Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Simulation Based Study of the Effect on Pedestrian Flow due to Parked Vehicles: A case study on Mangal Bazar to Mahapal Road Section

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Abstract

Shared-carriageways are common in narrow street networks. Due to the shared nature multiple interactions between pedestrians and vehicles is inevitable. This study uses the micro-simulation software VISSIM / VISWALK to develop a model that simulates the existing scenario of the interaction of pedestrians walking along the carriageway with moving vehicles and parked vehicles. The developed model is calibrated and validated to obtain a model that represents the actual pedestrian characteristics as observed in the survey. The travel time and walking speed of pedestrians walking along the carriageway are analyzed in the existing scenario which is then compared with the values obtained in other scenarios that represent vehicles parked on the carriageway as a result of the shared carriageway. By comparing these scenarios, the impact of each obstruction like encroachment of the entire carriageway by vehicles, parked vehicles and congestion on the travel time and walking speed of pedestrians is quantified which aids to propose scenarios to be implemented to improve pedestrian mobility.

Keywords

Simulation, Shared-Carriageway, Pedestrian Characteristics, VISSIM, VISWALK, Parked Vehicles

1. Introduction

Historically in ancient settlements, city street networks were made to accommodate pedestrians and non-motorized vehicles. Over the years with the introduction of motor-powered vehicles, these streets are simultaneously accommodating both vehicle and pedestrian movement on the same shared-carriageway. There has been a rise in ownership and use of private vehicles, which has led to vehicles dominating the road space, sidelining pedestrians and forcing them to compromise on the convenience of walking comfortably and safely. When vehicles and pedestrians share the same carriageway, interactions between them are bound to happen. These interactions hinder the smooth flow of pedestrians as well as of the traffic and hence reduce the efficiency of the carriageway as a whole.

[1] Romanian cities are improving the pedestrian environment in city centers which are also tourist destinations by creating pedestrian-only zones and redesigning public squares which is a way forward to reduce a person's dependency on private vehicles but still is not sufficient enough to solve problems of peripheral neighborhoods. Contrary to this, the road network in the city center of Lalitpur city is dominated by private vehicles which need to be addressed to improve pedestrian mobility. Furthermore, when vehicles are parked along the carriageway, pedestrians have to navigate narrower paths or maneuver closer to moving traffic to reach their destinations.

[2] Simulation model that replicated the existing condition of the JR Takatsuki station was developed and then the pedestrian flow pattern was predicted for the proposed new platform. It was found that the congestion on the current platform was attenuated but the new platforms posed the possibility of congestion as a result of flow conflicts among transferring passengers. Thus, the effects of parked vehicles on pedestrian flow along the carriageway have been quantified by using the simulation tool.

1.1 Problem Statement

Interaction with obstructions such as moving vehicles and parked vehicles pose an inconvenience to pedestrians moving along the carriageway. Thus, it is essential to determine the influence of these obstructions on pedestrian characteristics such as pedestrian volume, walking speed and travel time.

The obstructions that are covered by this study are:

- Encroachment of the path followed by pedestrians due to congestion
- Parked vehicles on the carriageway

1.2 Objective of Study

The primary objective of this study is to determine the influence of above-mentioned obstructions on pedestrian flow characteristics (walking speed, travel time)

The specific objectives are enlisted as below:

- To simulate the existing pedestrian characteristics
  - During morning hours when pedestrian flow and vehicle flow are low
  - During evening hours when the pedestrian flow as well as vehicle flow is high
- To simulate the pedestrian characteristics along the carriageway under the influence of parked vehicles

2. Related Works

[3] The level of service of pedestrian walkways in Thessaloniki Greece, coastal front during peak and the non-peak hour was simulated and the result was compared with the users' perception. It was observed that in the prevailing condition, public perception was different compared to the simulated data which indicates the importance of taking the pedestrians' perception into account while designing shared-use infrastructures. [4] has conducted a micro-simulation of traffic flow using the VISSIM software to evaluate the impact of various side frictions on heterogeneous traffic. These side frictions were created on the road segment by making conflict areas. Likewise, as traffic flow is disrupted by the presence of side frictions, pedestrian flow is also bound to be affected due to the presence of various activities and obstacles present in its vicinity. [5] carried out the study to determine the effect of various side frictions on traffic characteristics in urban arterials. The study showed that the dwell time of buses was the most significant parameter which was followed by the number of parking maneuvers and then the pedestrian flow.

[1] has mentioned that planning for walking is one of the three main ways to deal with traffic congestion problems in transport planning practice, others being planning for public transport and planning for cycling. For a city structure with limited road capacity set in the ancient time before people's dependency on the vehicular mode of transport, it is important to draw attention to pedestrian mobility within the city. [6] This study mentions how in situations that require meeting the demands of vehicles and pedestrians, the local authorities tend to give preferences to infrastructures for vehicles. It also concluded that the adjacent road and traffic characteristics also significantly influence the pedestrians' perception of comfort and safety along with factors such as walking environment and condition.

[7] developed a model representing the existing scenarios of the station where the actual and desired walking speeds of the pedestrians were studied using microscopic simulation. This study also conducted a sensitivity analysis of simulated walking speed to various adjustments to the parameters of the social force model to represent the actual pattern of the pedestrians in the study area. [8] calibrated and validated the walking behavior parameter in a sky bridge by trial and error to find out the actual values that represented the pedestrian behavior in the study area.

It can be observed that every obstruction does not have the same level of impact on the smooth flow of pedestrians. Comparatively fewer studies have been conducted regarding the influence of various factors on pedestrian flow characteristics compared to traffic flow. From the outcomes of various studies, it is visible that side frictions have an impact on traffic flow characteristics. Similarly, this study will use simulation tool to determine the influence of the above-mentioned obstructions on pedestrian flow characteristics. Figure 1 gives the overall framework of methodology of the study.

3. Methodology

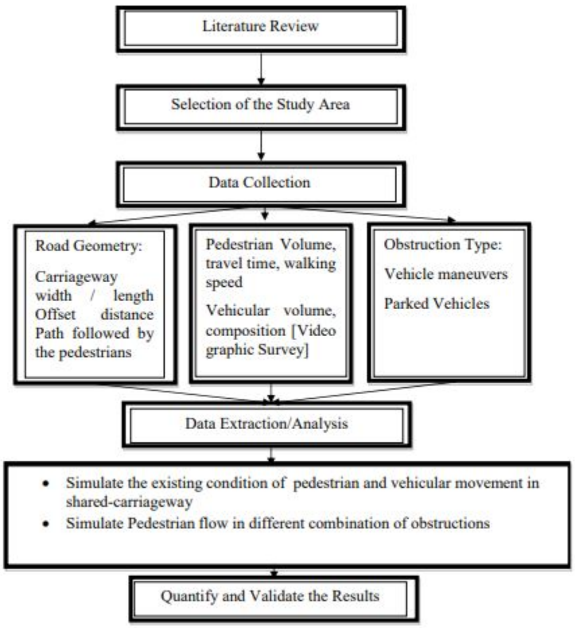

Figure 1: Framework of Methodology

3.1 VISSIM/VISWALK Software

VISSIM is micro-simulation software in which traffic and pedestrian flow can be simulated. This software helps to plan and design such that future layouts of road sections are efficient. Within the VISSIM package is the pedestrian simulation component VISWALK, which will be used to simulate pedestrian flow and collect data such as walking speed and travel time. It also enables to optimization/design of spaces and conducts capacity planning. The pedestrian behavior model in the VISWALK software is the social force model in which it is assumed that the pedestrians show an attractive force towards their destinations and display repulsiveness towards other pedestrians and obstructions.

3.2 Study Area

For simulating the pedestrian flow characteristics, Mangal Bazar to Mahapal road section has been selected, which is a section of urban road within the core Lalitpur city. The speed limit of this section for vehicle movement is 20km/hr. The core area of Lalitpur is believed to be founded in the 3rd century BC. It has a densely populated settlement having a network of narrow streets with restricted right of way, shared carriageway and shallow drain trenches provided on both sides. The built-up area along the road segment has mixed land use development with the agglomeration of buildings where people reside and work and several historic buildings which are a significant part of the cultural heritage of the city. This urban road gives direct access to the city center, Patan Durbar Square, which is a popular tourist destination that (accommodates) attracts many local and international tourists daily.

As the volume of vehicles using the road has increased over the years, traffic congestion poses to be one of the major problems in this road segment. To alleviate the congestion, the one-way traffic rule for four-wheeler vehicles has been implemented in the road section. This action has been able to reduce the congestion, but has not been able to completely address the problem as congestion at the junctions is still frequent. At the same time, as pedestrians and vehicles share the carriageway; roadside parking, vehicle maneuvers and congestion encroach the path followed by pedestrians walking along the carriageway. This impacts the mobility of pedestrians in terms of safety and convenience. For the analysis of pedestrian flow characteristics, a 10m section of carriageway adjacent to Patan Durbar Square, which has high pedestrian movement, was surveyed.

3.3 Data Collection

Video graphic surveys of the selected section were carried out, in the morning hour and the evening hour, for the span of 3 days (Sunday, Monday and Tuesday; from July 17th to July 19th) to collect pedestrian and vehicle data. The morning hour showcased lower pedestrian as well as vehicle volume, whereas during the evening hour both pedestrian and vehicle volumes were comparatively higher. The geometric dimensions of the road section were noted manually and a 10m trap length of carriageway section adjacent to Patan Durbar Square was demarcated to collect the required data for simulation.

3.4 Data Extraction

The data required for the simulation of the shared carriageway were extracted manually by meticulously reviewing the recorded videos from the video graphic surveys. Data such as pedestrian volume, routes followed by the pedestrians, pedestrian travel time and vehicle volume, vehicle routes, and vehicle composition were extracted. A model representing the existing scenario was developed. To simulate the pedestrian characteristics (walking speed and travel time) in the selected study area, the average of the first two-day data were used as input in the developed model in VISSIM software. The model was then calibrated for the volume and walking speed of the pedestrians walking along the carriageway. After the model was calibrated, the third-day data was used as input to validate the developed model.

3.5 Model Construction

The model that represents the existing scenario was constructed from scratch in VISSIM by using the measurements collected from the field surveys. The study area, area 1 as shown in Figure 2 is the portion of the carriageway where characteristics of the pedestrians walking along the carriageway have been measured. Flow and route inputs of the pedestrians and vehicles were fed into the software as per the data extracted from the meticulous review of the field videos. The input for the desired speed distribution of the pedestrians used was the value obtained for observed walking speed distribution at the morning hour when the pedestrian and vehicle flow was low, as the actual walking speed of the pedestrians should be closer to their desired speeds at low flow condition compared to the high flow condition [7]. To construct the model in which pedestrians walk the same way as seen in the observations of the survey videos, origins were placed at a distance from the study area and the model was extended so that they have sufficient time to accelerate towards their desired walking speed [7] . Likewise, the destination is narrowed down and placed near the edge of the carriageway, right next to the study area to illustrate the fact that pedestrians tend to move towards the exterior of the carriageway to reach their destination. Similarly, origin, destinations and routes for cross-flow pedestrians and vehicles running on the carriageway were positioned as per the field observations. Two base models were developed namely the morning base model and evening base model. Both the base models were constructed geometrically similar, representing the existing scenario. Input values of pedestrian and vehicle data were fed into the model as per the observation from the video graphic surveys. To represent bystanders and other activities in the evening hour, additional obstacles were placed in the open space in the evening base model. Figure 2 gives the overview of the developed model and the function of each area of the model is mentioned in Table 1.

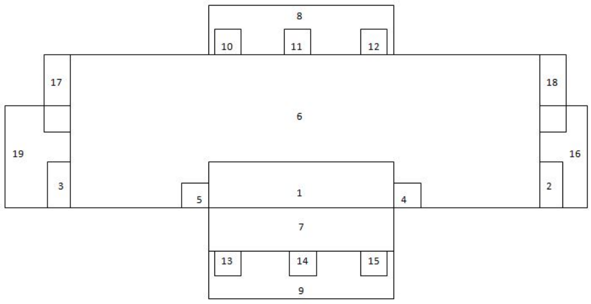

Figure 2: Overview of Developed Model

Table 1: The areas and function of those areas in the developed model

Area Number	Function
1	Study Area
2, 3	Pedestrian Origins
4, 5	Pedestrian Destinations
6	Carriageway
7	Open space
8, 9	Cross-flow ped. Origins
10, 11, 12	Cross-flow ped. Destinations
13, 14, 15	Cross-flow ped. Destinations
16, 17	Vehicle Origins
18, 19	Vehicle Destinations

4. Model Calibration and Validation

4.1 Model Calibration

After finalizing the model, calibration for pedestrian volume and walking speed was done to check if the developed model represented the existing scenario. Calibration for both the morning base model and evening base model was done using the average of first two-day data obtained from morning and evening hour surveys respectively.

For morning and evening base models, 10 simulations were run in which each simulation was one and a half hours long. The output obtained in the first and last fifteen minutes of each simulation run was discarded as warm-up periods. The pedestrian volume was calibrated by calculating GEH value for each simulation run. The GEH value was calculated using equation 1. According to GEH statistics guideline mentioned in [9], GEH value less than 5 is taken as an acceptable fit. For calibrating the walking speed, the chi-square test was used for 95 percent confidence interval. The chi-square value was calculated using equation 2. Using the chi-square test, difference between observed data and expected data is evaluated.

As ten simulation runs are made, the degree of freedom for the test is 9. The value of chi-square obtained from the table for 95 percent confidence interval and a degree of freedom 9 is 16.92. The micro-simulation model developed is said to represent the observation condition if the calculated chi-square value is less than the value obtained from the chi-square table.

GEH Formula:

$$GEH = \sqrt{\frac{2*(M-C)^2}{M+C}} \tag{1}$$

Where,

M= Output Pedestrian Volume from simulation run (pedestrian per hour)

C= Input Pedestrian Volume (pedestrian per hour)

Chi Square Test Formula:

$$X^2 = \sum \frac{[(O-E)^2]}{E} \tag{2}$$

Where,

O= Output Walking speed from simulation run

E= Observed Walking speed in the field

4.1.1 Morning Base Model Calibration

The observed volume of the pedestrians walking along the carriageway obtained from the two-day data was 256. GEH Value for each simulation runs was found to be well below the standard required value of 5, which is an acceptable fit, as shown in Table 2. Similarly, the calculated chi-square value for walking speed was 0.158 which is less than the table value of 16.92, which means the model represents the condition of observation as shown in Table 3.

Table 2: Volume Calibration of Morning Base Model

Sim.Run	Sim.Volume	Obs.Volume	GEH
1	265	256	0.558
2	260	256	0.249
3	267	256	0.680
4	265	256	0.558
5	260	256	0.249
6	241	256	0.951
7	248	256	0.504
8	274	256	1.106
9	251	256	0.315
10	267	256	0.680

Table 3: Walking Speed Calibration of Morning Base Model

Sim.Run	Sim.Speed	Obs.Speed	$[(O-E)^2]/E$
1	4.503	4.777	0.016
2	4.483	4.777	0.018
3	4.543	4.777	0.012
4	4.552	4.777	0.011
5	4.499	4.777	0.016
6	4.577	4.777	0.008
7	4.508	4.777	0.015
8	4.448	4.777	0.023
9	4.481	4.777	0.018
10	4.459	4.777	0.021
		Total	0.158
		From Table	16.920

4.1.2 Evening Base Model Calibration

The observed volume of the pedestrians walking along the carriageway in the evening obtained from the two-day data was 603. GEH Value for each simulation runs was found to be well below the standard required value of 5, which is an acceptable fit, as shown in Table 4. Similarly, the calculated chi-square value for walking speed was 0.005 which is less than the table value of 16.92, which means the model represents the condition of observation as shown in Table 5.

Table 4: Volume Calibration of Evening Base Model

Sim.Run	Sim.Volume	Obs.Volume	GEH
1	606	603	0.122
2	593	603	0.409
3	593	603	0.409
4	615	603	0.486
5	589	603	0.574
6	609	603	0.243
7	595	603	0.327
8	601	603	0.084
9	629	603	1.047
10	616	603	0.526

Table 5: Walking Speed Calibration of Evening Base Model

Sim.Run	Sim.Speed	Obs.Speed	$[(O-E)^2]/E$
1	4.163	4.183	0.000
2	4.163	4.183	0.000
3	4.248	4.183	0.001
4	4.218	4.183	0.000
5	4.194	4.183	0.000
6	4.071	4.183	0.003
7	4.238	4.183	0.001
8	4.173	4.183	0.000
9	4.164	4.183	0.000
10	4.170	4.183	0.000
		Total	0.005
		From Table	16.920

4.2 Model Validation

After calibrating both the morning base model and evening base model, validation was done by using the third day data obtained from the field. Ten simulations were run and the simulated results were compared with the observed values in the field.

4.2.1 Morning Base Model Validation

The observed volume of the pedestrians walking along the carriageway obtained from the third-day data was 270. GEH Value for each simulation runs was found to be well below the standard required value of 5, which is an acceptable fit, as shown in Table 6. Similarly, the calculated chi-square value for walking speed was 0.258 which is less than the table value of 16.92, which means the model represents the condition of observation as shown in Table 7.

Table 6: Volume Validation of Morning Base Model

Sim.Run	Sim.Volume	Obs.Volume	GEH
1	281	270	0.663
2	287	270	1.019
3	267	270	0.184
4	267	270	0.184
5	275	270	0.303
6	260	270	0.614
7	282	270	0.722
8	284	270	0.841
9	270	270	0.000
10	282	270	0.722

Table 7: Walking Speed Validation of Morning Base Model

Sim.Run	Sim.Speed	Obs.Speed	$[(O-E)^2]/E$
1	4.458	4.846	0.031
2	4.460	4.846	0.031
3	4.575	4.846	0.015
4	4.514	4.846	0.023
5	4.469	4.846	0.029
6	4.512	4.846	0.023
7	4.543	4.846	0.019
8	4.457	4.846	0.031
9	4.493	4.846	0.026
10	4.462	4.846	0.030
		Total	0.258
		From Table	16.920

4.2.2 Evening Base Model Validation

The observed volume of the pedestrians walking along the carriageway obtained from the third-day data was 428. GEH Value for each simulation runs was found to be well below the standard required value of 5, which is an acceptable fit, as shown in Table 8. Similarly, the calculated chi square value for walking speed was 0.013 which is less than the table value of 16.92, which means the model represents the condition of observation as shown in Table 9.

Table 8: Volume Validation of Evening Base Model

Sim.Run	Sim.Volume	Obs.Volume	GEH
1	444	428	0.766
2	429	428	0.045
3	443	428	0.719
4	424	428	0.195
5	424	428	0.195
6	417	428	0.535
7	426	428	0.095
8	434	428	0.290
9	433	428	0.241
10	437	428	0.432

Table 9: Walking Speed Validation of Evening Base Model

Sim.Run	Sim.Speed	Obs.Speed	$[(O-E)^2]/E$
1	4.241	4.198	0.000
2	4.283	4.198	0.002
3	4.306	4.198	0.003
4	4.334	4.198	0.004
5	4.195	4.198	0.000
6	4.231	4.198	0.000
7	4.288	4.198	0.002
8	4.297	4.198	0.002
9	4.215	4.198	0.000
10	4.241	4.198	0.000
		Total	0.013
		From Table	16.920

5. Scenario Analysis

Three scenarios were constructed on the evening base model representing congestion and vehicles parked on the carriageway to quantify the influence of each obstruction on the walking speed and travel time of the pedestrians walking along the carriageway. Table 10 gives the value of travel time and Table 11 gives the average walking speed of the pedestrians in each of the scenarios while traversing a 10m road section.

5.1 Scenario 1 - Congestion Condition

In this scenario, congestion condition was achieved by adding obstacles along the carriageway such that the pedestrians have to traverse a narrow path to reach their destination. For this scenario, no inputs were given for cross-flow pedestrians as during congestion pedestrians could not cross the carriageway. The remaining input data were as per the evening base model.

5.2 Scenario 2 - Parked four-wheeler vehicle

In this scenario, an obstacle of the size of a four-wheeler was placed in the study area to represent a parked four-wheeler vehicle. All input data were as per the evening base model.

5.3 Scenario 3 - Parked two-wheeler vehicles

In this scenario, obstacles projecting the area of a motorcycle and a scooter were placed on the carriageway to represent parked two-wheeler vehicles. All input data were as per the evening base model.

5.4 Scenario Results

Table 10: Comparison of Travel Time in three scenarios

Scenarios	1	2	3
Sim. Run			
1	9.110	9.035	9.056
2	8.945	8.976	9.114
3	8.900	9.355	9.123
4	9.035	9.026	9.030
5	9.080	8.885	9.109
6	9.046	8.844	9.221
7	8.990	8.858	8.969
8	9.048	8.994	9.300
9	9.055	9.000	9.205
10	9.188	9.471	9.270
Avg. travel time(sec)	9.039	9.044	9.139
Tot.loss in time (min)	15.092	15.139	16.097

Table 11: Comparison of Average walking speed in three scenarios

Scenarios	1	2	3
Sim. Run			
1	3.952	3.985	3.975
2	4.025	4.011	3.950
3	4.045	3.848	3.946
4	3.985	3.988	3.987
5	3.965	4.052	3.952
6	3.980	4.071	3.904
7	4.004	4.064	4.104
8	3.979	4.003	3.871
9	3.976	4.000	3.911
10	3.918	3.801	3.883
Avg. speed(km/hr)	3.982	3.982	3.939

The travel time and walking speed results obtained in the three scenarios were compared with the observed values of the morning hour. The morning hour travel time and walking speed obtained from the field were 7.538sec and 4.777km/hr respectively. The walking speed of the pedestrian decreased in each of the scenarios. In both scenario 1 and 2, the speed decreased to 3.982km/hr and in scenario 3 the speed decreased to 3.939km/hr. From Table 10, the cumulative loss in time of 603 pedestrians traversing a 10m road section in scenario 1 was 15.092 minutes. Likewise, 15.139 minutes were lost in scenario 2 and 16.097 minutes were lost in scenario 3.

In scenario 2, where a four-wheeler vehicle was parked on the carriageway occupying a large area, pedestrians to reach their destination walked around the vehicle towards the inner portion of the carriageway. The tendency of pedestrians to walk on the inner portion of the carriageway increases their interaction with the moving vehicles which in turn affects their safety. In both scenarios 1 and 2, the pedestrians had to either take a detour through available open space beyond the carriageway or walk around the parked vehicle to reach their destination. This increased their travel time to reach the destination and decreased their walking speed.

Compared to the first two scenarios, scenario 3 (Parked two-wheeler vehicles), yielded the highest increase in travel time of the pedestrians walking along the carriageway. As observed in the field and based on the result analysis, multiple parked vehicles mean an increase in maneuvers required by pedestrians to reach their desired destination. This in turn leads to an increase in the travel time of the pedestrians.

6. Conclusion and Recommendation

A model was developed that represented the existing condition of the selected study area for the morning hour and the evening hour in which interaction of pedestrians walking along the carriageway with moving vehicles and pedestrians walking in different directions can be observed.

Mangal Bazar to Mahapal road section lies adjacent to Patan Durbar Square, where many vehicles park along the carriageway to access the heritage site. As the road section has a shared-carriageway, these parked vehicles impede the pedestrians walking along the carriageway, thus impacting the travel time and walking speed of the pedestrians.

Recommended methods to improve pedestrian mobility are:

- Designate space for loading/unloading and parking vehicles
- Restrict haphazard road-side parking
- Implement car-free zone during pedestrian peak hours
- Implement one-way traffic rule for all motorized vehicles

Further scenarios need to be analyzed to investigate the effect of different combination of obstructions on pedestrian flow.

7. Acknowledgement

The authors are thankful to Mr. Pichu Ranjit for his help in the field survey.

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