Modelling Mixed Traffic Flow at Signalized IntersectionUsing Social Force Model

Duc Nguyen HUYNH[a], Manfred BOLTZE[b], Anh Tuan VU[c],

[a,b,c]*Vietnamese-German Transport Research Centre, Vietnamese-German University, Viet Nam*
[a]*the first author; E-mail: hdnguyen@vgtrc.vgu.edu.vn*
[b]*E-mail: boltze@vgtrc.vgu.edu.vn*
[c]*E-mail: drtuan.va@vgtrc.vgu.edu.vn*

Abstract: It is urgent to understand the traffic performance by modelling traffic streams under mixed traffic conditions, in which motorcycles contribute to a dominant rate of the total traffic composition. This study aims to analyze the interactions between the left-turn and the opposite straight-through vehicles and estimate the capacity of both flows. An attempt is made to develop a social force model for the vehicles. The result indicates that the social force model is an appropriate approach to model the mixed traffic flow at signalized intersections. The study also outlines various aspects of integrating such a model into the existing methods for microscopic traffic flow simulation and capacity analysis.

Keywords: Social Force Model, Mixed Traffic Flow, Motorcycle, Capacity Analysis

1. INTRODUCTION

Mixed-traffic streams are becoming more common in urban areas all over the world. However, vehicle composition of the mixed streams varies across countries. In developed countries, four-wheeled vehicles such as cars, buses, trucks are major modes in the mixed streams. However, in developing countries, particularly in cities of these countries, the rate of motorcycles in the mixed traffic flows is very high. For example, in Ho Chi Minh City of Vietnam, the total number of registered vehicle in 2012 was about 5.71 million, including 0.51 million four-wheeled vehicles and 5.2 million motorcycles(HCMC Department of Transport, 2012). Roughly speaking, motorcycles contribute to around 90% of the total vehicles in the mixed-traffic flows. This makes the characteristics of the mixed traffic flows in developing countries different from those in developed countries.

In the mixed traffic stream, motorcycles perform specific behaviour patterns that are generally more complex than the patterns of four-wheeled vehicles. Motorcycles often run in erratic and chaotic trajectories and often do not follow the lane disciplines strictly. More specifically, at signalized intersections, there is an interesting traffic phenomenon, in which vehicles tend to form groups before crossing the intersection during peak hours. This may be a reflection of the motorcycle driver's psychology. Making groups to cross the intersection makes the drivers feel safer and more confident, especially the leading driver(s). If he or she feels having more power thanks to the support of the following drivers, he can cross the conflicting area with a smaller gap than the one who feels less powerful (such as crossing alone or being supported by a smaller number of followers). As a result, when two or more groups of vehicles negotiate a conflict at the intersection, the stronger or bigger group can run through the conflicting area while the weaker group has to wait until it can find an acceptable gap. Such behaviour is so called "grouping behaviour" (Vu and Shimizu, 2009). In Ho Chi

Minh City, Viet Nam, because the majority of intersections are two-phase signalized, the interaction between the straight-through group and the left-turn group becomes the most common traffic performance. Thus, modelling the grouping behaviour may be a key method for capacity analysis of the signalized intersections.

However, the conventional traffic flow theories and traffic simulation models that mainly focus on car-dominated flows do not consider the specific characteristics of such driver behaviour and traffic flow. Most of the available methods for traffic analysis and simulation assume that vehicles move on lanes and do not form groups. Car following theories describe how one vehicle follows a preceding vehicle in a homogeneous flow.In the car following model, it is assumed that the vehicle is controlled by the longitudinal behaviour of the driver, but the lateral behaviour is not considered. In the other words, especially at a signalized intersection, vehicles are modelled to run in platoons, not in groups. Various models were formulated to represent the reaction of the driver to changes in the relative positions of the vehicle ahead such as Pipes, Forbes, General Motors and Optimal velocity(Tom,2012). Although, there is also a combination of the car following and the lane change behaviors to model both the longitudinal and lateral behavior of the car, but it is still not suitable to describe the traffic movement of vehicle streams in mixed traffic conditions where vehicles run in groups..

In Cellular Automata Model proposed by Lawrence and Chiung-Wen(2003), motorcycles' driving behaviour in mixed traffic flow was mentioned. However, using a CA model to explain moving behaviour of a motorcycle in themixed traffic seems inappropriatebecause the rules of updating positions and speedsof the subject motorcycle were fixed. As aforementioned, motorcycles can move in an erratic mannerby following the leading vehicles. Thus, using fixed rules to express their moving behaviour is unreasonable. Furthermore, CA modelmay not be applicable in depicting the traffic performance at intersections since there area lot of conflicts andinteractions among many vehicles, especially interactions among groups ofmotorcycles and cars in Vietnam. Therefore, such methods are not applicable to analysing the capacity of signalized intersections. Accordingly, new modelling approaches need to be developed for capacity analysis. The main objectives of this study are to develop a new modelling approach by deploying the social force model, which is widely applied to simulate the behaviour of pedestrian flows (PTV, 2012), and to assess this model regarding its applicability for capacity analysis of signalized intersections in motorcycle-dominated cities.

This paper presents a simulation framework as shown inFigure 1. Firstly, the traffic situation at a signalized intersection is observed and the capacity is derived from the observations. Then, a simulation process based on the social force model is conducted by applying VISWALK, which is a simulation software used for simulating the performance of pedestrian flows. Next, by comparing the traffic volumes that are computed from the real observations and the model based simulation, the calibration process is carried out by changing the values of model parameters. Finally, the developed model is assessed based on the difference between the observed capacity and the estimated capacity.

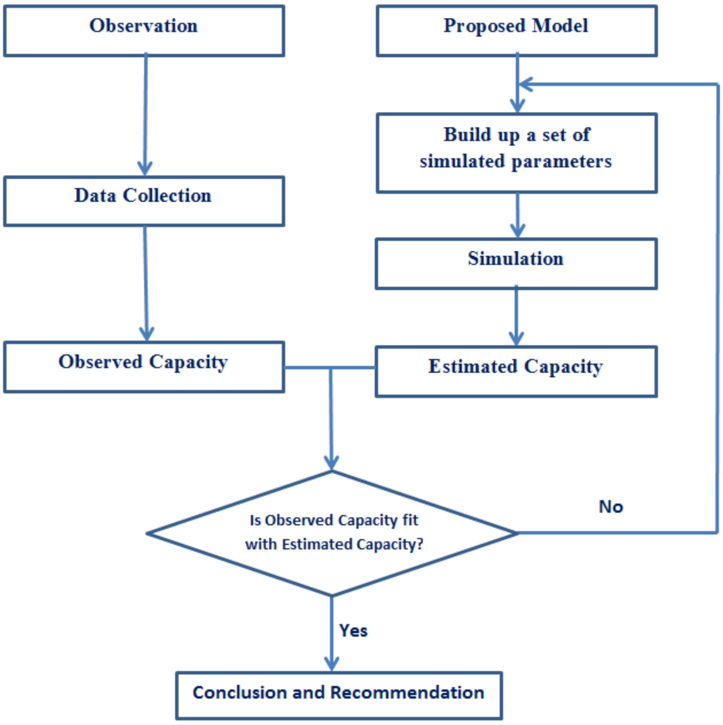


Figure 1: Simulation Framework

2. OBSEVRVED CAPACITY OF MIXED TRAFFIC FLOW IN VIET NAM

Data of traffic volume at each traffic stream were collected at peak hours (17:00- 18:00) to analyze the performance of different vehicles in mixed traffic conditions as well as the capacity of each flow. The data were also used to find out the mutual impact among the traffic flows, especially the impact between the left-turn stream and straight-through stream within a cycle time.

A two-phase signalized intersection in Ho Chi Minh City named as Cao Thang-3/2 intersection was selected. The total lane width of the major road and the minor road are 9.5 m and 6.0 m, respectively. The cycle length is 94 seconds. In each cycle length, the traffic volume of left-turn stream and straight-through stream were counted to assess the relationship between them, whether they have a mutual dependence or not. Actually, 65 observation pairs of left-turn vehicles and straight-through vehicleson the major road, in a total of 65 cycles, were collected to analyze the relationship between the two directions in terms of traffic volume 65 observation pairs were likewise collected following the same procedure onthe minor road. The general figure of the surveyed intersection is shown inFigure 2.

Figure 2: Surveyed Intersection (Cao Thang-3/2 Intersection)

The traffic counts showed that motorcycles usually contribute to about 92% of the total traffic during peak hours. Thus, the behaviour of motorcycles may represent the general behaviour of the traffic flow at the intersection. Moreover, there is a significant difference between the traffic volumes on the minor and major roads. On the major road the volume is greaterthan 250 vehicles at each cycle, while the figure on the minor road is usually lower than100 vehicles.

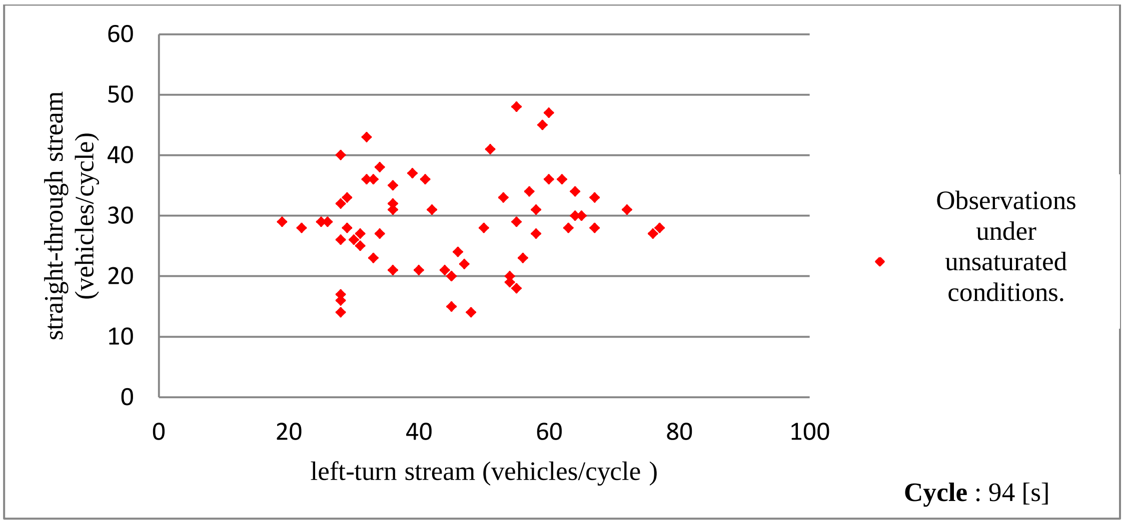


Figure 3: Relationship between traffic volumes of the left-turn and straight-through flows on the minor road at each cycle

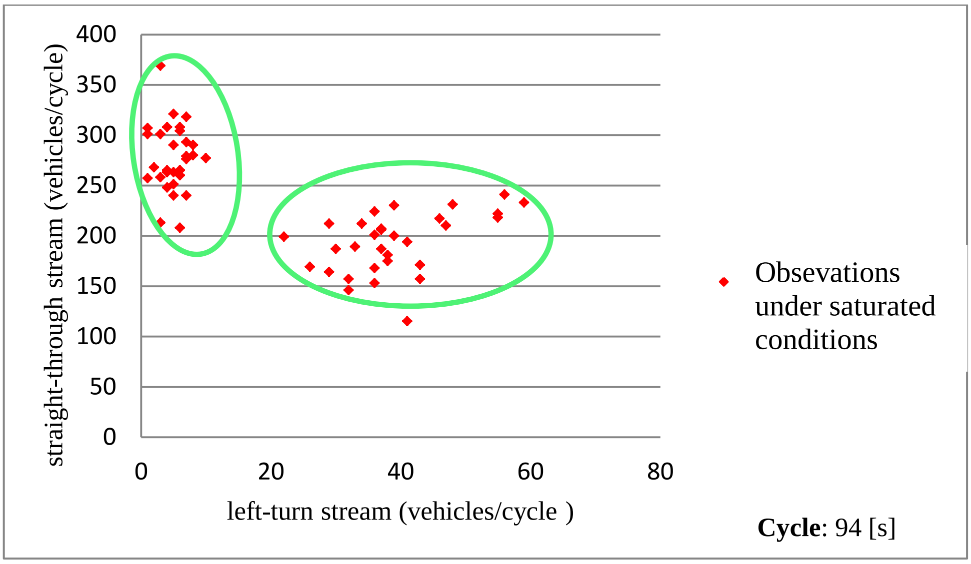


Figure 4: Relationship between traffic volumes of the left-turn and straight-through flows on the major road at each cycle

Figure 3 and Figure 4 show the relationship between traffic volumes of the left-turn flow and straight-through flow at each cycle. In figure 3on the minor road, although the data was collected at peak hours, it showed that there is a very weak correlation between the two traffic volumes as the distribution of the observations is scattered. In other words, the volume of the left-turn flow may not affect the volume of the straight-through flow. The reason could be that the observations are not under saturated condition. When the straight-through traffic is not so dense, the left-turn vehicles can easily find a suitable gap to cross the intersection. Furthermore, under the condition of mixed traffic with a very high share of motorcycles, due to its high flexibility and small dimensions, motorcycles can easily manoeuvre (i.e., change movement direction, change speed, or run in parallel) to find the quickest path to the destination. Thus, in case of low traffic density, vehicles can run independently regardless of direction and that is why we do not have the clustering in that graph.

However, on the major road, there seems to be a strong relationship between the two traffic streams. Figure 4shows that the higher the volume of the left-turn stream, the lower the volume of the straight-through stream, and vice versa. In other words, the performance of one stream may significantly affect the performance of another. When the traffic light turns green, motorcycles and other vehicles from both directions on the main road start to go through and turn left in order to cross the intersection. In case the traffic density is so high that the straight-through traffic flow reaches the saturation state, it is more difficult for the left-turn vehicles to find an acceptable gap than in the case of low traffic density. However, while waiting for an acceptable gap, the left-turn vehicles are willing to make groups and then cross the intersection together. If the left-turn group becomes big enough, it is likely to accept even a very small gap, thereby reducing the volume of the straight-through flow.Indeed, all observed have had saturated conditions, which usually means a remaining queue at the end of the green time.When vehicles entering the intersection in the main road can not fully discharge during the green time due to the hindrance of left-turn vehicles, especially the vehicles entering at the end of the green time period. Thus the left-turn vehicles running in the same phase with the straight-through vehicles influence the capacity of straight-through streams. The conflicts between individual vehicles actually become conflicts between the left-turn vehicle groups and the straight-through ones. Again, this is called grouping behaviour or group conflicts under the mixed traffic condition

It is interesting to look at the inter-group conflict phenomenon in detail. While negotiating the conflict, the behaviour of the leading vehicle(s) in each group, whether it is strong or weak, is likely to determine the performance of that group. In general, there are three types of inter-group conflict: (1) the left-turn group stops and yields the way, and the straight-through group continues moving forward; (2) the left-turn continues turning left while the straight-through stops and yields the way; (3) the left-turn continues turning left while the straight-through also continues moving forward. The conflict of the third type happens when both groups have the same strong behaviour and the same power, so they do not want to give the priority to each other. Vehicles from both groups mix together, decreasing the speeds and reducing the performance of both groups.However, if the driver of the leading vehicle in one group is more aggressive or stronger than the driver of the leading vehicle in the other group, the weaker group usually yields and gives the right of way to the stronger group. As a result, the conflict of the first or second types occurs. Such behaviours of inter-group conflict result in the pattern where the dots or observation points are distributed at two ends of the curve.Figure 4 clearly shows that formal right of way rules are not applied, but instead other factors like social forces can determine the capacity in each cycle significantly.

The result of the field survey gives a high motivation to develop a new model to explain the traffic performance at signalized intersections because the existing traffic flow models cannot describe the grouping behaviour discovered from observations. In the next chapter, a social force model will be developed by including new forces and factors in order to depict more exactly the traffic movement of vehicles in mixed traffic conditions.

3. PROPOSED SOCIAL FORCE MODEL FOR MIXED TRAFFIC FLOW

The use of social forces to model pedestrian movements was proposed by Helbing and Molnar(1995) to introduce the social force concept to explain the behaviour of pedestrians. Social forces include the forces that make a pedestrian change direction and speed in order to reach a specific target. These forces are classified into three groups: driving force, repulsive forces and attractive forces. The driving force helps pedestrians to move in the desired direction. The repulsive forces from the other vehicles or objects help the pedestrian to avoid collisions with other pedestrians or static obstacles. The attractive forces from the other people or objects help the pedestrian move to attractive objects(group of friends, window, pictures…). In fact, the application of social force model to analyse the movement of vehicles has already been mentioned by many researchers. Nguyen and Hanaoka (2011) introduced an application of social force model to describe non-lane based movementof motorcycles and describe the dynamic motion of motorcycles. Huang et al (2012) proposed a social force model that can be used to simulate the behaviour of vehicles on a two-dimensional space. The model is used not only for motorcycles but also for four-wheeled vehicles. However, in those social force modelsthe attractive force is omitted. So, the grouping behaviour of vehicles cannot be described and explained as observed in the field. Proposed social force model in this paper will be presented including the attractive force that makes vehicles run closer to form groups at signalized intersection.

At signalized intersections, traffic flows reach the saturation state at peak hours, the speed of vehicles is reduced to 12-15km/h and the movement characteristics are quite different compared with the state when vehicles are moving on the midblock. For example, vehicles run more slowly, try to avoid collisions, and make groups. From the original concept of social force model, our idea is that if we increase the speed of pedestrians from 4-6 km/h to

12-15 km/h and increase the social forces between them, the movement of pedestrians can be assumed as the movement of motorcycles' gravity center when moving at the intersection. Social forces for motorcycles are described in next chapters.

3.1 Determination of Vehicle's Dimension

To simplify the calculation model, each vehicle is represented by an ellipse shape. Depending on the actual dimensions of the vehicle, the ellipse shape will be different. The centre of the ellipse is the centre of the vehicle and general movement direction is the major axis of the ellipse (Figure 5).The radius $r(\varphi_{\alpha U})$in polar coordinate depends on the angle $\varphi_{\alpha U}$and the direction is as follows:

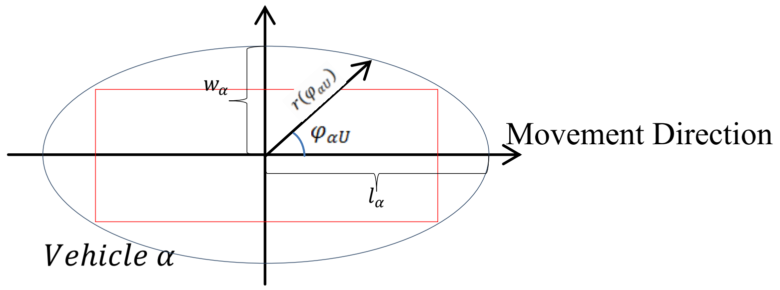


Figure 5: Ellipse shape to represent a vehicle

$$r(\varphi_{\alpha U}) = \frac{w}{\sqrt{1 - \frac{l^2 - w^2}{l^2} cos\varphi_{\alpha U}{}^2}} \tag{1}$$

where,

$r(\varphi_{\alpha U})$:radius in polar coordinate,
$\varphi_{\alpha U}$:angle in polar coordinate,
w_α, l_α :a half of the average width and length of the vehicle.

In mixed traffic conditions, there are several types of vehicle such as car, motorcycle, bus, small truck, large truck, etc., and each vehicle type has different dimensions. In this study, each major type of vehicle is represented by one ellipse shape with dimensions as shown inTable 1.

Table 1: Dimensions of vehicles

Type of Vehicle	Length (2l)	Width (2w)
Motorcycle	2m	0.7m
Car	4.7m	1.9m
Bus	10.5m	2.5m

3.2 Driving Force to move in the Desired Direction

A motorcycle in a free flow state always tends to move to a desired direction $\vec{e}_\alpha$ at a desired speed $\vec{v}_\alpha^0$. At a signalized intersection, a driver will change his speed from the current speed to a desired speed within a certain time τ_α if he thinks he can do so in order to pass the intersection as soon as possible. The speed change behavior can be explained by formulating a driving force as below:

$$\vec{F}_\alpha^0(\vec{v}_\alpha; v_\alpha^0 \vec{e}_\alpha) = \frac{1}{\tau_\alpha}(v_\alpha^0 \vec{e}_\alpha - \vec{v}_\alpha) \tag{2}$$

Where:

$\vec{v}_\alpha^0 = \vec{e}_\alpha \times v_\alpha^0$: desired speed of vehicle,
$\vec{v}_\alpha$: current speed of vehicle,
τ_α : relaxation time.

The driving force helps the motorcycle move forward, otherwise it cannot reach the destination. The smaller the driving force, the smaller the difference between the desired and the current velocity v_α. It is noticeable that the desired speed does not point into the beeline connecting direction to the destination but approximately to the next corner on the way to the destination.

3.3 Repulsive Forces from Other Vehicles

The movement of motorcycle α is affected by other vehicles. When another motorcycle β moves closer, motorcycle α will tend to reduce its own speed and tries to move far away from the influencing motorcycle to make it safer and more comfortable. This phenomenon can be explained by the repulsive forces of influenced vehicles to the studied or targeted motorcycle.

During the time Δt, the targeted motorcycle α and the influencing motorcycle β run in the distance of the distance of $\Delta t\ v_\alpha$and $\Delta t\ v_\beta$respectively. It is assumed that the targeted motorcycle will depend on the movement of other motorcycles in the next time step to figure out the space it needs. So, if we pose the relative coordinate on the motorcycle α and observe the movement of motorcycle β, vehicle β will run with the distance of $\Delta t\ \Delta v_{\alpha\beta}$ within the time Δt. The distance of motorcycle β from the time (t) to the time (t+Δt) can be assumed as the distance between two focus points of one ellipse that position of target motorcycle α pose on it (Figure 6)

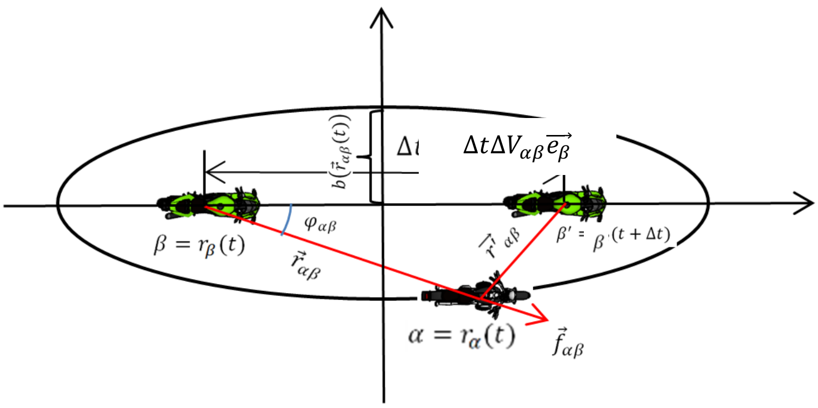


Figure 6: Repulsive Force between two motorcycles

For an ellipse, the sum of the distances from any point on the ellipse to those two focus points is constant.

$$r_{\alpha\beta} + r'_{\alpha\beta} = 2 \times \sqrt{(b^2 + \left(\frac{\Delta t\ \Delta v_{\alpha\beta}(t)}{2}\right)^2} \tag{3}$$

With $r'_{\alpha\beta} = \left\|\vec{r}_{\alpha\beta} - \Delta t\ \ \Delta v_{\alpha\beta}(t)\vec{e}_\beta\right\|$(4)

Thus, the semi minor $b\left(\vec{r}_{\alpha\beta}(t)\right)$ can be derived as below:

$$b = \frac{1}{2} \times \sqrt{((\left\|\vec{r}_{\alpha\beta}\right\| + \left\|\vec{r}_{\alpha\beta} - \Delta t \Delta V_{\alpha\beta}(t)\vec{e}_\beta\right\|)^2 - (\Delta t\ \Delta V_{\alpha\beta}(t)\vec{e}_\beta)^2} \tag{5}$$

The repulsive force can described as a monotonic decreasing function of b as described below:

$$\vec{f}_{\alpha}^{\beta}\left(\vec{r}_{\alpha\beta}(t)\right) = -\nabla_{\vec{r}_{\alpha\beta}} V_{\alpha\beta}[b\left(\vec{r}_{\alpha\beta}(t)\right)] \tag{6}$$

$$\vec{f}_{\alpha}^{\beta} = A_{\alpha\beta} e^{\frac{-b}{B_{\alpha\beta}}} \vec{n}_{\alpha\beta} \tag{7}$$

Where:

$V_{\alpha\beta}$: therepulsive potential between α and β,
$\vec{r}_{\alpha\beta}$: currentdistance between motorcycle α and β,
$\vec{n}_{\alpha\beta}$: theunity vector pointing from the influencing to the influenced vehicle,
$A_{\alpha\beta}$,$B_{\alpha\beta}$: parameters.

3.4 Repulsive Force from the Border

The driver of motorcycle α tends to keep a distance from a border B (such as median strip, curb, guardrail) to avoid hitting it. If it runs closer to the border, it will reduce the speed and change the direction to go far from the border. This effect can be explained by repulsive force of the border as below.

$$\vec{F}_{\alpha}^{B} = U_{\alpha B}(\|\vec{r}_{\alpha B}\|) \tag{8}$$

Equation (8) has the same formulation as Equation (6). Therefore, the assumptions of repulsive force from other vehicles can be applied in repulsive force from the border.$d_{\alpha B}$indicates the distance from the targeted motorcycle to border B that is nearest to the motorcycle. It is assumed thatthe repulsive force is a linear function of the distance.

$$\vec{f}_{\alpha B} = A_{\alpha B} e^{\frac{r_{\alpha} - d_{\alpha B}}{B_{\alpha B}}} \vec{n}_{\alpha B} \tag{9}$$

Where:

$U_{\alpha B}$: therepulsive potential between α and B,
$\vec{r}_{\alpha B}$: currentdistance between motorcycle α and B
$\vec{n}_{\alpha B}$:theunity vector pointing from the border to the influenced vehicle,$A_{\alpha B}$,$B_{\alpha B}$: parameters.

3.5 Attractive Force from the Leading Vehicle

In case of crowded traffic, when entering the intersection, vehicles that move in the same direction tend to make groups. As mentioned above, this helps them get more confident and more powerful to cross the intersection as soon as possible. This phenomenon can be explained by assuming that the targeted vehicle is attracted by the preceding vehicle or vehicles. The attractive force increases as the distance between the object vehicle and the preceding vehicle increases.This is a new feature and may also be a contribution of this paper because the previous social force models did not mention the grouping behavior and the attractive force between the targeted vehicle and the preceding vehicle.

Figure 7: Grouping behaviour of vehicles

The attractive function is assumed as an increasing function of the distance between the subjectvehicle and the preceding one, and decreasing function of the time t. The function is created as followed:

$$W_{\alpha i} = C_{\alpha i} e^{\frac{d_{\alpha U} - (r_{\alpha} + r_{i)}}{D_{\alpha i}}} \vec{n}_{\alpha i} \quad (10)$$

Where:

$d_{\alpha i}$: distancepoints from the center of vehicle α to the center of vehicle i,
r_{α}, r_i : theradius of vehicle α and i,
$\vec{n}_{\alpha i}$: theunit vector pointing from the vehicle α to the vehicle i,
$C_{\alpha i}$,$D_{\alpha i}$: parameters.

To define the precedingvehicle of the targeted vehicle, some assumptions should be established. Firstly the precedingvehicle must be in the vision of targeted vehicle. Secondly the precedingvehicle must have the closest distance with the targeted vehicle.

3.6 Boundary Condition between Repulsive Force and Attractive Force

There is a relationship between the repulsive force and the attractive force that applies to the targeted vehicle. The repulsive and the attractive occur only when the distance between the influenced vehicle and the influencing vehicle reaches a certain value calledD_{effect} (the distance between the two vehicles is the distance between two ellipse shapes that represent those vehicles). Ifthe distance between the two vehicles is higher than an effective distance,there is no interaction between them and so the repulsive force and the attractive force will not occur.

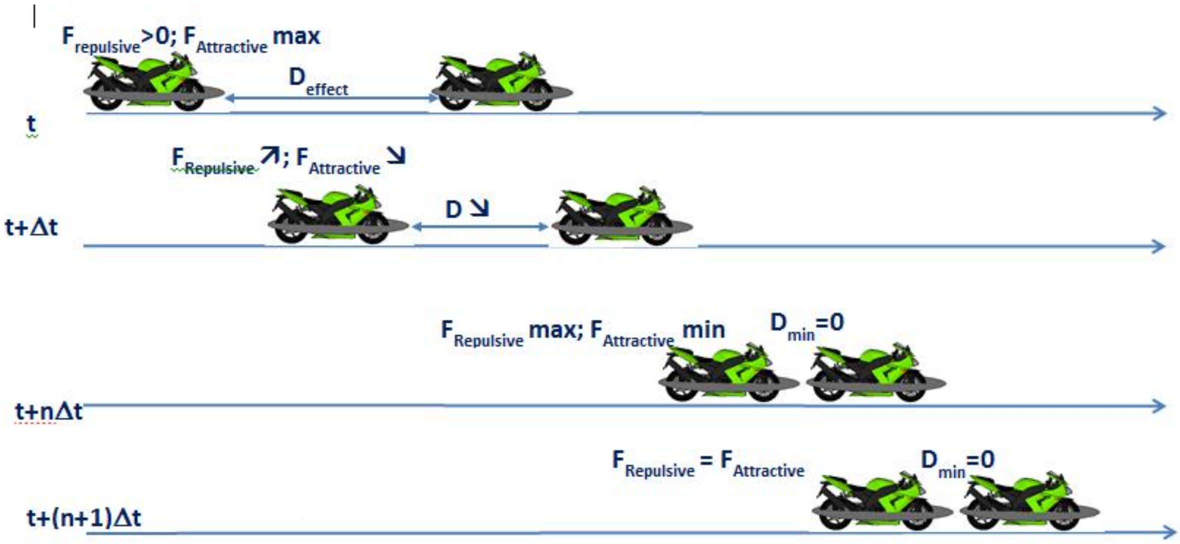


Figure 8: The relationship between repulsive force and the attractive force

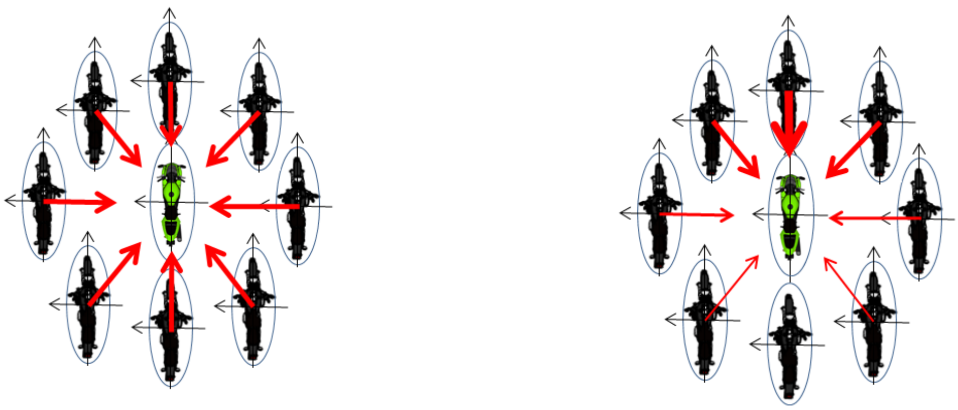
Figure 8depicts the interaction between the subject vehicle and the preceding vehicle over time. More specifically, at time t when the distance between two vehicles reachesD_{effect}, the repulsive force and the attractive force occur. According to the aforementioned, the attractive force reaches the largest value and the repulsive force is quite low due to the far distance. At time t+Δt, the targeted vehicle try to get closer to the leading vehicle to reduce the gap between them, which leads to the reduction of distance, and as a consequence the repulsive force increases and the attractive force decreases respectively. Until time t+nΔt when the targeted vehicle reaches the closest distance with the leading vehicle, the distance between two vehicles reduces to zero. At that time the repulsive force can reach the max value and the attractive force goes down to the minimum value accordingly. Finally in the next time t+(n+1)Δt, the targeted vehicle will always try to maintain the closest distance with the leading vehicle so the vehicles from conflicting stream cannot cross. At that time, the following vehicle will run at the same speed and the same direction as the leading vehicle. This means that the driving force of two vehicles is the same and the repulsive force and the attractive force of the following vehicle is equal. This is the boundary condition of the repulsive force and the attractive force in this model.

3.7 Angle of Sight

Angle of sight is a factor included in the model to demonstrate different impacts of influential vehicles to the targeted vehicle depending on the positions between them. The driver is certainly affected by objects or vehicles in his or her angle of sight. On the other hand, he or she can also be impacted by vehicles at the back because he or she can hear the sound of the vehicles. Obviously, the impact of a rear vehicle is smaller than the one in front of the targeted vehicle. To capture such influence, a factor w ($0<w<1$) is introduced in Equation (11).

$$w_{\alpha U} = \lambda_{\alpha U} + (1 - \lambda_{\alpha U}) \frac{1+\cos(\varphi_{\alpha U})}{2} \quad (11)$$

In Equation (11), w depends on the angle of sight between the last direction of movement of the targeted vehicle and the position of the influencing vehicle and the parameter lambda, which represents the impact strength of the influential vehicle. If $\varphi=0$, w becomes 1 regardless of lambda value. This means that the vehicle directly ahead of the targeted vehicle has the highest impact strength. If λ=1, then w=1, this leads to the fact that the influential vehicle at any position will have the same impact strength on the targeted vehicle (this is not realistic) (Figure 9a). In case λ=0, w=(1+cos φ)/2, the impact strength will be more exact (Figure 9b). All the vehicles at the back of the targeted vehicle will have no impact. With 0≤ λ<1, the front vehicles will have more impact on the targeted vehicle than the vehicles behind.



λ=1 (a) λ=0 (b)

Figure 9: The level of impact force according to the angle of sight and the value of lambda

To take the effect of perception of effective angle into account, the weaker influence *w* should be included in the repulsive and attractive forces (as shown below).

Repulsive Force from other vehicles
$$\vec{f}_{\alpha U}^{soc} = w_{\alpha U} A_{\alpha U} e^{\frac{r_\alpha + r_U - d_{\alpha U}}{B_{\alpha U}}} \vec{n}_{\alpha U} \quad (12)$$

Repulsive Force from Border:
$$\vec{f}_{\alpha B} = w_{\alpha B} A_{\alpha B} e^{\frac{r_\alpha - d_{\alpha B}}{B_{\alpha B}}} \vec{n}_{\alpha B} \quad (13)$$

Atractive Force from leading vehicle
$$W_{\alpha i} = w_{\alpha i} C_{\alpha i} e^{\frac{d_{\alpha U} - (r_\alpha + r_{i)}}{D_{\alpha i}}} \vec{n}_{\alpha i} \quad (14)$$

In summary, the sum of all social forces will create a total force that can help the vehicle move to the destination. The total force can be calculated as follows:

$$\vec{f}_\alpha(t) = \frac{d\vec{V}(t)}{dt} = \vec{f}_\alpha^0 + \sum_{U(U \neq \alpha)} \vec{f}_{\alpha U} + \sum_B \vec{f}_{\alpha B} + \vec{f}_{\alpha i} + \vec{\xi} (15)$$

$$\vec{f}_\alpha(t) = \frac{d\vec{V}(t)}{dt} = \frac{1}{\tau_\alpha}\left(v_\alpha^0 \vec{e}_\alpha - \vec{v}_\alpha\right) + \sum_{U(U \neq \alpha)} w_{\alpha U} A_{\alpha U} e^{\frac{r_\alpha + r_U - d_{\alpha U}}{B_{\alpha U}}} \vec{n}_{\alpha U} + \sum_B w_{\alpha B} A_{\alpha B} e^{\frac{r_\alpha - d_{\alpha B}}{B_{\alpha B}}} \vec{n}_{\alpha B} + w_{\alpha i} C_{\alpha i} e^{\frac{d_{\alpha U} - (r_\alpha + r_{i)}}{D_{\alpha i}}} \vec{n}_{\alpha i} + \vec{\xi} \quad (16)$$

4. SIMULATION OF TRAFFIC PERORMANCEIN MIXED TRAFFIC CONDITION

In this chapter, simulation of traffic performance of the surveyed intersection will be represented by using VISWALK, the software used so far for simulating pedestrian motion. By changing parameters of the model, the output of the simulation process is the traffic volume of left-turn stream and straight-through stream at each cycle are collected. Then a graph about the relationship between two streams will be described to compare with the real observed situation.

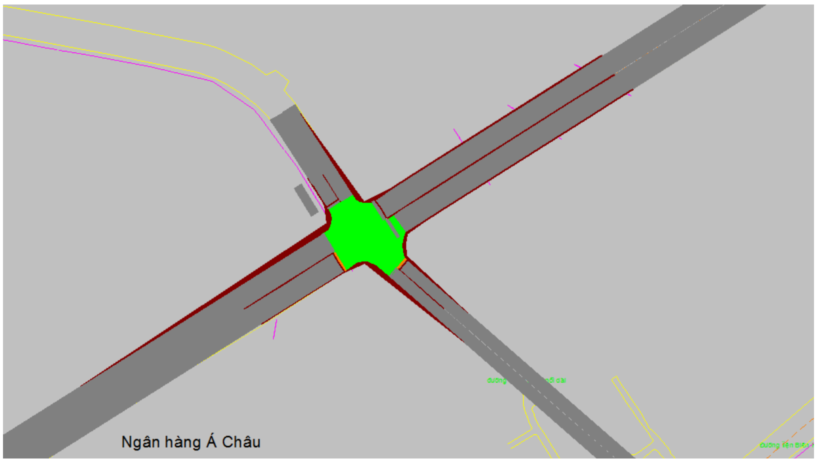


Figure 10: Layout of Simulated Intersection

Social force model is applied to simulate the pedestrian's motion in VISWALK. From that, the force acting on a pedestrian, causing him to decelerate or accelerate is composed of four forces: Driving Force ($\vec{F}_{Driving}$) helps a pedestrian move forward to the destination, social force ($\vec{F}_{Social}$) and force from wall ($\vec{F}_{wall}$) are the repulsive forces that help a pedestrian avoid the conflicts with other pedestrians and other static obstacles, and finally the force from noise ($\vec{F}_{noise}$) represents the strength of the random force term. However, the attractive force is not used in VISWALK due to simplifying the model. So the purpose of the simulation is to test the affect degree of attractive force to the general movement behaviour of vehicles

$$\vec{F} = \vec{F}_{Driving} + \vec{F}_{Social} + \vec{F}_{wall} + \vec{F}_{noise} \quad (17)$$

$$\vec{F}_{Driving} = \frac{\overrightarrow{v_o} - \vec{v}}{\tau} \quad (18)$$

$$\vec{F}_{social}(\vec{F}_{wall}) = w(\lambda_i, \varphi_{ij}) \sum_{j=1}^{react\_to\_n} A_i \exp(-\frac{d_{ij}}{B_i}) \hat{d}_{ij} \quad (19)$$

Where:

$\overrightarrow{v_o}$	: desiredspeed of vehicle,
$\vec{v}$	: currentspeed of vehicle,
τ	: relaxationtime,
$w(\lambda_i, \varphi_{ij})$	: functiondescribes the influence of angle of sight,
$react\_to\_n$	: numberof Influential Vehicles, n=8
A_i,B_i	: parameters.

Table 2 shows a list of VISWALK parameters that need to be modified in order to simulate the motion of vehicles. Firstly, the desired speed, v_{α}^{0}, is increased from the default value (4-6 km/h) to 12-15 km/h as the vehicle speed observed in real situation. Then, the vehicle dimension parameters (L, W) are changed according to the type of the vehicle as shown in Table 1**Error! Reference source not found.**. Next, the parameters of the social forces ($A_{\alpha U}$, $B_{\alpha U}$) are increased until the forces can create the space around the targeted vehicle that is similar to the real situation. Parameter λ is set to zero to reflect the level of impact force depending on the angle of sight. The parameter N is set to 8 to reflect 8 influential vehicles around the targeted vehicle. Finally, the simulation time step period (dt) is reduced from 0.05s to 0.01s to calculate more accurately the motion of the vehicle that runs at a higher speed and has larger dimensions than the pedestrian. The result of simulation process is shown in Figure 11.

Table 2: List of Modified Parameters in VISWALK

Description	Parameter	Motorcycle	Car	Bus
Desired Speed	v_α^0	12-14 km/h	12-14 km/h	12-14 km/h
Relaxation Time	τ_α	0.9	1	1.2
Social Force from other Objects (vehicles, pedestrians, static obstacle)	$A_{\alpha U}; B_{\alpha U}$	3,2	4,2	5,2
Form Factor Constant	λ	0	0	0
Length of Vehicle	L	2	4.7	10.5
Width of Vehicle	W	0.7	1.9	2.5
Number of Influential Vehicles	n	8	8	8
Random Part	Noise	1.2	2	2
Simulation time step period per second	dt	0.01	0.01	0.01

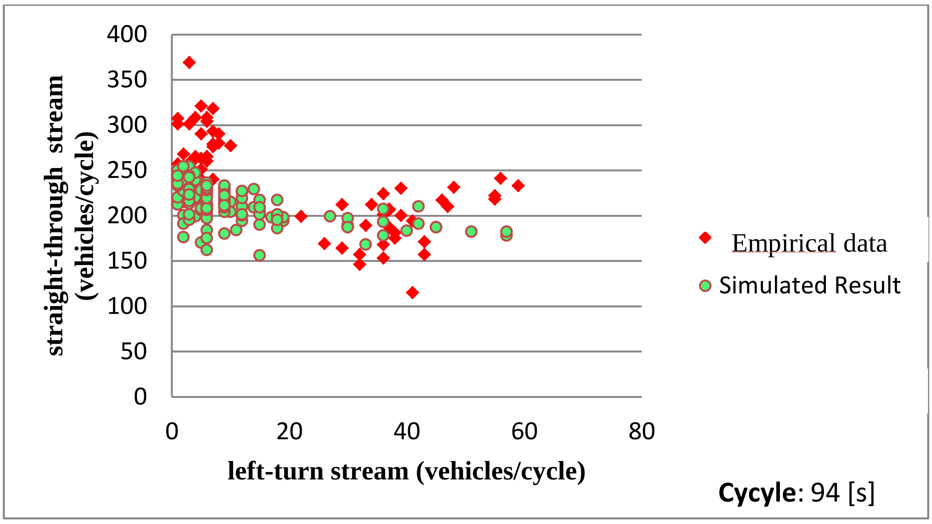


Figure 11: Simulated relationship between the traffic volumes of the two flows on the main road at each cycle

Figure 11compares the traffic volume relationship between the empirical data (or real observations) and the simulation result. The simulation result also shows the trend of the interdependent relationship of two streams, left-turn stream and straight-through stream. When the volume of the left-turn stream increases, the volume of the straight-through stream decreases due to the conflict and vice versa. However, the Social Force Model applied in VISWALK does not include the attractive force.As a consequence, the grouping behaviour is not reflected. In the model, vehicles' motionsare created by the combination of driving force and repulsive force. The driving force helps vehicles to run to the destination with the desired speed and the repulsive force helps vehicles avoid other vehicles and static obstacles. There are also many cases where vehicles in two streams mix together to cross the conflict area. So in Figure 11, we can see that the dots of the simulated result distribute more evenly than the dots from empirical data.

In conclusion, the existing VISWALK software cannot be applied to simulate the performance of traffic streams in mixed conditions at the signalized intersection due to lacking attractive force. It needs to be improved to put this kind of force into the model to describe more accurately the movement behaviour of vehicle in such mixed conditions in the future.

5. CONCLUSION AND FUTURE WORK

This paper describes in details the traffic performance of and the relationship among traffic streams at the signalized intersection under the mixed traffic conditions. The result from the field survey indicates that the traffic behaviour depends on the traffic state. In fact,in uncrowdedtraffic, vehicles run independently and do not affect each other. But in crowded traffic, vehicles in each stream tend to make groups to cross the intersectionand they influence each other.More specifically, the left-turn group and opposite straight-through group affect each other when they run in the same phase. As a result, the capacity of vehicles going in one direction is changed depending on the number of vehiclesgoing in the other direction.

This paper also describes a microscopic traffic flow model that can be used to simulate the behaviour of vehicles based on the social force model. From the proposed social force model, attractive force is introduced as the most valuable contribution to make a comprehensive force compared with other social force models that were developed byother researchers.

Compared to the social force model for pedestrian, the proposed model is more complex. It needs to be modified with regard to the list of major parameters in the model. The modified parameters reflect more accurately the actual movement of vehicles, especially motorcycles, with consideration to speed, vehicle dimensions, safety space, and grouping behaviour. These remain for future work. Furthermore, more field surveys should be conducted so as to capture various traffic situations, such as variable share of passenger cars in the mixed traffic.

REFERENCES

Helbing, D., Molnar, P. (1995) Social force model for pedestriandynamics. *Physical Review E*, Vol.51, No.5, pp.4282-4286.

Ho Chi Minh City Department of Transport(2012) General Report, Ho Chi Minh City, Viet Nam.

Huang, W., Fellendorf, M., Schoenauer, R. (2012) Social Force based Vehicle Model for Two-Dimensional Spaces. *Transportation Research Board 91st Annual Meeting.*

Lawrence, W.L., Chiung-Wen, C. (2003) Motorcycle's moving behavior in mixed traffic:
Particle-hoping model with cellular automata.*Journal of the Eastern Asia Society for Transportation Studies*, Vol.5, pp.23-37.

Nguyen, X.L., Hanaoka, S. (2011) An Application of Social Force Approach for Motorcycle Dynamics. *Proceedings of the Eastern Asia Society for Transportation Studies*, *Vol 9*.

PTV Planung Transport Verkehr AG. (2012)*VISSIM 5.40 User Manual;* Karlsruhe, Germany.

Steffen, B. (2008) A Modification of the Social Force Model by Foresight.*PED - Pedestrian and Evacuation Dynamics 2008.*

Tom, V.M. (2012) Chapter 14: Car Following Models. *Traffic Engineering and Management.*

Vu, A.T., Shimizu, T. (2009) An analysis of the interactions between vehicle groups at intersection under mixed traffic flow conditions, *Journal of the Eastern Asia Society for Transportation Studies,* Vol. 8, pp.1999-2017.