Development of the Conflict-Solving Model to Simulate the Mixed Traffic Behavior

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The paper focus on the unique mechanism to solve the conflict of motorcycle, named conflict-solving model. The proposed model is based on the two-player game theory and anticipation approach. The microscopic simulation, which is developed from the model, replicate effectively the maneuver to avoid accident of motorcycle. The erratic trajectory of motorcycle at intersection are reproduced successfully in the simulation. The simulated trajectories in conflict and non-conflict situation is compared with the real trajectory from the videos. The results reveal the effectiveness of suggested model in replicating motorcycle behavior at intersection, with the error 0.24 meters is small compared to the motorcycle lateral size 1 meter.

Key Words : *Game theory, Conflict-solving Model, Mixed traffic, Intersection, Microsimulation*

1. INTRODUCTION

Motorcycles contribute a high proportion of transportation in the large cities in Asian countries. In these cities, not the homogeneous traffic but the mixed traffic is the actual road condition. And motorcycles, which have high flexibility and freedom, continuously maneuver and alter speed to maximize their utility. The major issue is to describe the erratic trajectories of motorcycle. Even though several previous researches studied about the non-lane-based movement, the intersection field, specifically when motorcycle conflicts with other vehicles, receives less attention. Therefore, this study focuses on the accident avoidance's mechanism of motorcycle at intersection.

Many researchers have made an effort to build the complex and unorganized traffic system. One of the approach that is "to treat vehicles as individual units instead of a continuous flow and see what behavior emerges when vehicles are given simple rules to follow" [1]. Following this trail, as one of the possible solution to simulate the traffic system is the agent-based modelling. By definition, "Agent-based modelling is a microscopic computer simulation technique focusing on simulating the actions and interaction of cluster of computational agents" [2]. On the road, the traffic is also regarded as the combination of vehicles' movements. Each moving vehicle is regarded as an individual agent. Thus, many researches have successfully used the agent-based model in traffic simulation [1,3,4,2,5,6]. The traffic simulation in this study has been developed by using the *NetLogo*, an integrated agent-based modelling environment.

In order to tackle the conflict, the gap acceptance principle was popularly applied at intersection [7]. The theory is that vehicle is only allowed to move into intersection when the time between two vehicles must be sufficient to allow insertion into or crossing of a flow. The gap acceptance behavioral model was developed for the two-wheelers at the uncontrolled T-intersection [8]. The model focuses on resolution of conflict between turning flow and the opposite straight-through. Even though the model uses adaptive neuro-fuzzy interference technique for given the critical lag and gap, it does not consider the opportunistic behaviors in the decision making process.

While most of the models employed the priority rule, which is only obeyed by four-wheeled vehicles, there is another promising manner to solve a conflict. The anticipation approach and two-player game theory are applied to build the microsimulation model for pedestrian movement [9]. However, the study's subject is pedestrian and the study's scope is Japan, the model must be modified before applied for motorcycle. For example, the differences in size and shape lead to the differences in specifying distance between pedestrian to pedestrian and vehicle to vehicle.

In addition, the interactions between vehicles inside intersection were examined in following researches. A simulation model is proposed for the non-crossing flow at signalized intersection in terms of queue density and dissipation under heterogeneous traffic [10]. The relationship between group behavior and conflict inside the intersection are made clear [11]. The social force are also applied to describe the group behavior of motorcycle at signalized intersection [12,13].

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In this background, the idea to apply the anticipation movement and the two-player game theory to describe the interaction mechanism of motorcycle is conducted. The study has the main objective is that to develop the conflict-solving model to replicate the "cut tail" and "giving way" behavior of motorcycle.

2. SIMULATION FRAMEWORK

Generally, the vehicle's movement is contributed from several models, the mid-block running model, the emergency model and intersection reaction model. Inside the intersection reaction model, there are two sub-models intersection-traveling model and conflict-solving model. Each model is designed to produce some particular behaviors. Based on the perceived situation, the controller decides which model is reasonably invoked by determining acceleration and direction for next moving step. **Fig.1** illustrates the model framework of the simulation.

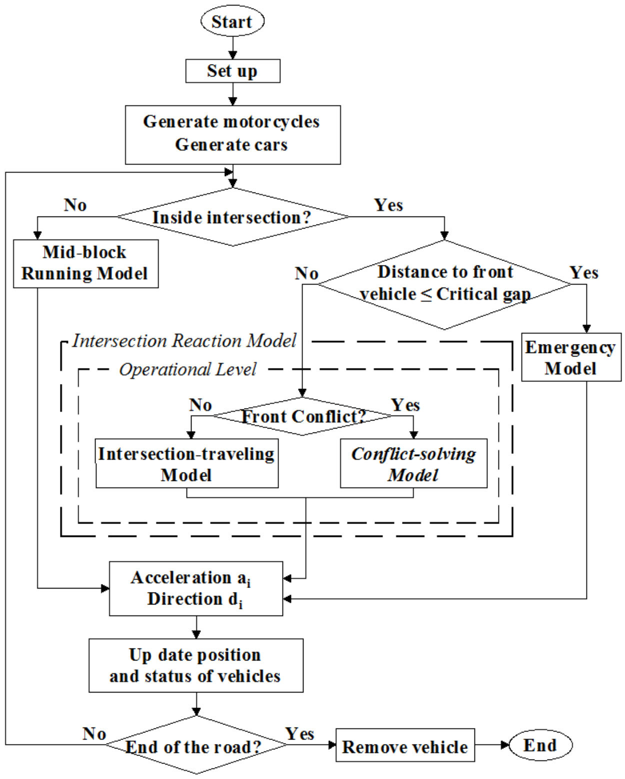

Fig.1 Framework of the simulation

3. INTERSECTION REACTION MODEL

In multidirectional flows environment, vehicles from one flow usually get conflict with vehicles from other crossing flows, especially motorcycle. While each motorcycle has its own intended trajectory, the collision is unavoidable if every motorcycle insists on taking its intended trajectory. However, in the reality, motorcycles can keep away from an accident by changing the velocity and moving direction. The intersection reaction model responds to these behaviors of motorcycle. The model simulates the making decision procedure to reach the destination while avoiding collision with other vehicles. The model is structured into three levels, strategic level, tactical level and operation level as followings.

(1) Strategic level

The strategic level is the generalist level of the intersection reaction model. Each generated vehicle is assigned several characteristics, included the original position, original direction, decision at intersection and other properties. The decision at intersection could be go straight, turn left or turn right. In this level, the destination position and direction are provided.

(2) Tactical level

The tactical level determines the macroscopic route that minimizes travel time from the entering to existing position at intersection. Based on the position and requirements from the strategic level, the desired direction, an altering by time vector, is provided as an input for operational level.

In order to produce a smooth and authentic trajectory, the simulator applies the parabola-based trajectory. The defining desired direction process goes through these following steps. Firstly, when the motorcycle is generated, the route choice inside intersection as an input from the strategic level. Secondly, when the motorcycle enters the intersection, the virtual destinations were given to keep the motorcycles turn towards the chosen route and lead vehicle out of the intersection. The trajectory is approximated from the entering point to the destination in parabolic shape.

Following the parabola-based trajectory, the desired direction is assumed to be the tangent line of the parabola at the current position. The parameters of parabolic are calculated based on the coordination of two given points. With the assumption that the first point, the peak of parabolic, is the first virtual destination and the second point is the current position of motorcycle.

(3) Operational level

The operational level calculates the algebraic value of acceleration and acceleration angle .In the moving process, the model assumes that motorcycle wants to move towards the desired direction so far as possible. The velocity and moving direction is smoothly changed by updating the value of acceleration and acceleration angle after each 0.1 second.

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4. ANTICIPATION MOVEMENT APPROACH

In order to declare the status of vehicle, the anticipation movement approach is utilized. The anticipation movement is the predicting trajectory of a vehicle from the current position. During the anticipation period *T*, all motorcycles are assumed that they will consistently move in the same direction and velocity as at time *t*. These vehicles' information are assigned to the environmental layer as the anticipation line. The anticipation line is a straight line from the middle point of vehicle towards the moving direction. The length of this line equals the anticipation movement length, which is calculated as following equation,

$$L_{anticipation} = T \times V_{current} \tag{1}$$

where,

$L_{anticipation}$ (m) : the anticipation approach length

$T = 1.5\,\text{second}$: the anticipation period

$V_{current}$ (m/sec) : the velocity at the calculation time

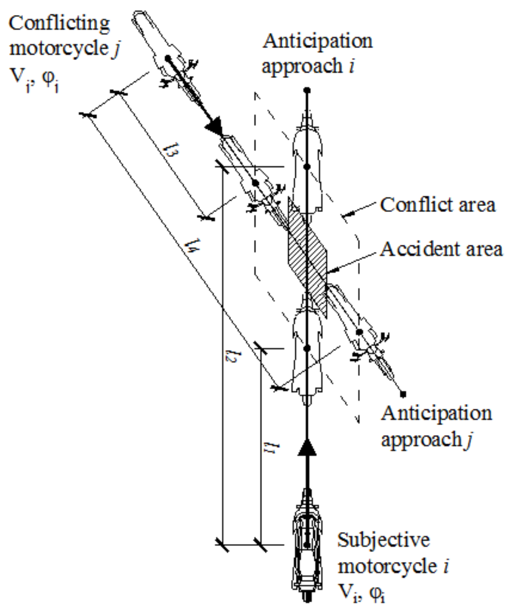


Fig.2 Conflict area recognition

The cross between two or more anticipation lines is the sign of the conflict area. Thus the crossing point is employed as an indicator for the potential accident recognition as exemplified by the **Fig.2**.

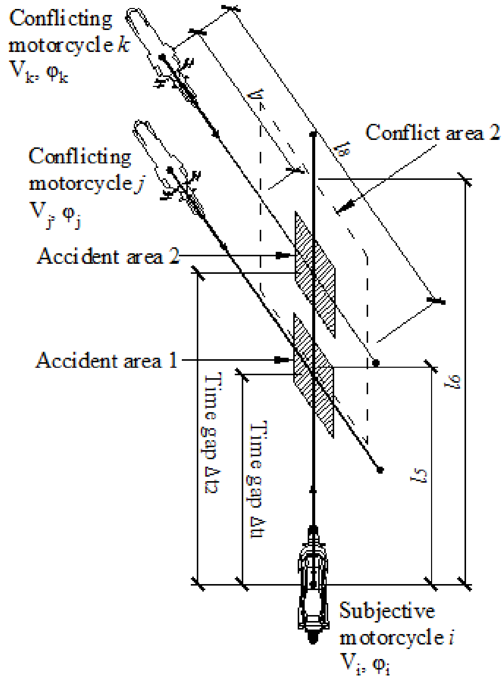


Fig.3 Multi-conflict area situation

Consider the case of conflict between subjective motorcycle i and conflicting motorcycle j are given in **Fig.2**. The subjective motorcycle i is moving with the velocity V_i at the direction φ_i and the conflicted motorcycle j is moving with the velocity V_j at the direction φ_j. The anticipation line i and band j is the moving area in the anticipation period. The hatched box shows a potential accident area with the consideration of motorcycle' width. Each vehicle identifies its conflicts by these crossing points along the anticipation line. However, as mentioned in the two-player game theory, among these conflicts, only the closest conflict in time gap is considered. For example, in **Fig.3**, the conflict area 1 is closer than the conflict area 2 and therefore is considered.

5. CONFLICT-SOLVING MODEL

(1) Calculation

It is assumed that subjective motorcycle i shows the "*giving way*" behavior and conflicting motorcycle j insist on its current direction and velocity. The subjective motorcycle i has sixty one options in the choice set Ω to stay away from collision. The maximum moving distance of motorcycle i at the direction θ_m, which is denoted by $L_j^i(\theta_m)$, is calculated within the anticipation period T. This calculation is taken with the assumption that velocity of motorcycle i, namely V_i, is a constant during the anticipation period T. Each option θ_m in the choice set Ω is calculated to find out the possible moving distance along the desired direction. On the purpose of maximizing the moving distance toward the desired direction φ_d, the optimal direction θ_{opt} is chosen as the farthest distance along the desired direction φ_d among the choice set as the following equation,

$$q_{opt} = \max_{q_m \in \Omega}\left(L_i^j\left(q_m\right)\cos\left(q_m - j_d\right)\right) \quad (2)$$

where,

q_{opt} : the optimal direction in the choice set Ω

$L_i^j(q_m)$: the maximum moving distance of motorcycle i at the direction q_m

q_m : one of direction in the choice set Ω

j_d : the desired direction

Fig.4 shows an example for calculating the optimal direction θ_{opt} when subjective motorcycle i comes to conflict with two motorcycles, namely j and k, at direction θ_m. Even though the two-player game theory is applied, the anticipation movement of the second conflicting motorcycle k is also taken into account for calculation the optimal direction θ_{opt}.

The acceleration towards the optimal direction in this model is calculated by assuming that motorcycle minimizes the number of change in velocity. Consider the case in **Fig.4**, the optimal velocity is chosen as the dashed line. If there are no expected collision in the anticipation period T, the motorcycle continues to go in their desired direction and speed up until the desired velocity. This behavior results in the maximum moving distance towards desired direction φ_d within the anticipation period T with the velocity below the desired velocity.

Consider the two conflict area recognized, there are six possible cases of conflict situation. In each case, vehicle reacts in the different way. The equation of the maximum distance also split into six small case based on the value of the anticipation period T. The T value could belong to the following intervals; $[0, t_3]$, $[t_4, t_3]$, $[t_4, t_7]$, $[t_7, t_8]$, $[t_8, \infty]$. The specific equations are presented in **Table 1**.

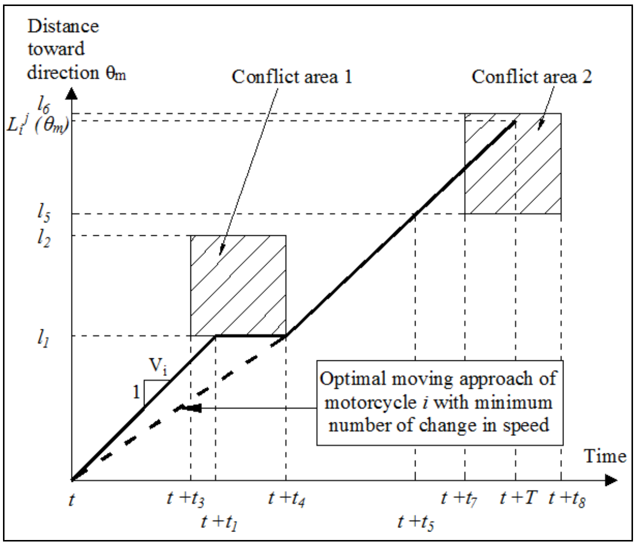


Fig.4 Calculation of maximum moving distance at one direction

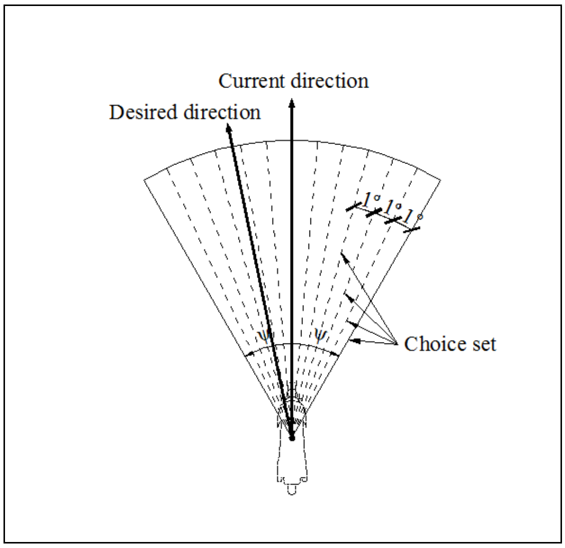


Fig.5 Choice set of motorcycle's moving direction

Table 1 Equation of the maximum moving distance

Case	t_1 vs t_4	t_5 vs t_7, t_8	*T* (compare with the below values) 0 – t_3	t_3 – t_4	t_4 – t_7	t_7 – t_8	t_8 – ∞
1	$t_1 > t_4$	$t_7 \le t_5 \le t_8$	L = Tv			L = l_5	L = l_5 + (T – t_8)v
2		$t_5 > t_8$	L = Tv				
3		$t_5 \le t_7$	L = Tv				
4	$t_1 < t_4$	$t_7 \le t_5 \le t_8$	-	L = l_1	L = l_1 + (T – t_4)v	L = l_5	L = l_5 + (T – t_8)v
5		$t_5 > t_8$	-	L = l_1	L = l_1 + (T – t_4)v		
6		$t_5 \le t_7$	-	L = l_1	L = l_1 + (T – t_4)v		

where,

t_1, t_2, t_5, t_6 (second) : the estimated period for subjective motorcycle, from current position, travels the distance l_1, l_2, l_5, l_6 in turn.

t_3, t_4 (second) : the estimated period for first conflicting motorcycle, from current position, travels the distance l_3, l_4 in turn.

t_7, t_8 (second) : the estimated period for first conflicting motorcycle, from current position, travels the distance l_7, l_8 in turn.

(2) Choice set of moving direction

In the field, a motorcycle can drive in any direction and speed to minimize the travel time. However, in order to reduce the calculation cost and replicate the capability to maneuver, some following constraints velocity and direction are adapted.

(1) The velocity of motorcycle can change during the anticipation period but under its desired velocity $0 \le V(t+i) \le V_{desired}$.

(2) The direction of movement arranges from φi – ψ to φi + ψ in each 1° part as illustrated in **Fig.5**.

A motorcycle can choose their direction from a choice set Ω as,

$$\theta_m = \varphi_i(\mathrm{t}) + \frac{2m-n}{n}\psi \quad , m = 0, 1, \ldots, n \tag{3}$$

where,

q_m : is the chosen direction

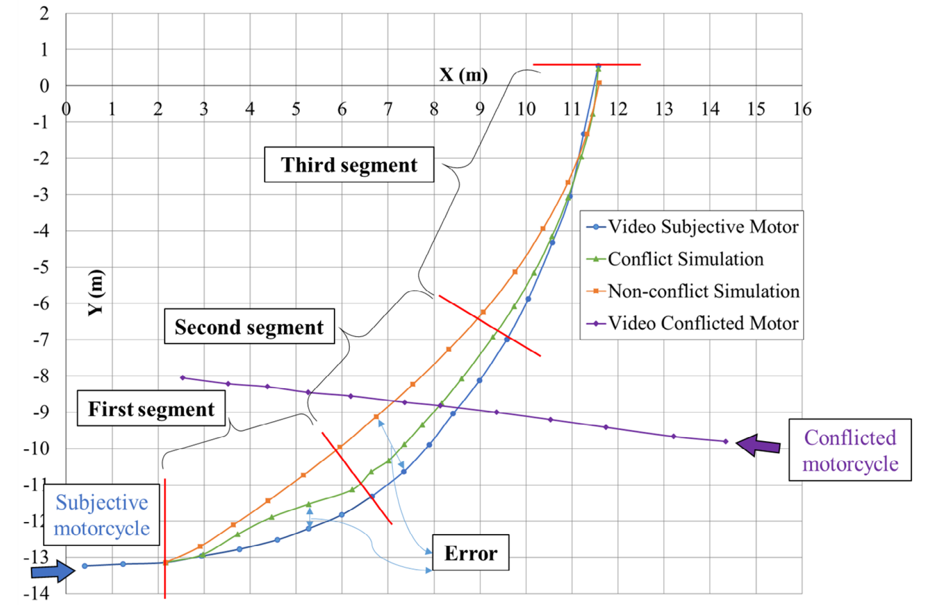
j_i(t) : is the direction at time *t* (current direction)

y = 30° : is the maximum possible angle for one side

$n = 61$: is the number of options in a choice set Ω

6. MODEL VALIDATION

On the purposed of validating the efficiency of the proposed models, the first simple situation, one conflicting trajectory, are taken into account. Twenty cases of one conflict are tracked from the videos and reproduced in the simulation. For each case, the simulation runs in two state, with and without conflict-solving model for comparison. The inputs are similar for both two state.



	First segment			Second segment			Third segment		
	Mean	Std Dev	Max	Mean	Std Dev	Max	Mean	Std Dev	Max
Conflict-solving model	0.31	0.17	0.83	0.49	0.33	1.44	0.24	0.09	0.42
Non-conflict-solving model	0.35	0.22	0.90	0.62	0.38	1.70	0.30	0.13	0.64
	N = 20 *Unit: meter*								

Fig.6 Example of left-turning trajectory evaluation

The conflict-solving model simulation reproduces the situation that at start moment, there are subjective motorcycle and conflicted motorcycle inside intersection. The parameters of two motorcycle at the start position are given as the same as in recorded videos. The reaction and movement of subjective motorcycle in the simulation are tracked and measured against the one in the videos. On the other hands, the non-conflict-solving model simulation reproduces the situation that at the start moment, there is only the subjective motorcycle inside the intersection. With the given condition, motorcycle starts to move in its desired path to reach its destination without any effect from other vehicle. The trajectory of motorcycle are divided into three segments based on the number of tracking points.

Fig.6 exemplifies the real trajectories of subjective and conflicted motorcycle, and two simulated trajectories of subjective motorcycle in case 20. The interval between two tracking points is 0.2 seconds. At each point, the error of approximation is the distance from the real trajectory and the simulated trajectory. The graph of error for first segment, second segment and third segment are drawn one after another in **Fig.7**, **Fig.8** and **Fig.9**.

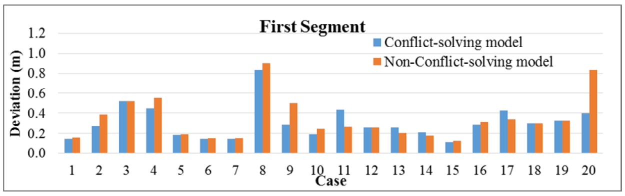


Fig.7 Errors calculation at first segment

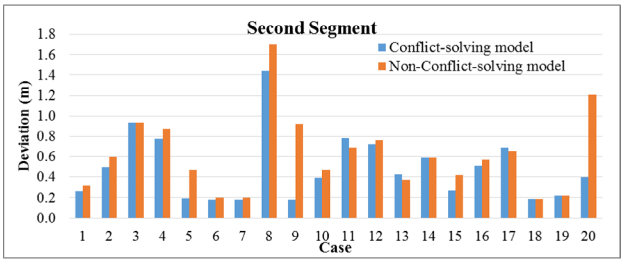


Fig.8 Errors calculation at second segment

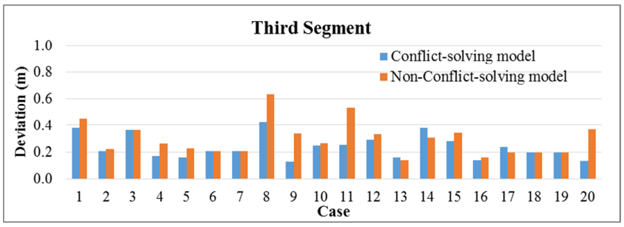


Fig.9 Errors calculation at third segment

The summary error of left-turning trajectory are presented in **Fig.6**. The result exposes that the error in the first and third segment is smaller than in the second segment. Since initial condition at the first and the last position are given, the small error in these segments is reasonable. Moreover, the simulation with conflict-solving model gets better result in both three segments. That proves the effective of the proposed conflict-solving model.

The left-turning trajectory is inspected by the error between the estimated and the real trajectory. The mean error in threes segment of trajectory are *0.31m; 0.49m; 0.24m*. Compared with the lateral size of motorcycle *1m*, these values prove the efficiency of the trajectory model and conflict solving model.

7. CONCLUSION AND FUTURE WORK

The paper introduced the conflict-solving model that replicates the maneuver to avoid accident of motorcycle. The proposed model firstly applies the two-player game theory to describe the situation that the motorcycle perceives the information and makes the decision. The anticipation movement approach is employed to depict the manner of detecting and reacting to the conflict areas. The errors of simulation trajectory, the smallest 0.31 meters, are small compared to the lateral size of motorcycle 1 meters. The results demonstrate that the model tackled effectively the conflict of crossing flows at signalized intersection.

However, more case studies and behavior analysis need to be conducted to improve the result. For superior decision in congested condition, the future research should consider simultaneously several vehicles and conflicts in the conflict-solving model. Moreover, the previous decision of vehicle should be taken into consider for error reduction. This would reduce the suddenly change in moving direction. The “grouping behavior” is not described in the research. Future work should include the “grouping behavior” in the conflict-solving model for better results.

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