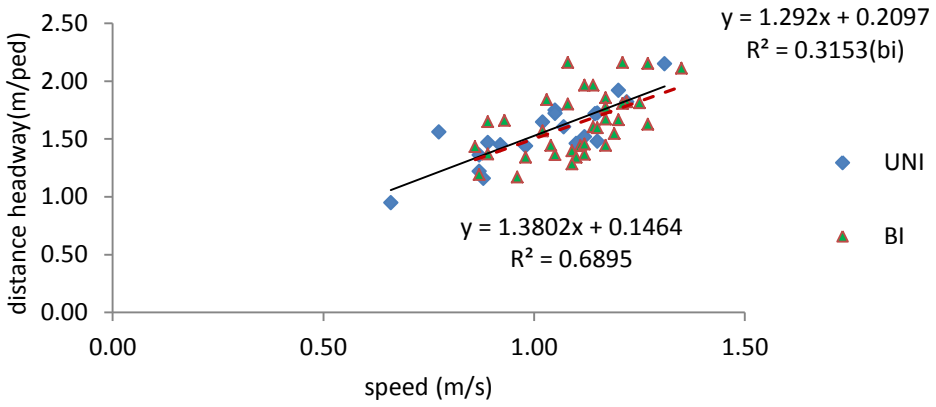


Fig 4.4.1 (b) distance headway versus speed diagram

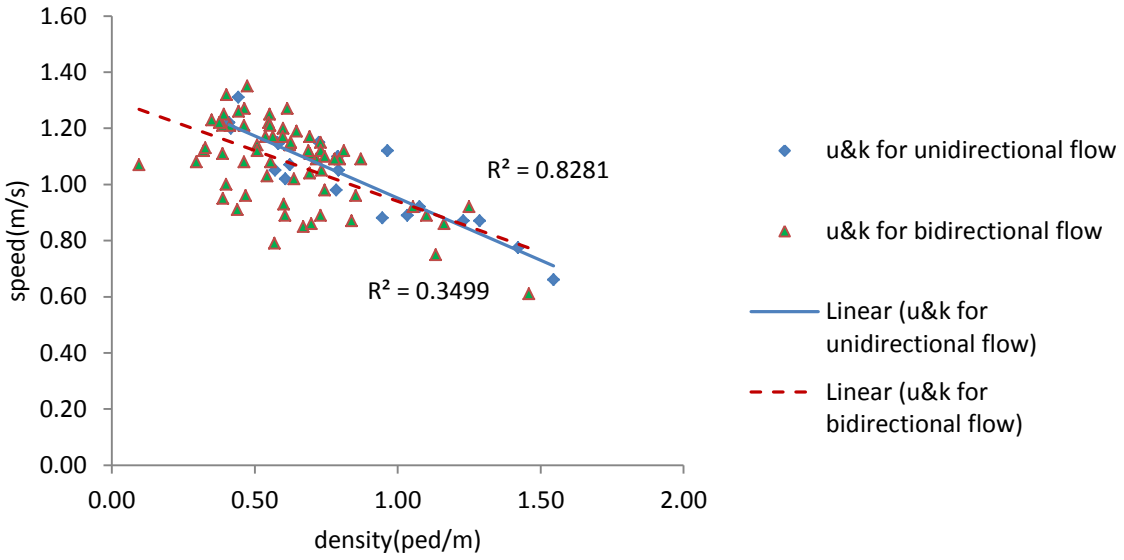


Fig 4.4.1 (c) speed versus density diagram

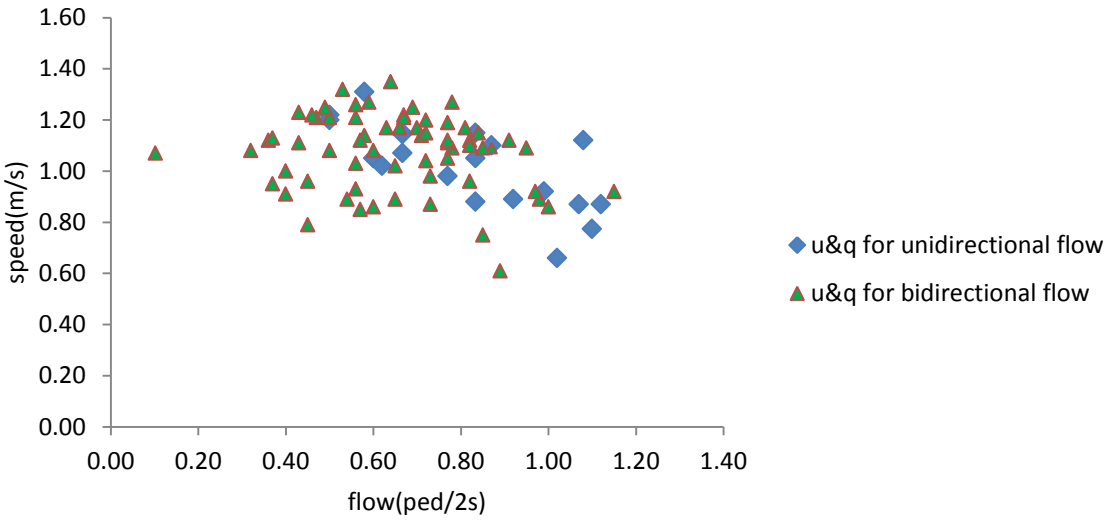


Fig 4.4.1 (d) speed versus flow diagram

Figure 4.4.1 flow-density (q-k); speed-distance headway (u-1/k); speed-density (u-k); speed-flow (u-q) curves data are obtaining from daily market and L. A. Hall (NIT Rourkela) at Rourkela.

The above figures data are obtained from pedestrian uni-directional flow and pedestrian bi-directional flow in Rourkela city. The above all diagrams have been explained pedestrian speed, flow and density values are more in uni-directional flow comparatively bi-directional flow. Pedestrian flow versus density curve have been explained, initially uni-directional and bi-directional flow curves will be coincide, after that uni-directional flow will be more comparatively bi-directional flow. Pedestrian speed versus density curve also represents uni-directional flow line will be present above the bi-directional flow line, in this figure at any specific density values speed of pedestrians in uni-directional flow will be more comparatively speed of pedestrians in bi-directional flow. Figure 4.4.1 (b) speed versus distance headway diagram represents intercept of bi-directional flow will be 0.2097 and intercept of uni-directional flow will be 0.1464.

4.4.2 Comparison of pedestrian fundamental diagram between uni-directional and bi-directional flow at daily market (section 2).

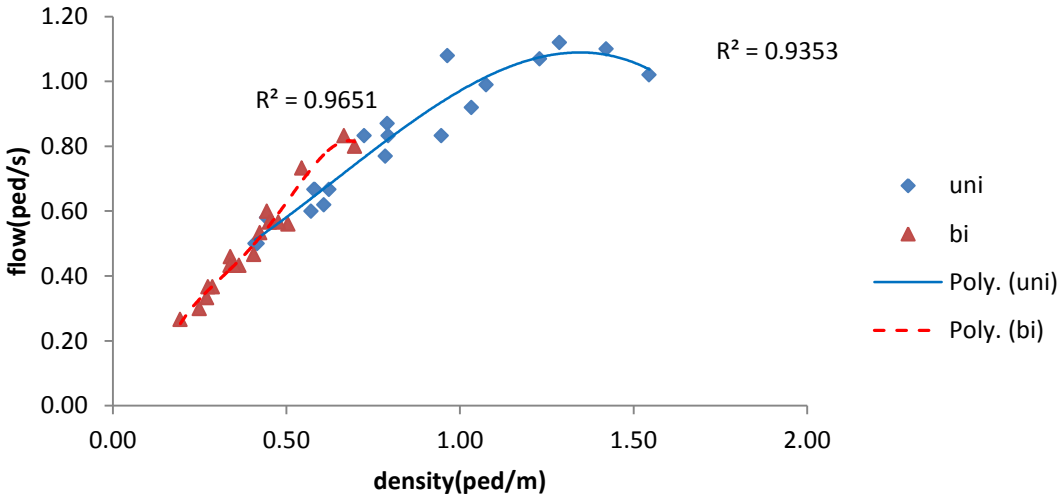


Fig 4.4.2 (a) flow versus density curve

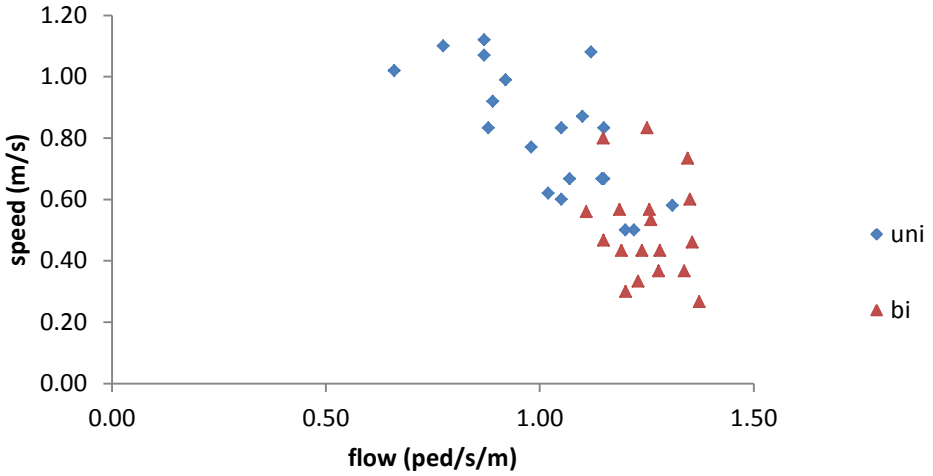


Fig 4.4.2 (b) speed versus flow curve

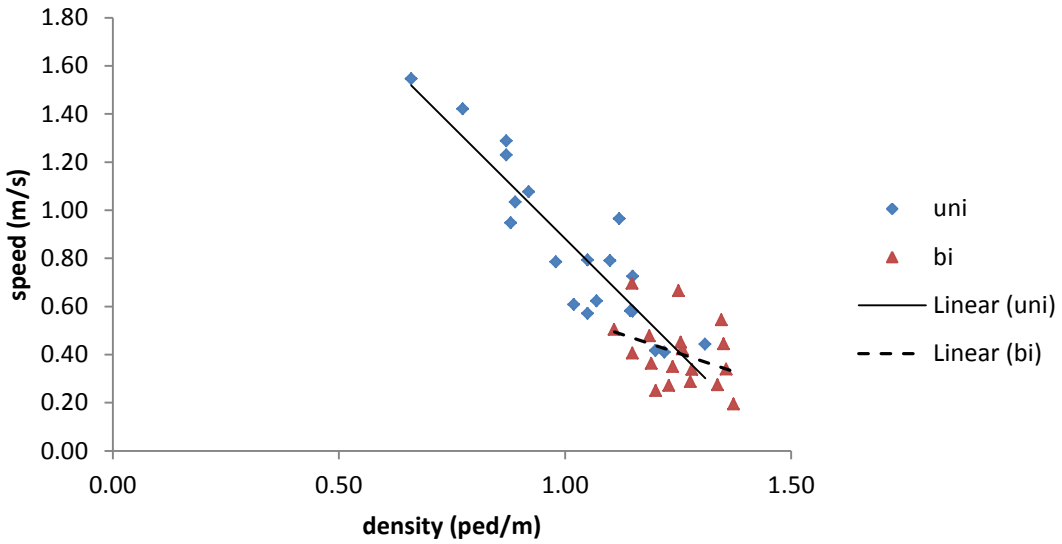


Fig 4.4.2 (c) speed versus density curve

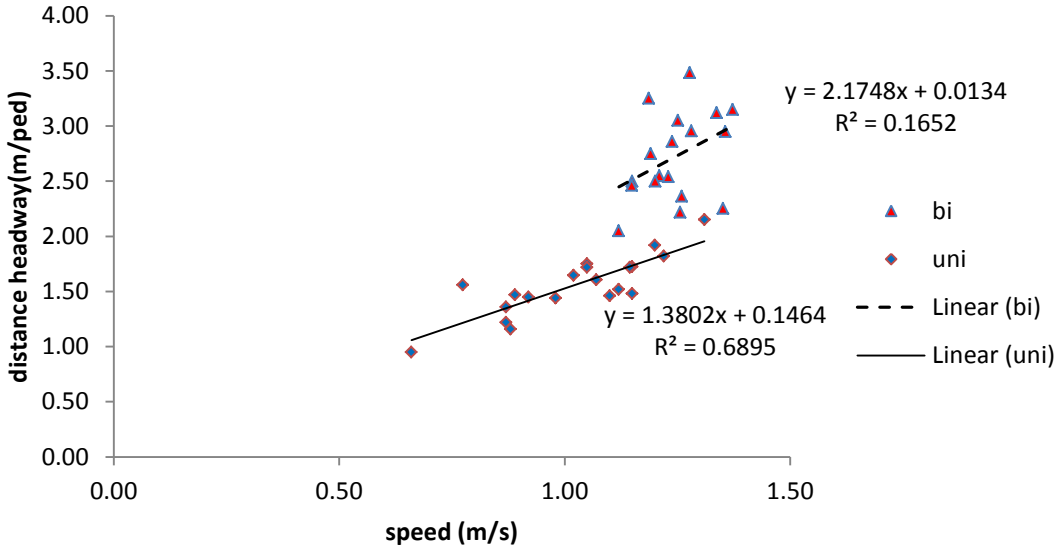


Fig 4.4.2 (d) distance headway versus speed

Figure 4.5 flow-density (q-k); speed-flow (u-q); speed-density (u-k); speed-distance headway (u-1/k) curves data are obtaining from daily market and L. A. Hall (NIT Rourkela) at Rourkela.

The above figures data are obtained from pedestrian uni-directional flow and pedestrian bi-directional flow in Rourkela city. The above all diagrams have been explained pedestrian speed, flow and density values are more in uni-directional flow comparatively bi-directional flow. Pedestrian flow versus density curve have been explained, initially uni-directional and bi-directional flow curves will be coincide, after that uni-directional flow will be more comparatively bi-directional flow. Pedestrian speed versus density curve also represents uni-directional flow line will be present above the bi-directional flow line, in this figure at any specific density values speed of pedestrians in uni-directional flow will be more comparatively speed of pedestrians in bi-directional flow. Figure 4.4.2 (d) speed versus distance headway diagram represents intercept of bi-directional flow will be 0.0134 and intercept of uni-directional flow will be 0.1464. Slope of bi-directional flow will be 2.1748 and slope of uni-directional flow will be 1.3802.

4.4.3 Comparison of pedestrian fundamental diagram between uni-directional and bi-directional flow at nala road (section 3).

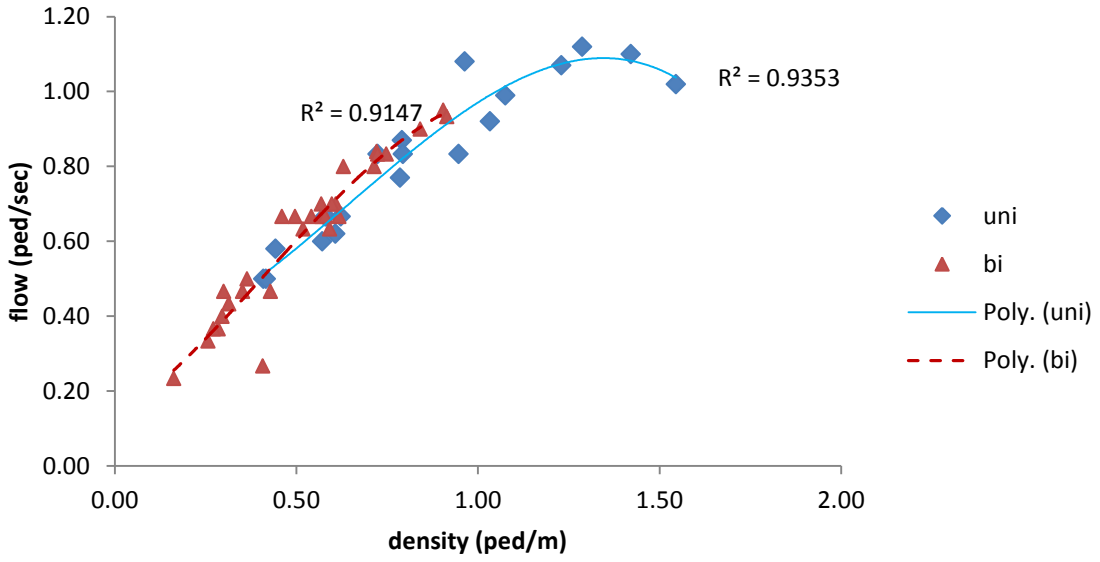


Fig 4.4.3 (a) flow versus density

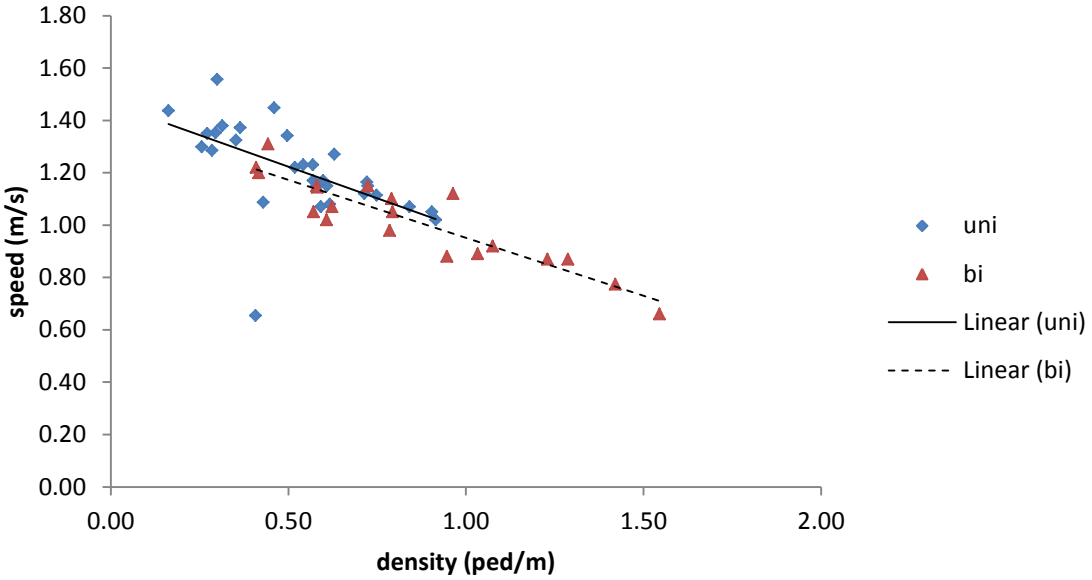


Fig 4.4.3 (b) speed versus density

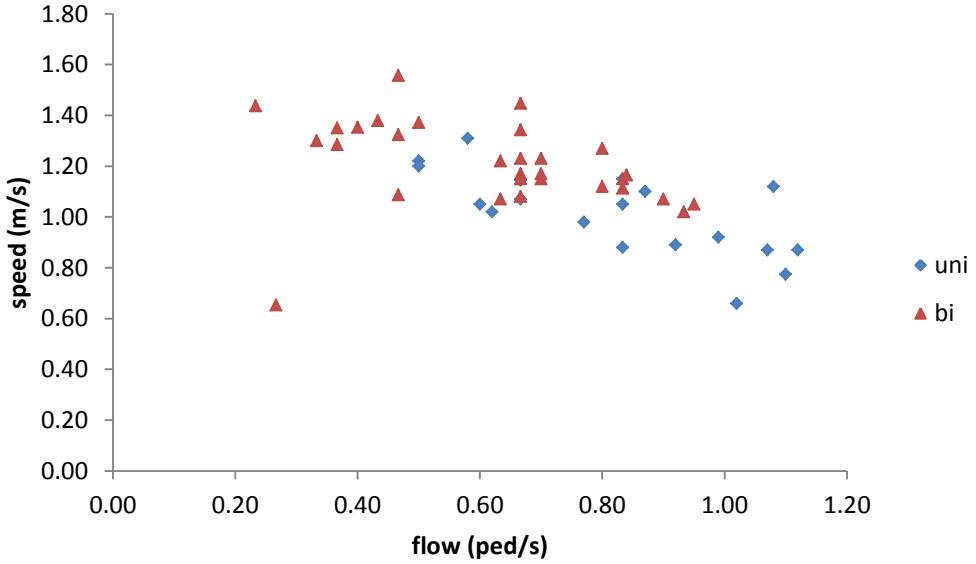


Fig 4.4.3 (c) speed versus flow

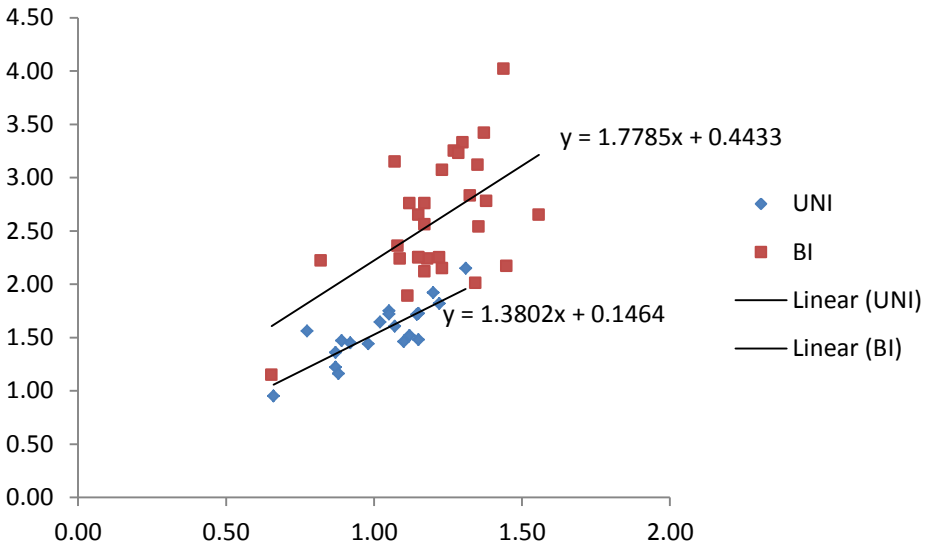


Fig 4.4.3 (d) distance headway versus speed

Figure 4.6 flow-density (q-k); speed-density (u-k); speed-flow (u-q); speed-distance headway (u-1/k) curves data are obtaining from nala road and L. A. Hall (NIT Rourkela) at Rourkela.

The above figures data are obtained from pedestrian uni-directional flow and pedestrian bi-directional flow in Rourkela city. The above all diagrams have been explained pedestrian speed, flow and density values are more in uni-directional flow comparatively bi-directional flow. Pedestrian flow versus density curve have been explained, initially uni-directional and bi-directional flow curves will be coincide, after that uni-directional flow will be more comparatively bi-directional flow. Pedestrian speed versus density curve also represents uni-directional flow line will be present above the bi-directional flow line, in this figure at any specific density values speed of pedestrians in uni-directional flow will be more comparatively speed of pedestrians in bi-directional flow. Figure 4.4.3 (d) speed versus distance headway diagram represents intercept of bi-directional flow will be 0.0894 and intercept of uni-directional flow will be 0.1464. Slope of bi-directional flow will be 2.1086 and slope of uni-directional flow will be 1.3802.

The above three sets of graphs represents the comparison of pedestrian fundamental diagrams between uni-directional flow and bi-directional flow. Flow verses density diagrams in above all sets will be look like in the same pattern, the pattern will be initially both uni-directional and bi-directional flow curves coincides up to some portion after that uni-directional curve present above the bidirectional curve.

The above comparisons of uni-directional and bi-directional pedestrian flow fundamental diagrams will be classified in to three sets, in the first set fundamental diagram was drawn data obtaining from L.A.Hall (NIT Rourkela) versus location1 data obtaining from daily market in Rourkela. Second set fundamental diagrams was drawn data obtaining from L.A.Hall verses location2 data obtaining from daily market in Rourkela similarly third set was obtaining from L.A.Hall data verses nala road data in Rourkela.

Bellow table was shown slope and intercept of uni-directional and bi-directional pedestrian flow obtaining from above three sets (fig 4.4; 4.5; 4.6) of pedestrian fundamental diagrams.

Table 4.4 slopes and intercepts for uni-directional and bi-directional flow

Fundamental diagram sets	Uni-directional flow			Bi-directional flow		
	slope	intercept	speed	slope	intercept	speed
1	1.3802	0.1464	1.02	1.292	0.2097	1.07
2	1.3802	0.1464	1.02	2.1748	0.0134	1.25
3	1.3802	0.1464	1.02	1.7785	0.4433	1.21

CHAPTER-5

SUMMARY, CONCLUSIONS AND FUTURE SCOPE

5.1 SUMMARY

In this thesis, four experiments was conducted on pedestrian sidewalks in three places there is daily market, nala road and NIT campus in Rourkela to shown the pedestrian flow behaviour along sidewalks and also pedestrian characteristics variation in terms of gender and different facility. Hypothesis test also conducted for calculating comparison of pedestrian speeds of different combinations. In this study we have calculated comparison of pedestrian fundamental diagrams between uni-directional flow and bi-directional flow. In the study experimental set-up will be select the section after that put a tripod perpendicular direction to the section with some distance from edge of the section, after that video camera will be placed above the tripod, next will take video of sometime interval. This video will be decoded after that calculates fundamental relations and hypothesis test also conducted for comparison of pedestrian speeds.

5.2 CONCLUSIONS

In this study experiments conducted on pedestrian flow behaviour along the sidewalks in different places in Rourkela city and also experiment conducted on pedestrian characteristics variations in pedestrian uni-directional flow and pedestrian bi-directional flow. From this study results male pedestrian speeds are more, comparatively female pedestrian speeds in above all three sections. In this study pedestrian average speed are more in nala road (section 3) less in daily market (section1). Nala road has more pedestrian sidewalk width comparatively remaining sections and also sidewalk surface will be even because pedestrian

sidewalk will be more in nala road. Hypothesis test will be conducted in different combination of pedestrians in different sections, male pedestrian speeds at section2 and section3 will be similar because Z-observed value is in between Z-critical value, this combination will be significant. In this study pedestrian uni-directional flow will be get maximum flow (capacity) comparatively pedestrian bi-directional flow. Pedestrian flow versus density graph initially these two (uni and bi-directional flow) lines will be coincides after that uni-directional flow line has above the bi-directional flow line.

5.3 FUTURE SCOPE

In this study, it was observed that fundamental diagrams between male and female pedestrians in different sections in Rourkela city and also found that fundamental diagrams between unidirectional and bi-directional pedestrian flow. In this study hypothesis test will be conducted for calculating pedestrian speed variations in different locations in different combinations. Hypothesis test will be conducted 13 number of combinations, in these all combinations except one combination (m2&m3) remaining all combinations pedestrian speeds will be significantly different.

In this study give some values about pedestrian characteristics of Rourkela city, this values will give capacity and level of service of different sections in Rourkela city, these are very important for future expansion of pedestrian facilities (sidewalks, wide-sidewalks etc...) and also present position of facilities in Rourkela city. In future many studies are conducted in different cities in India. Presently Indian prime minister will be announced 100 smart cities have developed in India with in short time because pedestrian facilities has considered mainly in this cities.

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