PEDESTRIAN WALKING SPEED VARIATION WITH GRADIENT OF ROADUNDER MIXED TRAFFIC FLOW CONDITIONS

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Abstract

Walking is an important mode of transport. The movement of pedestrians varies with gradient at the locations. While plain topography does not pose difficulty in walking, hilly locations require additional effort in ascending and cautious in descending for pedestrians during walking. The present research work aims to analyze the effect of gradient on pedestrian walking behavior with respect to age, gender and other influencing factors. The pedestrian's behaviour is observed by conducting a videographic survey during the peak hours. Based on the survey the pedestrian flow characteristics were extracted such as gender, age, baggage, movement and usage of phone. The analysis of data is done by considering various combinations, the relation between walking speed and gradient models are developed by using regression analysis. From the results, it is concluded that the gradient affects the walking speed of pedestrians. Their uphill walking speeds are lesser than the downhill speeds at all study locations for every pedestrian category. In uphill direction, the walking speeds of pedestrians without using phone are 5.40% higher than the pedestrians using phone. In downhill direction, the walking speeds of pedestrians without using phone are 4.38% higher than the pedestrians using phone. From the statistical test, it observed that gradient and sidewalk width significantly affect the walking speed of pedestrians.

Keywords: **Pedestrian, gradient, behavior, walking speed, regression**

Introduction

Walking is an important mode of transport. In areas of shorter distances, up to 1-2 km in length, significant proportion of trip generation are preferred on foot. Walking is essential for every trip, either at starting or at the end of the trip or sometimes at both times of trip but the movement of pedestrians has decreased to a greater extent with the increase of vehicular usage during the past few decades and the Growth of traffic resulted in various problems associated with pedestrian movement. Proper sidewalks, crosswalks and awareness about road-safety and rules make pedestrian movements safer.

In India, pedestrians and cyclists (vulnerable road users) together accounted for 16.2 percent of persons killed in road accidents during 2017 according to ROAD ACCIDENTS IN INDIA - 2017. The movement of pedestrians varies with

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gradientsatthe locations. While plain topography does not pose serious difficulty in walking, hilly areas pose additional difficulties for pedestrians during walking. There will be an additional effort which is required to climb up the gradient, while pedestrians should be careful and cautious during coming down the gradient. Researchers across the world addresses pedestrian behaviour on plain topography and the facilities to be provided for easy access of pedestrians. But the research work related to pedestrian movement at hilly locations are limited. In India, the pedestrian facilities are designed based on the code suggested by Indian Road Congress. The code is IRC-103 (2012) “Guidelines for Pedestrian Facilities”. The code does not completely detail the recommendations for provision of pedestrian facilities and their design in hilly regions. A research gap is identified to understand the pedestrian walking behaviour on surfaces with gradient. The present research work is aimed to analyze the pedestrian walking speed sidewalks with gradient and the walking speed variations on gradient surfaces with respect to age, gender, baggage and movement.

Literature Review

Researchers across the globe have studied pedestrian walking behavior on plain surfaces at various locations like sidewalks, crosswalks, walkways etc., Few researchers addressed the pedestrian behavior at hilly terrains. Al-Azzawi and Raeside (2007) studied pedestrian flows, speeds and density on sidewalks. Regression models were developed and the predictive performance of these models was assessed. Rastogi *et al*. (2013) analyzed the pedestrian walking behavior with the help of walking speed of pedestrian. Authors classified the Pedestrian facilities as sidewalk, wide-sidewalk and precincts. The results show that the pedestrian free flow speed is high on sidewalks (1.576 m/s) and low on precincts (1.340 m/s). Wang *et al*. (2013) developed the speed-density model and it is found that stochastic model more suitable than deterministic model. Marisamynathan and Perumal (2014) determined the pedestrian crossing speed and design crossing speed for old and adults are 0.95 m/s and 1.12 m/s respectively. Gupta and Pundir (2015) highlight the lack of a global and detailed consideration of pedestrian behavior along entire trips in urban areas. Ankur and Sunil (2016) found that average speed of pedestrians is more in downhill direction as compared to uphill direction and the difference between average walking speed in uphill and downhill direction reduces with decrease in the value of gradient. Gupta *et al*. (2017) found that females walking speed decreases by 41% as compared with males walking speed. Tabish and and Kumar (2017) established a methodology to reduce the pedestrian problems at intersections in Haryana, India. Rasouli *et al*. (2018) studied the way pedestrians communicate with drivers prior to crossing and the factors that influence their behavior were analyzed. Zaki (2018) proposed a method for counting pedestrians in groups and to show the feasibility of the method on a pedestrian group study from video data collected at moderately dense pedestrian crosswalk.

Study Area And Data Collection

Visakhapatnam has been chosen as the study area which lies to the North East of Andhra Pradesh, India. It is situated between Eastern Ghats and coast of Bay of Bengal with the population of 4,056,922 as of 2019 according to United Nations - World Population Prospects 2019. The city is situated at 45 m above mean sea level and lies between 17.6868°N and 83.2185°E. The topography of the city mostly falls under hilly terrain. The areas with high pedestrian traffic having higher altitude are selected for the study. Nine different study locations were chosen and the details of the study locations and the number of samples extracted at each location for the study were presented in Table 1.

Video-graphic method was adopted at each location during peak hours to record the movement of pedestrians. Various studies conducted by researchers have taken strip length of two convenient reference objects to measure the distance

Table 1. Details of survey locations

Study location	Name of the location	Gradient (%)	Time	Number of samples
1	Aasilmetta	7	8.30 am-9.30 am	276
2	Shivajipalem	1	8.30 am-9.30 am	291
3	Venkojipalem	8	4.30 pm-5.30 pm	449
4	Seetammadara	5	8.30 am-9.30 am	137
5	Maharanipeta	13	4.30 pm-5.30 pm	556
6	Hanumanthawaka	9	8.30 am-9.30 am	101
7	King George Hospital	4	4.30 pm-5.30 pm	346
8	Akkayapalem	3	8.30 am-9.30 am	157
9	Kommadi	5	4.30 pm-5.30 pm	470

between them so that the time taken by a pedestrian to walk through the known distance can be extracted from the video recording. Thereby the walking speed can be calculated. A strip length of 5 m was marked on the pedestrian facility using white tape for measuring the pedestrian speed. The geometric properties of the road like carriageway width, footpath width were measured using measuring tape. The gradient of the carriageway was calculated with help of auto level instrument.

Five pedestrian attributes were considered for this study such as age, gender, Baggage, phone usage and movement of pedestrians (uphill/ downhill). The required pedestrian characteristics like walking speeds, flow and density were extracted manually from the recorded videos. From the visual perception of a pedestrian, age is been taken. The age classification for the pedestrian studies are generally taken as three. The age criterion in this study is been considered as Child (<19), Adults (20-45), Old (>45). A total of 2,783 pedestrians were extracted from thestudy locations. The time taken by each pedestrian to cross the strip length was noted to an accuracy of 0.1 s to determine pedestrian speed. Based on these classification pedestrians walking speed of uphill direction travel were compared with pedestrians of the downhill direction of travel. Pedestrian's attributes classification considered for the study were shown in Table 2.

Data Analysis and Results

In this section, pedestrian walking speeds with respect to attributes age, gender, baggage, movement and phone usage are analyzed and compared to understand the walking behavior.

Pedestrian Sample Size

From the video recording data of pedestrian movement, a total sample of 2,783 are extracted from the 9 study locations. The Pedestrian sample size distribution with respect to age, gender, baggage, phone usage and movement were presented in Table 3. It was found that male pedestrian's proportion is 63.67% whereas female pedestrian's proportion is 36.33%. Around 58% of the pedestrians were using mobile phone during walking.

Walking Speed of Pedestrians

Walking speeds of pedestrians extracted from the play back videos from the study area segregated with respect to gender, age, baggage, phone usage and movement. The mean, maximum and minimum walking speeds of the classification of pedestrians in uphill and downhill direction were tabulated in Tables 4 and 5 respectively.

It is found that the mean speed of male pedestrians is 63.19 m/min which is faster compared to females whose mean speed is 58.42 m/min.

Table 2. Pedestrian categorization

Pedestrian Characteristics	Category
Age (years)	Child (<19), Adults (20-45), Old (>45)
Gender	Male, Female
Baggage	With baggage, Without Baggage
Movement	Single, Group(>= 2pedestrians)
Phone Usage	Yes, No

Table 3. Pedestrian Sample size distribution with respect to age, gender, baggage, phone usage and movement.

	Gender		Age			Baggage		Using Phone		Movement	
	Male	Female	Child	Adult	Old	With	Without	Yes	No	Single	Group
Sample Size	2,015	770	512	1,815	458	1,788	994	1,638	1,147	1,720	1,065
Percentage	72	28	19	65	16	64	36	58	42	62	38

Table 4. Walking Speeds of Pedestrians in Uphill direction

Characteristics	Pedestrians										
	Gender		Age			Baggage		Phone Usage		Movement	
	Male	Female	Child	Adult	Old	With	Without	Yes	No	Single	Group
Mean Walking Speed (m/min)	63.19	58.42	59.61	61.67	48.96	58.34	63.35	60.1	63.4	63.35	53.21
Max. Walking Speed (m/min)	120.00	99.22	98.00	150.00	86.68	100.00	150.00	80.00	100.00	150.00	80.00
Min. Walking Speed (m/min)	28.30	21.42	33.34	28.34	25.00	25.00	30.00	36.50	37.50	25.00	28.34
Standard Deviation	12.20	11.12	10.53	11.21	9.89	12.13	15.01	11.12	10.70	10.15	9.89
Sample Size	952	640	330	852	410	576	1016	780	812	1011	581

Table 5. Walking Speeds of Pedestrians in Downhill direction

Characteristics	Pedestrians										
	Gender		Age			Baggage		Using Phone		Movement	
	Male	Female	Child	Adult	Old	With	Without	Yes	No	Single	Group
Mean Walking Speed (m/min)	65	60.01	60	65	52.13	60.23	64.22	62.37	65.1	65.12	56.32
Max. Walking Speed (m/min)	150	120.13	100	150	86.69	97.21	100	100	150	150	98.12
Min. Walking Speed (m/min)	33.3	20.04	37.5	61.49	20.12	20.22	28.34	20.16	37.5	37.5	20
Standard Deviation	13.5	11.37	12.46	10.17	7.15	12.13	15.16	13.15	11	12.37	11.16
Sample Size	818	375	275	623	295	468	725	398	795	960	233

The adults were faster than child and old pedestrians with a mean walking speed of 61.67 m/min. While, old pedestrians were the slower with a mean walking speed of 48.96 m/min. Pedestrian walking speeds without baggage are 8.6% higherthan pedestrians walking with baggage. The average speed difference for baggage category is observed about 5.01 m/min. Pedestrian walking speed without using phone are 5.40% higher than the pedestrians using phone while walking. Pedestrians moving single are 19.14% faster than compared to pedestrians moving in a group.

In the downhill direction, it is observed that the male pedestrians walk 8.33% faster than female pedestrians with average walking speed difference of 5 m/min. The adultswere faster than child and old pedestrians with a mean walking speed of 65 m/min. while, old pedestrians were the slowest with a mean walking speed of 52.13 m/min. Pedestrians without baggage walk 6.62% faster than pedestrians walking with baggage. The average speed difference for baggage category is observed about 3.99 m/min. Pedestrians walking without using phone are 4.38% faster than the pedestrians using phone. Pedestrians moving in single walk 15.63% faster thanthose who are moving in the group.

Figure 1 shows the uphill and downhill walking speed of male and female pedestrians with age. For the male pedestrians walking uphill, the walking speeds of old age and child are 10.10% and 4.25% lesser than the adult pedestrians. Similarly for the female pedestrians walking uphill, the walking speeds are 21.20% and 4.50% lesser than the adult pedestrians.

Along the downhill, male-old age pedestrians walking speeds are 18.30% lesser than male-adult pedestrians. While the male-younger pedestrians are found to have 8.27% higher walking speeds than of male-adult pedestrians. In downhill direction, female-old pedestrians walking speeds are 18.00% lower than the female-adult pedestrians. The walking speeds of female-adult and female-child pedestrians are observed to be similar along the downhill.

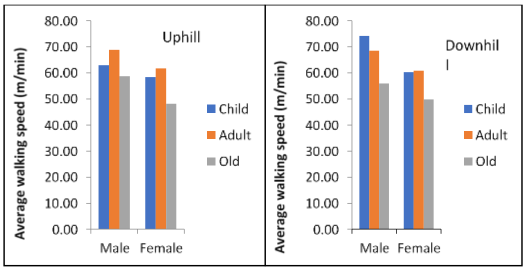

Figure 1. Average Walking Speed (Gender-Age)

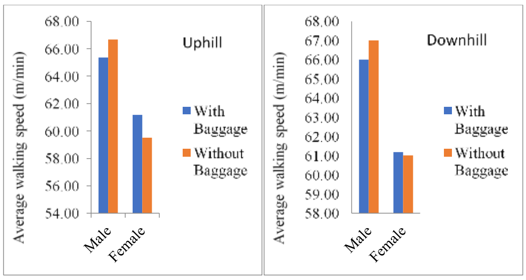

Figure 2. Average walking speed (Gender-Baggage)

Figure 2 shows the male and female pedestrians walking speeds variation with baggage along uphill and downhill direction. The baggage carrying male pedestrians were observed to have 2.00% lesser walking speeds than those walking without carrying baggage irrespective of direction. However the walking speeds of female pedestrians carrying baggage were observed to have 3.60% higher speeds than their counterparts in uphill direction. In the downhill direction, female pedestrian walking speeds are similar irrespective of baggage.

Figure 3 shows the male and female pedestrian walking speeds when walking in single and in group. The male and female pedestrians walking single have 11.20% and 13.70% higher walking speeds than their counterparts walking in group in uphill direction. In downhill direction, the walking speeds of male and female pedestrians walking in single have 5.70% and 5.80% higher walking speeds than those walking in group.

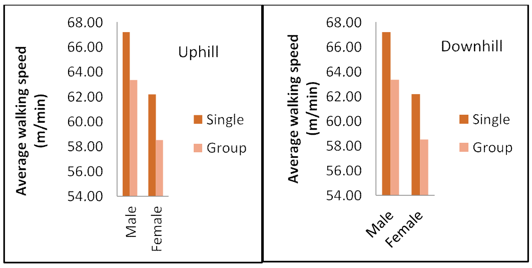

Figure 3. Average walking speed (Gender-Moving)

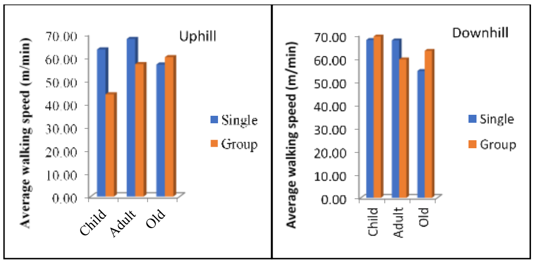

Figure 6. Average walking speed (Age-Moving) - Upward gradient

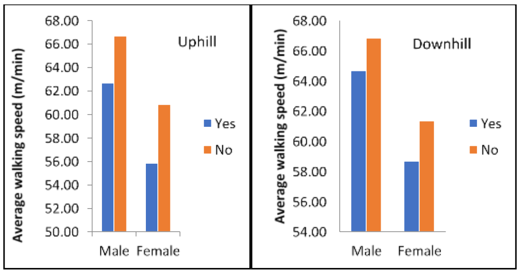

Figure 4. Average walking speed (Gender-Phone) - Upward gradient

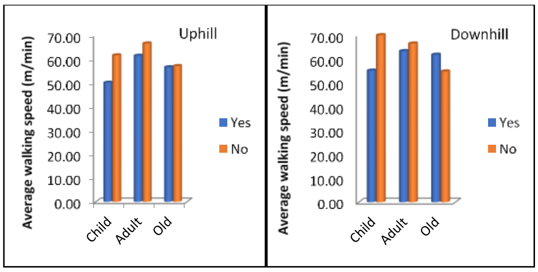

Figure 7. Average walking speed (Age-Phone)

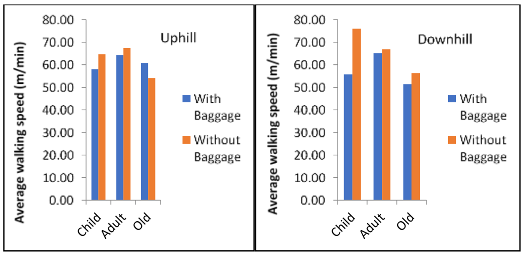

Figure 5. Average walking speed (Age-Baggage)

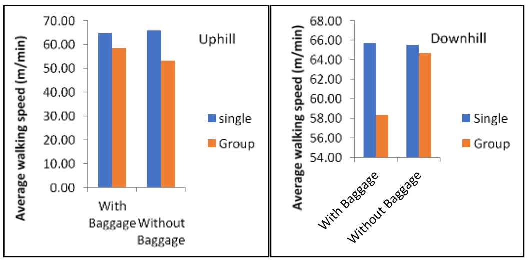

Figure 8. Average walking speed (Baggage-Moving)

Figure 4 shows the pedestrian walking speed variation with usage of phone in uphill and downhill directions. The walking speeds of male and female pedestrians are reduced by 5.90% and 8.20% when using phone while walking uphill. The walking in downhill direction speeds are reduced 3.24% and 4.34% for male and female pedestrians using phone.

The baggage handling effect on pedestrian walking speed is shown in the Figure 5 along the uphill and downhill directions. The walking speed is decreased by 5.30% for child and adults handling baggage than those of walking without baggage in uphill direction. In downhill direction, the walking speed of child is reduced by 26.80% with luggage. While the walking speeds of adults are similar irrespective of baggage. And the aged pedestrians walking speed is reduced by 4.60% with luggage.

From the Figure 6, the age-moving combination for upward gradient, in case of child and adults, the average walking speed of single moving persons more (30%) while compared to the people who are moving groups. In case of old people, the average walking speed of single moving persons decreased (3%) while compared to the people who are moving groups. Figure 6 shows the group effect on pedestrian mean walking speeds in uphill and downhill directions for the age classifications child, adult and aged. In uphill direction, child and aged pedestrians walking in groups were found to be walking slower by 30% than the pedestrians walking without companion. While the aged pedestrians walking without companion were observed to be having 3.00% higher walking speeds than those walking in group. Along the downhill directions, the children and aged pedestrians walking in groups have 7.00% lower walking speeds and adults were 12.00% slower than those walking without companion. The phone usage effect on pedestrian walking speeds along uphill and downhill directions were shown in Figure 7. Along the uphill direction, results showed that the walking speeds are reduced by 18.70% and 7.80% with phone usage for children and adults respectively. While the walking speeds are similar for the aged pedestrians irrespective of phone usage. In downhill direction, the walking speeds were observed to be reduced by 4.50%, 2.90%, and 5.00% for children, adults and aged pedestrians respectively with phone usage.

From the Figure 8, thebaggage-moving combination for upward gradient, in case of with baggage people the average walking speed of group moving persons is decreased (9.5%) while compared to the single moving persons. In case of without baggage people, average walking speed of group moving persons is decreased (19%) while compared to the single moving persons.

Figure 8 shows the baggage effect on pedestrian walking speeds who are walking in single and in group. In the uphill direction, mean walking speed of baggage handling pedestrians walking in group walk with 9.50% lower walking speeds than those pedestrians handling baggage without companion. Thebaggage-moving combination for downward gradient, in case of with baggage people the average walking speed of group moving persons is decreased while compared to the single moving persons. In case of without baggage people, average walking speed is almost equal in both conditions.

Figure 9 shows the pedestrian walking speed variation with baggage and phone usage. In uphill direction, the pedestrian carriage baggage and using phone were observed to be having 4.80% slower walking speeds than those handling baggage but not using phone. On comparison of pedestrian without baggage, the walking speed of pedestrians using phone is reduced by 2.90% than those not using phone. In downhill direction, on comparison of baggage handling pedestrians, the walking speeds of pedestrians using phone are observed to be walking slower by 6.5% than those not using phone. In case of without baggage the average waking speed is equal in both cases.

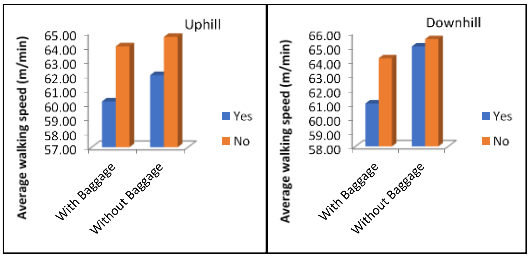

Figure 9. Average walking speed (Baggage-Phone)

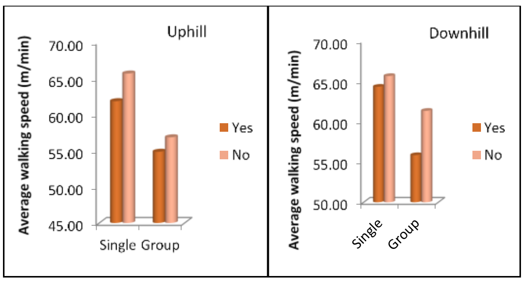

Figure 10. Average Walking speed (Moving-Phone)

Figure 10 shows the pedestrian walking speeds with usage of phone in group. Along the uphill direction, in case of single moving pedestrian, the average waking speed with the phone usage is found to be reduced by 4.5% in comparison to the pedestrians who are not using phone. In case of group, the average waking speed is equal in both cases. Along the downhill direction, in case of single moving pedestrian, the average waking speed of pedestrian using the phone found to be reduced by 1.9% incomparison to the pedestrian who are not using phone. In case of pedestrian moving in group, the average waking speed of pedestrian who are using the phone was reduced by 8.9% in comparison to the pedestrian who are not using phone.

Linear Regression Analysis

Linear regression is used to model a linear relation between a continuous dependent variable and one or more independent variables. These models are based on data obtained from experiments; predictive models are based on data obtained from observational study. This paper is focused on relation between walking speed and gradient. For this study, walking speed is chosen as dependent variable whereas gradient and lane width is chosen as independent variables. The pedestrian walking speed is analyzed using linear regression analysis. The 80% of data was used in regression and the 20% of data was used for validation.This test has been performed at 95% confidence interval and statistical results are given in Tables 6 and 7. It was observed that the ‘p’ value representing the gradient and the

Table 6. Regression results for Uphill

Variables	Coefficient	p-value
Intercept	38.47	0.03
Gradient	6.90	0.01
Lane width	-3.12	0.01
R^2	0.98	

Table 7. Regression results for Downhill

Variables	Coefficient	p-value
Intercept	75.4	0.01
Gradient	2.1	0.03
Lane width	-3.5	0.00
R^2	0.96	

'p' value representing the lane width were significant for upward and downward gradient as the values were less than 0.05. From the validation of models, the calculated root mean square error for upward and downward gradient is 0.45 and 0.48 respectively.

From the regression analysis devel0ped a model for upward gradient is

$$Y = 6.90x_1-3.12x_2+38.47 \quad (1)$$

From the regression analysis developed a model for downward gradient i.e.

$$Y = 2.1x_1-3.5x_2+75.4 \quad (2)$$

Where Y is the walking speed, x_1 is gradient and x_2 is lane width.

Conclusions

In this study, pedestrians walking speeds were studied at different gradients in Visakhapatnam, Andhra Pradesh, India. The pedestrians walking speeds were analyzed in relation to the pedestrian characteristics like Gender, age, baggage, moving pattern for individual pedestrians. The gradient affects the walking speed of pedestrians with the uphill walking speed lesser than the downhill speed at all study locations for every category. In uphill direction, pedestrians without using phone are 5.40% faster than the pedestrians using phone. Where as in downhill direction; pedestrians without using phone are 4.38% faster than the pedestrians with using phone. The walking speeds of pedestrians walking without companion are observed to be higher than their counterparts. The walking speed of pedestrian was significantly affected by the different combinations like gender-age, gender-baggage, gender -movement, gender-using phone, Age-baggage, Age-movement, Age-Using phone, Baggage-Movement, Baggage-Using phone, Movement-using phone. From the statistical test, it observed that gradient and lane width will significantly affect the walking speed of pedestrians. A relation between walking speed of pedestrian and gradient is developed. The findings of this study focus on the need of exclusive pedestrian facilities to improve the flow characteristics, which helps in decongesting the roads and reduce pedestrian friction thereby reducing the jam density. Future work can be extended by taking larger sample and to consider more factors like footpaths, obstructions and street lights giving better statistics results in other regression models. The model equations are valid when the gradient of road lies between 1 to 13%.

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