Modelling vehicular interactions with opposing vehicles on two way two lane roads

Hari Hara Sharan NAGALUR SUBRAVETI[1] and Miho IRYO[2]

[1]Masters Student, Dept. of Civil Eng., University of Tokyo
(Bw-604,4-6-1 Komaba, Meguro-ku, Tokyo 153-8505)
E-mail:harihs@iis.u-tokyo.ac.jp
[2]Associate Professor, Institute of Industrial Science, University of Tokyo
(Bw-601,4-6-1 Komaba, Meguro-ku, Tokyo 153-8505)
E-mail:m-iryo@iis.u-tokyo.ac.jp

Vehicular movements on two way two lane roads differ significantly from other facilities due to the high frequency of conflicts between the vehicles in opposing directions of travel. Presence of obstacles like parked vehicles, construction sites etc. causes an increase in the frequency of conflicts between the vehicles. These conflicts have a significant impact on the efficiency as well as the safety of such road sections. The existing driver behavior models assume that the opposing vehicles always have priority over the passing vehicles which may not always be true. The study tries to propose a framework of an interactive model between the passing and opposing vehicles on two lane roads and understand the impact of various parameters on the performance of this model for various scenarios. The developed model is evaluated analytically to understand the nature of the model and numerical simulations are conducted to check the performance of the model.

Key words: *two way two lane roads, conflicts, priority, interactive model, collision avoidance characteristics*

1. INTRODUCTION

Two lane roads form a major proportion of the road networks in most of the world. Two way two lane roads are the roads which have one lane for the use of traffic in each direction. Vehicular movements on two way two lane roads differ significantly from other facilities due to the high frequency of interactions between the vehicles in opposing directions of travel. Presence of obstacles like parked vehicles, construction sites etc. increase the frequency of interactions between the vehicles. Passing is one of the most important driving behaviors on these types of roads. The vehicle moving in the direction of the obstacle has to change to the lane used by vehicular traffic travelling in the opposing direction. The behavior of the passing vehicle affects the movement of the opposing vehicle and vice-versa. These interactions can have a significant impact on the efficiency as well as the safety of these road sections. The existing driver behavior models assume that the priority of passing lies with the opposing vehicle. However in reality, drivers of the passing traffic may adopt aggressive behavior to obtain priority and the opposing vehicles may giveway considering such behavior to avoid any potential conflicts. Assuming full priority leads to the availability of a fewer number of passing opportunities which can lead to the formation of vehicle platoons in the traffic flow. These in turn cause a decrease in the level of service and negatively affect safety due to the higher risk of conflicts, fuel consumption and emissions[1)]. The aim of this study is the development of an interactive passing maneuver model for two lane roads.

The developed interactive model can be a useful application for the development of the surrounding vehicle model for driving simulators. Driving Simulators (DS) are used for studying various aspects of transportation including driving behavior, road safety, road design and traffic flow[2)]. It is very important to model the behavior of surrounding vehicles in the DS realistically. As it is not possible to deterministically assume the behavior of the subject driver of the DS, the surrounding vehicle model should not consider a fixed priority rule but interactively choose its action.

The paper is divided in to the following sections:

- Brief review of existing research on passing behavior on two lane roads.
- Model development which includes the introduction of the conflict zone and the concept of decision making zone.
- Evaluation of the model analytically to understand the nature of the model.
- Implementation of the proposed model to a simulation program to check the performance of the model.

2. LITERATURE REVIEW

Passing is one of the most difficult driving maneuvers having an impact on the efficiency as well as safety of two lane roads. Complexity and higher dispersion of passing process on two lane roads has been reviewed in many observational studies[3,4,5,6]. The complexity of the passing maneuver is due to the number of decisions involved and factors affecting this decision. The existing driver behavior models[7,1] assumes that the opposing vehicles always have priority over the passing vehicles. They do not consider the impact of opposing vehicles behavior on the passing vehicle. The behavior of each vehicle affects the other and hence this should be treated as an interaction. Consistent and homogenous driver behavior was assumed in these models. However, it is not realistic to assume such a homogenous behavior. In reality, the vehicle with the full priority may giveway due to the aggressive behavior of the opposing vehicle. Therefore, it is important to model the passing maneuver in an interactive manner. Agent based modeling has been used described as a successful approach in many studies to study interaction[8.9]. This study also tries to model the vehicles as agents to study their interaction.

3. MODEL DEVELOPMENT

In the presence of obstacle, the passing vehicle has to change lane causing an interaction with the opposing vehicle. The behavior of one vehicle affects the other and hence this is to be treated as an interaction. A multi-agent system approach is adopted where the vehicles are modelled as intelligent agents which have the ability to interact and co-operate with other agents to solve any conflicting goals and having the individual goal of reaching their destination as soon as possible[9].

Fig 1 shows the conflict area under study. The light shaded vehicle in Fig1 represents the expected position of the passing vehicle on the completion of the maneuver.

The conflict zone is defined as the area where there is a potential for both cars to collide if both assume that priority lies with them i.e. both the vehicles occupy the zone at the same time.

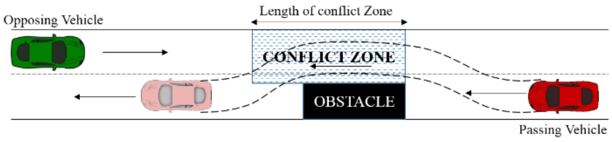

Fig.1 Two lane road with conflict zone

The vehicles try to avoid entering the conflict zone when there is a possibility of the other vehicle also entering it. The decisions of the each vehicle is hence simplified and classified into three choices in this model. They are given as:

1) Giving way to the other vehicle by decelerating,

2) Employing aggressive movement by accelerating to complete the passing maneuver or

3) Moving freely without any interaction when there is a sufficient gap between one's exit time of the conflict zone and the other's entering time.

The choice of aggressive movement is an extension of the forced merging concept in lane changing models introduced by[9,10,11]. Forced merging behavior is when a vehicle changes lane even when the available gap is the target lane is not feasible for a lane change. The vehicle forces the follower vehicle in the target lane to decelerate by forcing itself thus achieving the desired result. Similarly, in this study, when the vehicle finds the passing maneuver unfeasible, it may try to force the maneuver by employing aggressive maneuver i.e. accelerating to make the passing maneuver feasible. Each vehicle from its current position tries to evaluate the expected time required to enter and exit the conflict zone of its own as well as the other vehicle. The vehicles can recognize the position and speed of the other vehicle with respect to its own with some error. Fig 2 shows

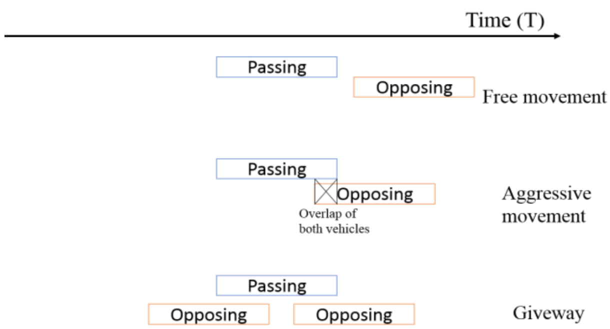

Fig.2 Expected duration of vehicles in conflict zone

a diagrammatic representation of the expected duration of vehicles in conflict zone. Based upon this evaluation, the vehicles try to decide on one of the three given choices. The Fig 2 is an example of how the passing vehicle chooses a decision based upon the expected duration in conflict zone.

The passing vehicle decides to choose free movement when it can exit the conflict zone before the other vehicle can enter thus avoiding any potential conflict. When there is a certain overlap of the expected time duration of both the vehicles in the conflict zone, the passing vehicle compares the percentage overlap of this time duration with a threshold parameter ε. When this calculated percentage is less than ε, the vehicles decides to accelerate and obtain the priority of passing. This implies that the passing vehicle accelerates to try to ensure that it can exit the conflict zone before the opposing vehicle can enter. This choice is termed as aggressive movement. When the percentage overlap is greater than ε, then the passing vehicle decides to give way to other vehicle by decelerating. The opposing vehicle also simultaneously makes this choice based upon the own evaluation of its own as well as the other vehicle's behavior.

The vehicles try to continually make decisions rather than making a one shot decision and update it with time depending upon the surrounding conditions and changes in the system. A new concept termed as the Decision Making (DM) zone is introduced in this model. It is defined as the area within which the vehicle units make decisions regarding the course of action to be adopted. The end point of the decision making zone is defined as the critical point which is determined for each vehicle separately.

For the passing vehicle, it is important to define the time required to abort the passing maneuver. The time required to abort the maneuver is defined as the time required to decelerate and return to its original lane without overtaking the obstacle. This time required to abort (t_A) should always be less than the time required for the opposing vehicle to exit the conflict zone (t_{OX}) so as to avoid any potential collision. Therefore, the critical point of the passing vehicle (CP_1) is defined as the point where $t_A = t_{OX}$. t_A is always less than t_{OX} in the decision making zone for the passing vehicle. Similarly for the opposing vehicle, it is necessary to calculate the deceleration required for the vehicle to safely stop before entering the conflict zone (d_2) so as to avoid any collision with the passing vehicle when it approaches in an aggressive manner. This deceleration is compared to the maximum deceleration allowed for the vehicle. The critical point for the opposing vehicle is defined as the point where $d_2 = \lambda_{md}$. d_2 is always less than λ_{md} in the decision making zone for the opposing vehicle to avoid any emergency braking and jerking circumstances.

4. CHARACTERISTICS OF AVOIDANCE PATTERN CHOICE AT A MOMENT

(1) Mathematical formulation of behavioral choice

In order to understand the nature of the model, it is important to evaluate the model analytically. Fig 3 shows a two lane road with all the variables and parameters used in the model.

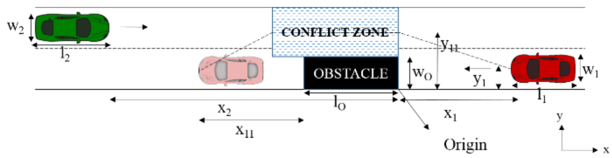

Fig.3 Two lane road with variable labels

In Fig 3, passing vehicle is denoted as vehicle 1 and the opposing vehicles as vehicle 2. The obstacle is indicated by the black object in Fig 3. *w* and *l* represent the width and length of the objects. A linear trapezoidal trajectory is assumed for the passing vehicle. *x* and *y* represent the longitudinal and lateral position of the vehicles. The coordinates of the origin is indicated in the figure. The positive direction of the *x* and *y* axes is shown in Fig 3. At any time step, the vehicles evaluate the expected durations in conflict zone from their current location by assuming the current speed to remain constant along the trajectory. x_{11} indicates the longitudinal distance of the passing vehicle from the far end of the obstacle. The variables are taken in their scalar form while calculation various parameters. The length of the conflict zone from Fig 3 is given by ($l_o + x_{11}$). For simplifying the calculation, the vehicles are said to have complete information of the other x_{11} is a parameter which varies from driver to driver. From the above figure, the following are calculated:

Entry time to conflict zone for passing vehicle t_{pe}:

$$t_{pe} = \frac{\sqrt{x_1^{\,2} + (y_{11} - y_1)^2}}{v_1} \tag{1}$$

Exit time from conflict zone for passing vehicle t_{px}:

$$t_{px} = \frac{\sqrt{(x_1^{\,2} + (y_1 - y_{11})^2)} + l_o + \sqrt{((x_{11} - l_o)^2 + (y_{11} - y_1)^2)}}{v_1} \tag{2}$$

Entry time to the conflict zone for the opposing vehicle t_{oe}:

$$t_{oe} = \frac{(x_2 - (l_o + x_{11}))}{v_2} \quad (3)$$

Exit time from the conflict zone for the opposing vehicle t_{ox}:

$$t_{ox} = \frac{(x_2 + l_2)}{v_2} \quad (4)$$

The percentage overlap for the passing vehicle when t_{px} is greater than t_{oe} is given by:

$$\frac{(t_{px} - t_{oe})}{t_{px}} * 100 \quad (5)$$

Similarly for the opposing vehicle, it is given as:

$$\frac{(t_{ox} - t_{pe})}{t_{ox}} * 100 \quad (6)$$

Based on the definition of free movement, the conditions for free movement for the passing and opposing vehicle are given as:

Passing vehicle: $t_{xp} < t_{eo}$

Opposing vehicle: $t_{xo} < t_{ep}$

For aggressive movement, the conditions are:

Passing vehicle: $\frac{(t_{px} - t_{oe})}{t_{px}} * 100 < \varepsilon_p$

Opposing vehicle: $\frac{(t_{ox} - t_{pe})}{t_{ox}} * 100 < \varepsilon_o$

where ε_p and ε_o are threshold parameters for passing and opposing vehicles respectively. The criteria for giveway is the opposite of the aggressive movement. Neglecting the y-component of the equation and solving for the above mentioned conditions, we get:

For passing vehicle:

$$\frac{v_1}{v_2} > \frac{x_1 + x_{11}}{x_2 - l_o - x_{11}} \ ; \textit{Free movement}$$

Assuming (ε_p/100) and (ε_o/100) as η_p and η_o respectively,

$$\frac{v_1}{v_2} > (1 - \eta_p)(\frac{x_1 + x_{11}}{x_2 - l_o - x_{11}}) \ ; \textit{Aggressive}$$

$$\frac{v_1}{v_2} < (1 - \eta_p)(\frac{x_1 + x_{11}}{x_2 - l_o - x_{11}}) \ ; \textit{Giveway}$$

Similarly for the opposing vehicle:

$$\frac{v_1}{v_2} < (\frac{x_1}{x_2 + l_2}) \ ; \textit{Free movement}$$

$$\frac{v_1}{v_2} < \frac{(\frac{x_1}{x_2 + l_2})}{(1 - \eta_o)} \ ; \textit{Aggressive}$$

$$\frac{v_1}{v_2} > \frac{(\frac{x_1}{x_2 + l_2})}{(1 - \eta_o)} \ ; \textit{Giveway}$$

Substituting α for $\frac{x_1 + x_{11}}{x_2 - l_o - x_{11}}$ and β for $\frac{x_1}{x_2 + l_2}$, we can express the solutions in terms of the ratio of the vehicular speeds in the simplified form.

Hence, the decisions of the passing vehicle can be classified as follows:

$$\begin{cases} \frac{v_1}{v_2} > \alpha; \textit{Free Movement} \\ (1 - \eta_p)\alpha < \frac{v_1}{v_2} < \alpha; \textit{AggressiveMovement} \\ \frac{v_1}{v_2} < (1 - \eta_p)\alpha; \textit{Giveway} \end{cases}$$

Similarly we can express the decisions for the opposing vehicle as:

$$\begin{cases} \frac{v_1}{v_2} < \beta; \textit{Free Movement} \\ \beta < \frac{v_1}{v_2} < \frac{\beta}{(1 - \eta_o)}; \textit{AggressiveMovement} \\ \frac{v_1}{v_2} > \frac{\beta}{(1 - \eta_o)}; \textit{Giveway} \end{cases}$$

Therefore, at any time step, the decisions of the vehicles can be simplified and expressed as a ratio of their velocities.

(2) Characteristics of conflict avoidance

For a good collision avoidance behavior, when the decision of one vehicle is free or aggressive movement, then the decision of the other vehicle should be giveway. Simultaneous aggressive behavior is very dangerous while simultaneous giveway behavior is unrealistic as it leads to high travel time for both the vehicles.

It can be observed that α is always greater than β. The criteria for choosing the decision as a ratio of their velocities can be expressed diagrammatically as shown in Fig.4. F, A, G stand for free, aggressive and giveway movement respectively and the notation in

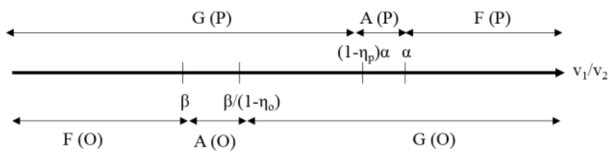

Fig.4 Diagrammatic representation of the criteria for choosing the decision

the parenthesis next to these decisions denote the vehicle. P represents the passing vehicle while O denotes the opposing vehicle. From this figure, the following observations can be inferred:

- $\dfrac{\beta}{(1-\eta_o)} < \dfrac{v_1}{v_2} < (1-\eta_p)\alpha$ implies that both vehicles will adopt give way behavior.

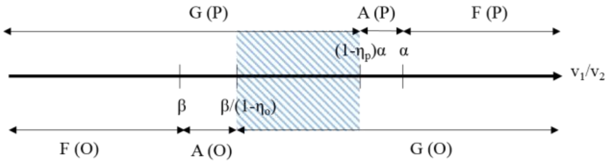

Fig.5 Simultaneous giveway behavior

- $(1-\eta_p)\alpha < \dfrac{v_1}{v_2} < \dfrac{\beta}{(1-\eta_o)}$ implies that both vehicles will adopt aggressive behavior.

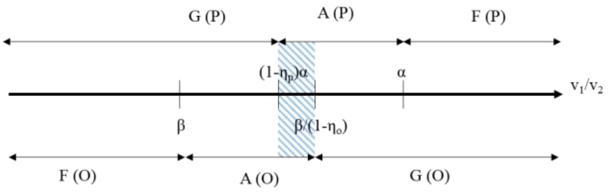

Fig.6 Simultaneous aggressive behavior

- Since $\alpha > \beta$, it implies that both vehicles never obtain free movement simultaneously.
- $\alpha < \dfrac{v_1}{v_2} < \dfrac{\beta}{(1-\eta_o)}$ Implies that the passing vehicle adopts free movement while opposing vehicle takes aggressive behavior.

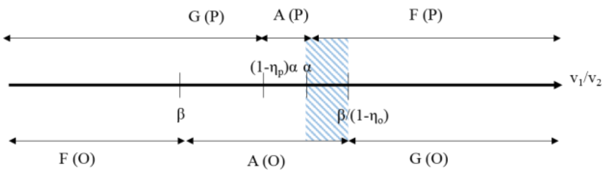

Fig.7 Free movement for passing vehicle and aggressive movement for opposing vehicle

- $(1-\eta_p)\alpha < \dfrac{v_1}{v_2} < \beta$ Implies that the opposing vehicle adopts free movement while the passing vehicle takes aggressive behavior.
- When $(1-\eta_p)\alpha = \dfrac{\beta}{(1-\eta_o)}$, the decisions will never overlap leading to no collisions. If the value of η_o is assumed to be equal to η_p and taken as a common threshold parameter for both

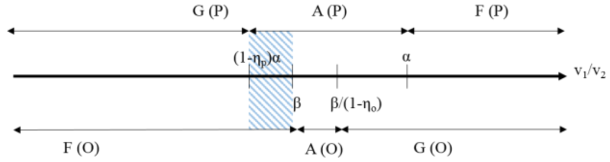

Fig.8 Free movement for opposing vehicle and aggressive movement for passing vehicle

vehicles η, then the value of η should be equal to $(1-\sqrt{\dfrac{\beta}{\alpha}})$ for this condition to be satisfied.

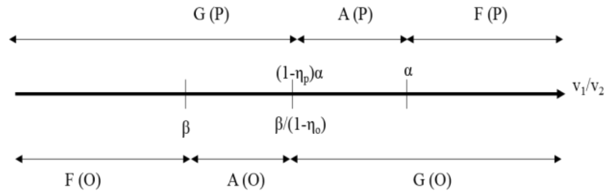

Fig.9 No conflict between vehicles

- α is directly proportional to the value of x_{11} while β is not related to x_{11}.
- To avoid any overlapping of free and aggressive behavior of both the vehicles, $\eta \le (1-\sqrt{\dfrac{\beta}{\alpha}})$

5. TIME DEPENDENT CHARACTERISTICS OF THE MODEL

In order to analyze the performance of the developed model, a simulation program was constructed to check the decisions adopted by each vehicle for different input parameters. The analytical approach formulated the decision making of drivers in terms of the ratio of their velocities at one particular time step. The simulation program allows us to understand the time dependent behavior of the drivers. The time update interval of the simulation program was fixed to be 0.5s. In order to determine the time dependent behavior, an acceleration and deceleration model needs to be formulated. The basic structure of the acceleration and deceleration model used in this study is adopted from[12]. The acceleration or deceleration of the vehicle is dependent upon the decision of the vehicle obtained at that particular time. An additional term is introduced here while developing the acceleration model. It is the desired speed of a vehicle. Desired speed of the vehicle is defined as the speed at which the vehicle can achieve the best course of action for itself. The desired speed indirectly captures the effect of the other vehicles behavior. Desired speed is calculated from the expected time of occupation of the vehicles in the conflict zone. Vehicle try to achieve the desired speed in order to avoid any overlap of their expected duration in the conflict zone with the other vehicle. The acceleration function is given as:

$$a(T+t)=\lambda_a\left(\frac{(v_d)^{\mu}-v}{t}\right) \tag{7}$$

where v_d is the desired speed of the vehicle and v is the speed of the vehicle at time T. λ_a is the sensitivity parameter and is positive and μ denotes the aggressivity parameter of the driver. In the case of free movement, v_d will be equal to the free flow speed. In case of aggressive movement, v_d will be the speed with which the vehicle can achieve feasibility of its desired maneuver. The deceleration function is given as:

$$a(T+t)=\lambda_d\left(\frac{v^2}{x}\right) \tag{8}$$

Here, λ_d is the sensitivity parameter and negative in this case. x denotes the distance of the vehicle from the obstacle. When the decision of the vehicles is to decelerate and give way, the aim of the vehicle is to decelerate safely to avoid entering the conflict zone and have any conflict with the other vehicle. Hence the deceleration of the vehicle is given as a function of v and x. The sensitivity parameters and aggressivity parameter are estimated from experiments. In the simulation program, for simplicity λ_a, λ_d, and μ are fixed as 1,-1 and 1 respectively. The maximum acceleration and deceleration allowed in a time step of 0.5s is set as 0.5 m/s^2 and -0.5m/s^2 respectively for smooth movement of the vehicles. The maximum deceleration allowed in case of emergency braking is taken as 2 m/s^2 for a maximum speed of 50kmph[13]. The values of the various input parameters used in the simulation program are shown in Table 1:

Table 1 Values of input parameters

Length of the passing and opposing vehicle	4.5m
Width of the passing and opposing vehicle	1.8m
Width of single lane	2.4m
Width of obstacle	2m
Length of obstacle	6m
Threshold parameter ε_p and $\varepsilon_o=\varepsilon$	5%
Maximum speed	50 kmph
Decision update interval	3s
Speed and location update interval	0.5s

When the vehicles obtain similar decisions, i.e. when the vehicles accelerate or decelerate simultaneously, the expected time to arrive to the conflict zone is calculated for each vehicle and compared. Based on this time, the priority to change decision is made and this decision is updated after a time interval of 3s which is equal to the decision update interval. Thus in case of similar decision making, based on the priority of arrival to the conflict zone, the decision is changed in the next decision update interval based on the speed observation of the past 3s. To evaluate the performance of the model by simulation, two cases observed in the analytical approach are used. Cases where the vehicles obtain simultaneous giveway and simultaneous aggressive behavior are evaluated and the speed and acceleration profiles are obtained. The simulation is started when the distance of the vehicles from the obstacle (origin point specified in Fig.3) is 150m. The value of the parameter x_{11} is taken to be 20m. For these values, the value of α and β are 1.37 and 0.97 respectively.

Case 1: Simultaneous giveway behavior

The criteria for simultaneous giveway behavior is:

$$\frac{\beta}{(1-\eta_o)}<\frac{v_1}{v_2}<(1-\eta_p)\alpha$$

Therefore for the selected values of the input parameters, to obtain simultaneous giveway behavior, the ratio of velocities should be:

$$1.02<\frac{v_1}{v_2}<1.3$$

In order to satisfy this criteria, the speeds of the passing vehicle is set as 45km/hr and the speed of the opposing vehicle is changed so that the ratio of their velocities satisfies the above criteria.

The time-dependent decisions of the vehicles for five scenarios is shown in Table 2.

Table 2 Time dependent decisions for vehicles with initial simultaneous giveway behavior

Scenario	1		2		3		4		5	
V1 (kmph)	45		45		45		45		45	
V2 (kmph)	43		41		39		37.5		36	
X1 (m)	150		150		150		150		150	
X2 (m)	150		150		150		150		150	
Decision	Passing	Opposing	Passing	Opposing	Passing	Opposing	Passing	Opposing	Passing	Opposing
T=0	G	G	G	G	G	G	G	G	G	G
T=3	G	G	G	G	G	G	G	G	G	G
T=6	G	F	G	F	G	F	G	F	F	G
T=9				F		F		F		G

The blank column in the table indicates that the vehicle has exited the decision making zone. It can be observed from the table that for scenarios 1 to 4, the passing vehicle continues to giveway allowing the opposing vehicle to gradually change decision from giving way to free movement. In scenario 5, the passing vehicle changes the decision from giveway to free movement. It can also be observed from the multiple scenarios shown in the Table 2 that there is good collision avoidance behavior. The decisions of the vehicles for every 3s in shown in Table 2. F, A, G denote free, aggressive and giveway choice in the table.The acceleration vs time and speed vs time graphs as well as the distance to obstacle vs time for the passing and opposing vehicles for scenario 4 is shown in Fig 10, 11, 12 and 13 respectively.

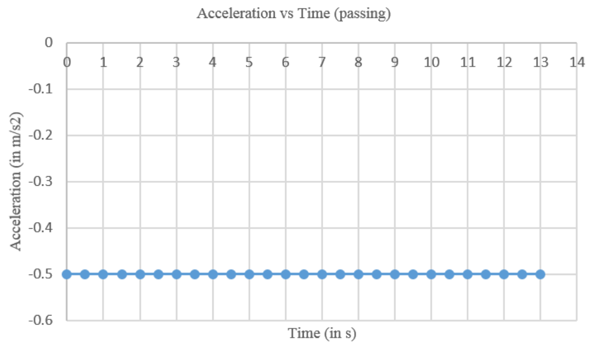

Fig.10 Acceleration vs Time graph for passing vehicle

The passing vehicle decelerates at a constant rate of -0.5m/s^2 till the end of interaction while the opposing vehicle initially decelerates till 3s when it changes the decision and decelerate. This is based on the assignment of priority to accelerate due to the comparison of the expected arrival time to the conflict zone for the opposing vehicle. This change from

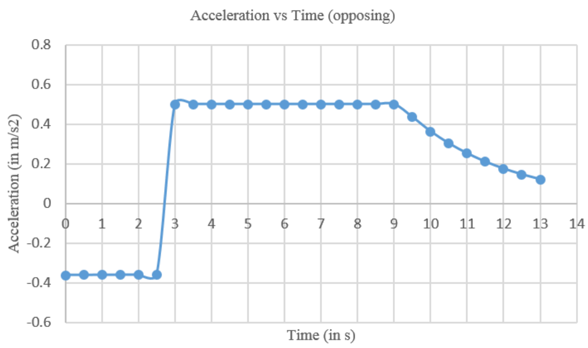

Fig.11 Acceleration vs Time graph for opposing vehiucle

deceleration to acceleration for the opposing vehicle and continuous deceleration for the passing vehicle can also be observed from the velocity vs time graph in Fig.12. Fig 13 shows the graph of the location of the vehicle to obstacle vs time. It can be observed from the graph that the passing vehicle which gives way to the opposing vehicle by decelerating is around 30m away from the obstacle when the opposing vehicle crosses the obstacle. After the opposing vehicle passes, the passing vehicle again accelerates as there is no more interaction.

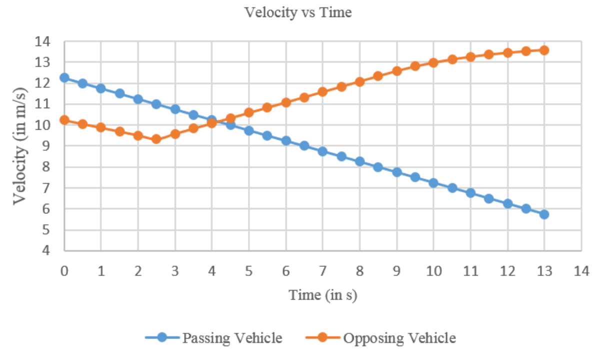

Fig.12 Velocity vs Time

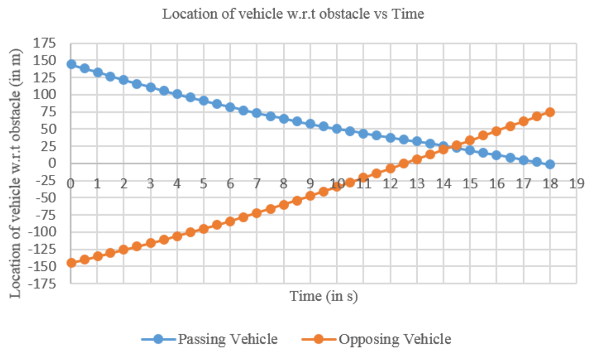

Fig.13 Location of vehicle w.r.t obstacle vs Time

Case 2: Simultaneous aggressive behavior

The criteria for simultaneous aggressive behavior is:

$$(1-\eta_p)\alpha < \frac{v_1}{v_2} < \frac{\beta}{(1-\eta_o)}$$

To obtain this criteria, the value of ε is set to 20%. Then for the selected values of the input parameter, the ratio of velocities should be:

$$1.096 < \frac{v_1}{v_2} < 1.212$$

In order to satisfy this criteria, the speed of the passing vehicle is set as 45km/hr and the speed of the opposing vehicle is changed so that the ratio of their velocities satisfies the above criteria.

The time-dependent decisions of the vehicles for three such scenarios is shown in Table 3.

The acceleration vs time and speed vs time graphs as well as the distance to obstacle vs time for the passing and opposing vehicles for scenario 3 are shown in Fig 14, 15, 16 and 17 respectively.

It can be observed from the acceleration graphs that the passing vehicle accelerates and decelerates and accelerates again while the opposing vehicle continuously accelerates as seen in Fig 15. The decision for the passing vehicle at T=6s is not given as at this time interval, it is not in the decision making zone.

Table 3 Time dependent decisions of the vehicles for initial simultaneous aggressive behavior

Scenario	*1*		*2*		*3*	
V1 (kmph)	45		45		45	
V2 (kmph)	41		39		37.5	
X1 (m)	150		150		150	
X2 (m)	200		200		200	
Decision	**Passing**	**Opposing**	**Passing**	**Opposing**	**Passing**	**Opposing**
T=0	A	A	A	A	A	A
T=3	G	A	G	A	G	A
T=6		F		F		A

Thus the decisions obtained in Table 3 do not lead to a good collision avoidance behavior.

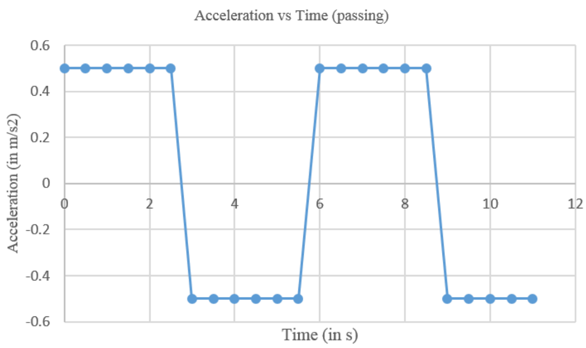

Fig.14 Acceleration vs Time (passing)

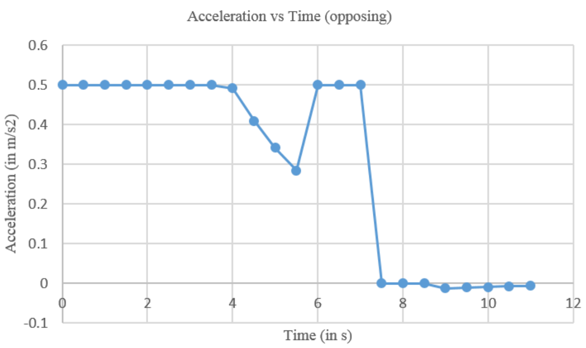

Fig.15 Acceleration vs Time (opposing)

It can be seen from Fig 16 that the vehicles have the nearly the same velocity at the end of the simulation. Fig 17 shows the distance to obstacle for the vehicles vs time. It can be observed that both the vehicles simultaneously reach the obstacle due to taking the aggressive decision and thus this will lead to a collision. Therefore, the value of the threshold parameter ε should be chosen carefully so as to avoid any collision of the vehicles. The higher the value of the threshold parameter, the more aggressive the passing maneuver

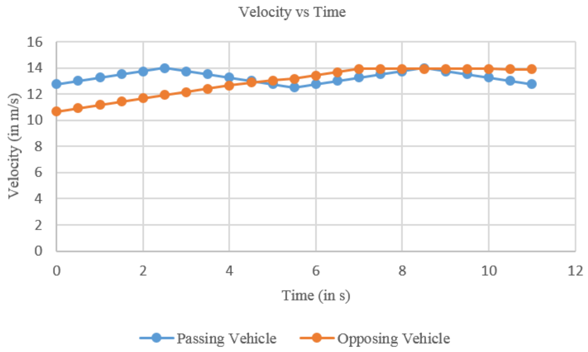

Fig.16 Velocity vs Time

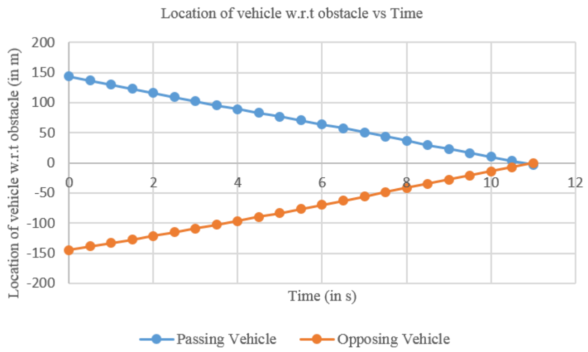

Fig.17 Location of vehicle w.r.t obstacle vs Time

6. CONCLUSIONS

An interactive passing maneuver model was developed to study the passing behavior of vehicles on two lane roads. The current model shows a good performance of collision avoidance behaviour in most of the cases. Certain cases exhibit similar decision choices leading to unrealistic behaviour. This can be attributed to the tuning of the parameter ε. Other parameters like x_{11} and the decision update interval also impact the performance of the model. Scenarios where both vehicles obtain giveway behavior though unrealistic is safer than secnarios where both obtain aggressive behavior. Therefore, care has to be taken to avoid any such instances. Future works include Improving the robustness of the model for all cases. The current model considers the vehicles to have perfect information of the other vehicles but in reality this is not the case. Hence, modelling with imperfect information needs to considered. It is important to calibrate and validate the developed model to understand if it provides an accurate representation of the system under study. Driving simulator experiments will be considered to collect data required for the calibration and validation of the model.

REFERENCES

1) Farah, H. and Toledo, T. : Passing behavior on two-lane highways, *Transportation research part F: traffic psychology and behavior.,* 13(6), pp.355-364, 2010.
2) Hegeman, G., van der Horst, R., Brookhuis, K., & Hoogendoorn, S. : Functioning and acceptance of overtaking assistant design tested in driving simulator experiment, *Transportation Research Record: Journal of the Transportation Research Board 2018.,* pp.45-52, 2007
3) Carlson, P.J., Miles, J.D., Johnson, P.K. : Daytime high-speed passing maneuvers observed on rural two-lane, two-way highway findings and implications, *Transportation Research Record: Journal of the Transportation Research Board 1961.,* pp.9-15, 2006
4) Harwood, D.W., Gilmore, D.K., Richard, K.R. : Criteria for passing sight distance for roadway design and marking, *Transportation Research Record: Journal of the Transportation Research Board 2195.,* pp.36-46, 2010
5) Llorca, C., Moreno, A., García, A., & Pérez-Zuriaga, A. : Daytime and nighttime passing maneuvers on a two-lane rural road in Spain, *Transportation Research Record: Journal of the Transportation Research Board 2358.,* pp.3-11, 2013
6) Llorca, C., Moreno, A., García, A., & Pérez-Zuriaga, A. : Influence of age, gender and delay on overtaking dynamics, *Intelligent Transport Systems, IET, 7(2).,* pp.174-183, 2013
7) Llorca, C., Moreno, A. T., Lenorzer, A., Casas, J., & Garcia, A. : Development of a new microscopic passing maneuver model for two-lane rural roads, *Transportation research part C: emerging technologies, 52.,* pp.157-172, 2015
8) Turnwald, A., Olszowy, W., Wollherr, D., & Buss, M. : Interactive navigation of humans from a game theoretic perspective, *Intelligent Robots and Systems (IROS), IEEE/RSJ International Conference on IEEE.*, pp. 703-708, 2014
9) Hidas, P. : Modelling vehicle interactions in microscopic simulation of merging and weaving, *Transportation Research Part C: Emerging Technologies, 13(1).,* pp.37-62 ,2005
10) Ahmed, K. I. : Modeling drivers' acceleration and lane changing behavior, *Doctoral dissertation, Massachusetts Institute of Technology.,* 1999.
11) Wang J., Liu, R., Montgomery F. : A simulation Laboratory for Motorway Merging Behavior. In: Mahmassani, H (ed.) *Transportation and Traffic Theory: Flows,Dynamics and Human Interaction, Elsevier, 5(3).*, pp.127-140, 2005
12) MINH, Chu Cong, and Kazushi SANO. : Acceleration and deceleration models of motorcycle at signalized intersections, *Journal of the Eastern Asia Society for Transportation Studies 7.,* pp.2396-2411, 2007
13) Akçelik, R.; Besley, M. : Acceleration and deceleration models. *In Proceedings of 23rd Conference of Australian Institute of Transport Research. Monash University Melbourne,Australia.,* pp.10-12, 2001

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