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Modelling and Simulation of the Car Following Behavior in Real Traffic Flow

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***Abstract:** In generally typical highway traffic scenario a vehicle, following vehicle ahead needs to maintain benign gap to avoid mishap. Accordingly speed of follower vehicle needs to be controlled keeping watch on variation of speed of vehicle ahead. In this paper a car follow model is designed and it is estimating the speed of follower vehicle with respect to that of vehicle ahead is presented. This paper brings out the details of mathematical equations of the proposed model along with implementation of same in Matlab Code as well using Simulink model.*

***Keywords:** Position of vehicle ahead, Speed of follower vehicle, speed of lead car and Matlab Simulation.*

I. INTRODUCTION

It's a phenomenon in which follower vehicle follows the vehicle ahead in close vicinity. Its need exists when the follower vehicle can get influenced by the speed at which vehicle ahead moves. Car follow logic derives the path of the follower vehicle in conjunction with that of vehicle ahead. Car follow influences both the quantum of vehicles that can be occupied on road at a given instance of time and its speed. More the close proximity of both the vehicles, higher will be the quantum of vehicle occupancy of road [1-2].Follower vehicle should take precaution such that it will not hit the vehicle ahead. Accordingly it has to sustain an adequate gap and speed. Car follow logic cannot be implemented in case if the speed of the follower vehicle is much less. If the follower vehicle is in very close proximity to the vehicle ahead, car follow logic can be executed very effectively. Further this effectiveness increases with speed [3-4]. As far as the gap is concerned careless drivers maintain very less gap and heavy vehicle drivers tend to maintain more gap keeping their brake reaction time in view. In figure 1 follower vehicle (Vehicle B) was progressing at very high speed than that of vehicle ahead to start with. Once it approached at time instance t1, it tends to travel as governed by the speed of vehicle ahead [5-6]. Gap between these vehicles along time axis is known as time headway and the same along distance axis is known as space headway. Time headway is nothing but time lapse between two adjacent vehicles passing a specific station. Space headway is nothing but gap between two adjacent vehicles measured from far end of vehicle ahead to far end of the follower vehicle at a specific time. Including speed, space headway and time headway are considered as significant attributes of highway traffic [7].

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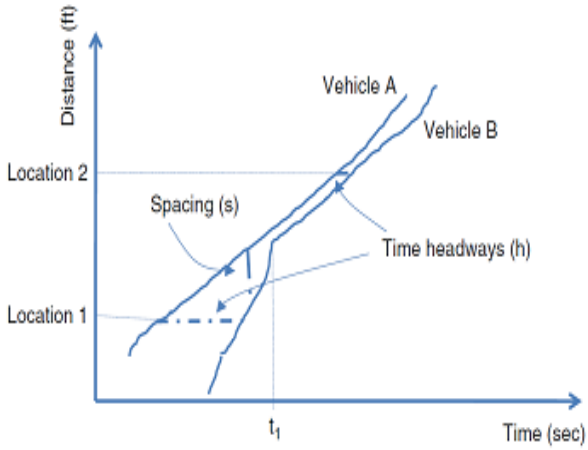

Fig. 1 Positions of two vehicles in a typical traffic scenario

A position of two vehicles in a typical traffic scenario is shown in figure 1. Time headway keeps changing in space which means time headway characterized at station 1(Location 1) will be different from that of station 2 (Location 2) which is on earlier side to station 1 (Location 1). Same is the case for space headway as inter-distance between two consecutive vehicles keeps changing with time [8-9].Further space headway keeps changing every day as a function of many parameters like psychological driving competence of driver and as well as the competence of vehicle for a given typical traffic scenario. Car follow philosophy enables to recognize the influence of change in space headway on traffic.

II. PROPOSED METHOD

The Car-follow model estimates motion of follower vehicle at current time instance with respect to its relation with vehicle ahead at previous time instance. Sense of car follow model is represented in figure 2. Motion of follower vehicle (Vehicle labeled by n+1) with respect to vehicle ahead (Vehicle labeled as by n+1) is shown in figure 2. At a given time instance t, follower vehicle follows vehicle ahead with a time headway magnitude of h (n+1) at close proximity of s(n+1)t.

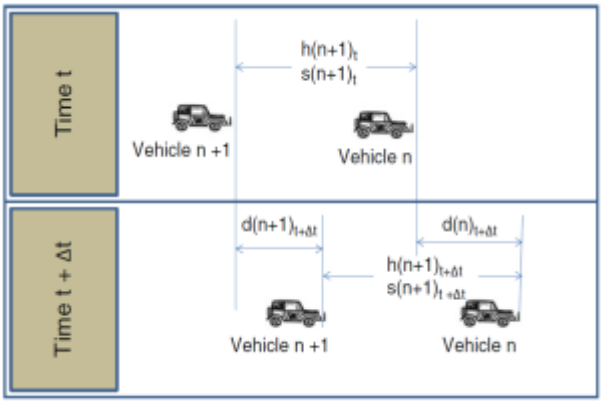

Fig. 2 Representation of car follow model

Distance traveled by vehicle ahead in a time span of

dt = d(n)t+dt

Similarly, Distance traveled by follower vehicle ahead in a time span of dt = d(n+1)t+dt

If the vehicle ahead is not influenced by traffic conditions its speed will simply be governed by topology of the highway along with attributes of both driver and vehicle. Motion of the follower vehicle will depend on path of the vehicle ahead over and above the attributes of both vehicle and the driver [10-11].

Time headway of follower vehicle = h(n+1)t+dt

Spacing of follower vehicle = s(n+1)t+dt

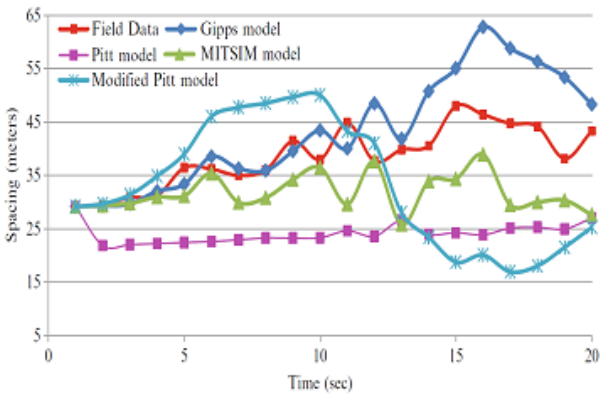

Fig.3 Performance comparison of various models with measured data

Various car follow models are available and figure 3 gives performance comparison of all those models with respect to that of measured data. From figure 3, it is clear that performance of Gipps model is close to that of measured data. Hence the same is considered in this project.

A. Gipps Car Follow Model (For Matlab)

A model proposed by Gipps [8] is used to demonstrate car follow strategy. This model is rated as multi-capable model as it takes into account the necessary speed of the follower vehicle considering whether the follower vehicle is in halt mode or follower mode. This model enables to estimate the following two different speeds.

- Speed of follower vehicle when it is not in car follow mode
- Speed of follower vehicle when it is in car follow mode with vehicle ahead

Finally least of above will be chosen as speed of follower vehicle for executing car follow logic keeping safety into consideration. Car follower model: Speed of follower vehicle when it is not in car follow mode. A model formulated based on empirical data is given below.

$$v_{f_{t+dt}} = v_{f_t} + 2.5a_{f_{max}}\, dt\left(1-\frac{v_{f_t}}{v_{f_{des}}}\right)\left(0.025+\frac{v_{f_t}}{v_{f_{des}}}\right)^{\frac{1}{2}} \quad 1.1$$

Where

V_{ft+dt}: Speed of follower vehicle at t+dt

V_{ft}: Speed of follower vehicle at t

a_{fmax}: Highest acceleration of follower vehicle

dt: Time duration

V_{fdes}: Necessary speed of follower vehicle

Car follower model: Speed of follower vehicle when it is in car follow mode

To enable the follower vehicle to come to halt safely even for the most stringent braking of the vehicle ahead. This model is derived from most stringent braking condition of the vehicle ahead and predicts the halting gap of the follower vehicle while taking the time taken by the drive to react having cushion for factor of safety into account.

$$v_{f_{t+dt}} = b_f\, dt + \sqrt{b_f^{\,2}dt^2 - b_f\left[2\left[s_{L_t} - L_L - s_{f_t}\right] - v_{f_t}dt - \frac{v_{L_t}^{\,2}}{b_L}\right]} \quad 1.2$$

Where

b_f: Conservative deceleration of follower vehicle

s_{Lt}: Position of vehicle ahead

L_L: Length of vehicle ahead with cushion for benign gap

s_{ft}: Position of follower vehicle

V_{Lt}: Speed of vehicle ahead at t

b_L: Conservative deceleration of vehicle ahead as determined by follower vehicle.

B. Car Follow Model (For Simulink)

The proposed model in this work shoulders upon considering two vehicles moving on the same path in succession. The driver in the front vehicle has a known speed independent of the speed recorded by the rear vehicle. The rear vehicle acclimatizes to the front vehicle. This car follow model is shown in figure 3.

Where

x_{fc} : Position of the following car

x_{lc} : Position of the lead car

$\dot{x}_{fc}$: Speed of the following car

$\dot{x}_{lc}$: Speed of the lead car

$\ddot{x}_{fc}$: Acceleration of the following car

This is the control variable that the driver adjusts to keep up with the lead car (and avoid a collision). Proposed car follow model assumes the velocity profile of the lead car is known as a function of time.

The primary relation that is embedded in the proposed car follow model is stated below. The acceleration profile of the "following" car is just a function of the relative speeds of the two cars;

$$\ddot{x}_{fc}(t+\tau) = k\,(\dot{x}(t)_{lc} - \dot{x}(t)_{fc}) \qquad (1.3)$$

Where

k: Gain constant of the response process

$\ddot{x}_{fc}(t+\tau)$: Acceleration of the following vehicle

$\dot{x}_{lc}(t)$: Speed of the lead car

$\dot{x}_{fc}(t)$: Speed of the following car

III. Simulation and Results

1. Initially, implementation of car follow model in MATLAB (Speed)

Steps for implementation of car follow model in MATLAB for estimation of position of vehicle ahead is given below.

```
clf
clear
% Time vector
t=1:1:30;
t=t';
 % Time interval
dt=1;
% Acceleration of vehicle ahead
acc_l=zeros (30,1);
% Position of vehicle ahead
dist_l=zeros (30,1);
% Speed of follower vehicle using first formula
v_f_1=zeros (30,1);
v_f_1(1,1)=60*(5/18);
% desired speed of follower vehicle
v_f_des=50*(5/18);
 % Speed of follower vehicle using second formula
v_f_2=zeros (30,1);
v_f_2(1,1)=v_f_1(1,1);
% Length of vehicle ahead plus safe gap
Ln=7;
v_f=zeros(30,1);
v_f(1,1)=v_f_1(1,1);
 % Acceleration of follower vehicle
acc_f=zeros(30,1);
% Maximum acceleration of follower vehicle
Key in maximum acceleration of vehicle
afmax=1.9812;
 % Position of follower vehicle
dist_f=zeros(30,1);
dist_f(1,1)=-120*12*0.0254;
% Severe deceleration of vehicle ahead as estimated by follower vehicle
bL=-3.5052;
% Speed of vehicle ahead
Key in speed of vehicle ahead from figure 3.1 (Input)
v_l_kmph=[52.37 50.95 48 46 44 42 41 39 37 35 33 31 29 25 22 19 21 24 26 29 31 33 36 39 42 45 49 50.91 51.5 50.67];
v_l=v_l_kmph*(5/18);
v_l=v_l';
fori = 2:30
% Estimation of speed of follower vehicle using First formula
```

$$a = \frac{v_2 - v_1}{t}$$

```
acc_l(i,1)=acc_l(i,1)+((v_l(i,1)-v_l(i-1,1)/dt));
```

$$s = \frac{v_2 + v_1}{2}$$

```
dist_l(i,1)=dist_l(i-1,1)+(0.5*(v_l(1,1)+v_l(i-1,1))*dt);
 vff1=v_f_1(i-1,1);
 vff2=2.5*afmax;
 vff3=1-(vff1/v_f_des);
 vff4=(0.025+(vff1/v_f_des))^0.5;
vff=vff1+vff2*vff3*vff4;
      v_f_1(i,1)=v_f_1(i,1)+vff;
% Estimation of speed of follower vehicle using second formula
      vf1=-2.8956;
      vf2=vf1^2
      vf3=2*(dist_l(i-1,1)-Ln-dist_f(i-1,1))
      vf4=v_f_1(i-1,1)
```

```
    vf5=((v_l(i-1,1))^2)/(bL)
    vf6=vf3-vf4-vf5
    vf7=vf2-vf1*vf6
    vf8=vf7^0.5
  vf=vf1+vf8
  v_f_2(i,1)=v_f_2(i,1)+vf;
```

Computation of speed of follower vehicle by choosing minimum of speeds computed using equation 3.1 and 3.2

```
  v_f(i,1)=v_f(i,1)+min(v_f_1(i,1),v_f_2(i,1));
```

Computation of position of follower vehicle using speed of follower vehicle computed just before

```
  dist_f(i,1)=dist_f(i-1,1)+0.5*((v_f_1(1,1)+v_f(i-1,1))*dt);
  End of for loop
  End
   t=1:1:30;
  plot(t,v_l,t,v_f,'LineWidth',4)
  grid on
```

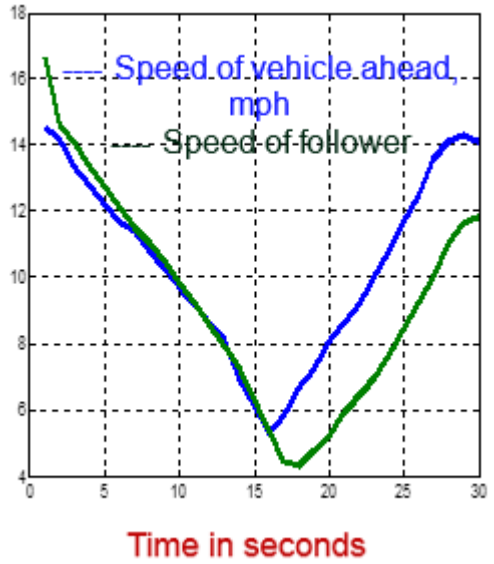

Fig. 4 Speed of follower vehicle vs. speed of vehicle ahead

2. Steps for implementation of car follow model in MATLAB (Position)

Steps for implementation of car follow model in MATLAB for estimation of position of follower vehicle is given below.

```
  clf
  clear
  % Time vector
  t=1:1:30;
  t=t';
  % Time interval
  dt=1;
  % Acceleration of vehicle ahead
  acc_l=zeros(30,1);
  % Position of vehicle ahead
  dist_l=zeros(30,1);
  % Speed of follower vehicle using first formula
  v_f_1=zeros(30,1);
  v_f_1(1,1)=60*(5/18);
  % Desired speed of follower vehicle
  v_f_des=50*(5/18);
   % Speed of follower vehicle using second formula
  v_f_2=zeros(30,1);
  v_f_2(1,1)=v_f_1(1,1);
  % Length of vehicle ahead plus safe gap
  Ln=7;
```

% Minimum of Speed of follower vehicle estimated using first and second formulae

```
  v_f=zeros(30,1);
  v_f(1,1)=v_f_1(1,1);
   % Acceleration of follower vehicle
  acc_f=zeros(30,1);
   % Maximum acceleration of follower vehicle
  afmax=1.9812;
   % Position of follower vehicle
  dist_f=zeros(30,1);
  dist_f(1,1)=-120*12*0.0254;
```

% Severe deceleration of vehicle ahead as estimated by follower vehicle

```
  bL=-3.5052;
  % Speed of vehicle ahead
  v_l_kmph=[52.37 50.95 48 46 44 42 41 39 37 35 33 31 29 25 22 19 21 24 26 29 31 33 36 39 42 45 49 50.91 51.5 50.67];
  v_l=v_l_kmph*(5/18);
  v_l=v_l';
  fori = 2:30
```

% Estimation of speed of follower vehicle using First formula

$$a = \frac{v_2 - v_1}{t}$$

Where

V_2: Instantaneous velocity

V_1: Velocity at previous instance

t: Time interval

```
acc_l(i,1)=acc_l(i,1)+((v_l(i,1)-v_l(i-1,1)/dt));
```

$$s = \frac{v_2 + v_1}{2}$$

```
dist_l(i,1)=dist_l(i-1,1)+(0.5*(v_l(1,1)+v_l(i-1,1))*dt);
 vff1=v_f_1(i-1,1);
vff2=2.5*afmax;
vff3=1-(vff1/v_f_des);
vff4=(0.025+(vff1/v_f_des))^0.5;
vff=vff1+vff2*vff3*vff4;
 v_f_1(i,1)=v_f_1(i,1)+vff;
```

% Estimation of speed of follower vehicle using second formula

```
vf1=-2.8956;
vf2=vf1^2
vf3=2*(dist_l(i-1,1)-Ln-dist_f(i-1,1))
vf4=v_f_1(i-1,1)
vf5=((v_l(i-1,1))^2)/(bL)
vf6=vf3-vf4-vf5
vf7=vf2-vf1*vf6
vf8=vf7^0.5
 vf=vf1+vf8
 v_f_2(i,1)=v_f_2(i,1)+vf;
 v_f(i,1)=v_f(i,1)+min(v_f_1(i,1),v_f_2(i,1));
dist_f(i,1)=dist_f(i-1,1)+0.5*((v_f_1(1,1)+v_f(i-1,1))*dt);
End of for loop
 End
Creating a time vector for creating speed plot
 t=1:1:30;
```

Plotting position of vehicle ahead and follower vehicle as a function of time

```
plot(t,dist_l,t,dist_f,'LineWidth',4)
Switching on grid on plot
grid on
```

This programme is enclosed as Appendix 'G'. Executing the above mentioned programme will generate plot shown in figure 4. Strength of the proposed car follow model can be noticed from figure 5 as it shows position of follower vehicle is always maintained with specific gap with respect to that of vehicle ahead.

3. IMPLEMENTATION OF CAR FOLLOW MODEL IN SIMULINK

Recalling equation 1.1

$$\ddot{x}_{fc}(t+\tau) = k\,(\dot{x}(t)_{lc} - \dot{x}(t)_{fc})$$

Input for solving above equation is $\dot{x}_{lc}(t)$ i.e. speed of the lead car which is given below.

Following input is considered

- k = 1.5

Following initial conditions are considered

- $\dot{x}_{fc}(0)$= 30 m/sec
- x_{lc} = 30 m
- x_{fc}= 0 m

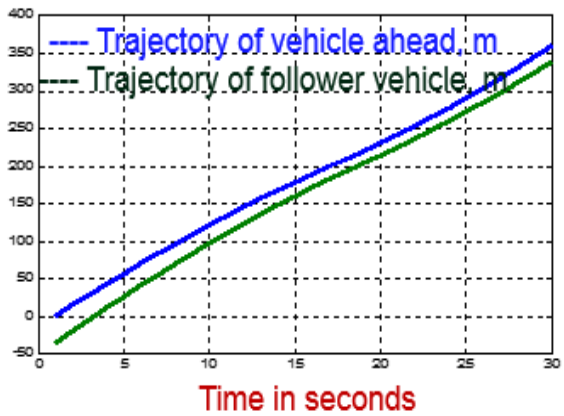

Fig. 5 Position of follower vehicle vs. speed of vehicle ahead

Table 1 Speed of the lead car with time

Time (Seconds)	Speed of the lead car (m/sec)
0	30
2	25
3	20
5	15
6	10
8	5
10	0
15	0

For the initial velocity values of lead car and following car, acceleration of following car has been estimated using equation 1.1.

Then the acceleration values of following car are obtained for various incoming input values of velocity of lead car using the same equation. Velocity has been obtained by integrating acceleration and position has been obtained by integrating velocity at a given time instance. figure 6 represents the car follow model using Simulink. figure 7 and figure 8 indicates the gap between the lead and follow vehicle is maintained and the results are similar to MATLAB.

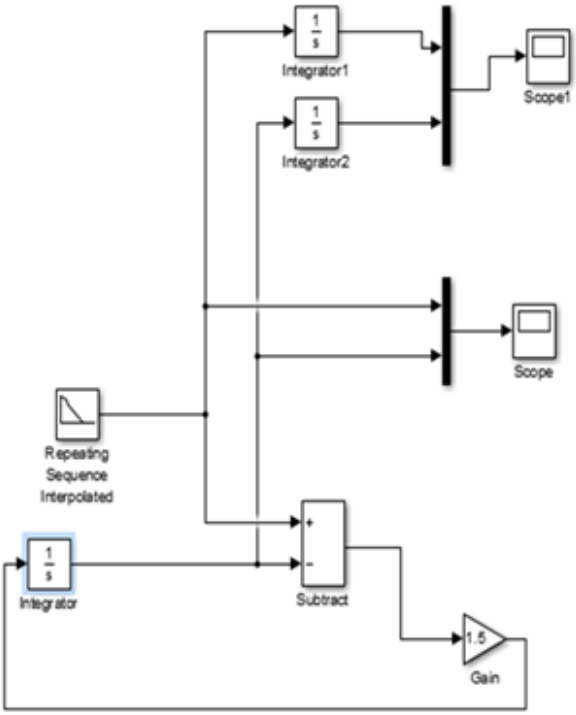

Fig. 6 Simulink Model for car follow Model

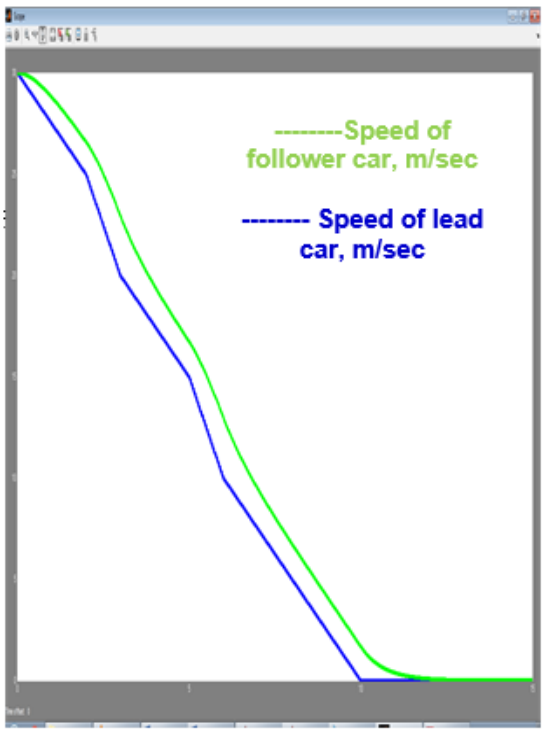

Fig. 7 Velocities of follower and lead cars

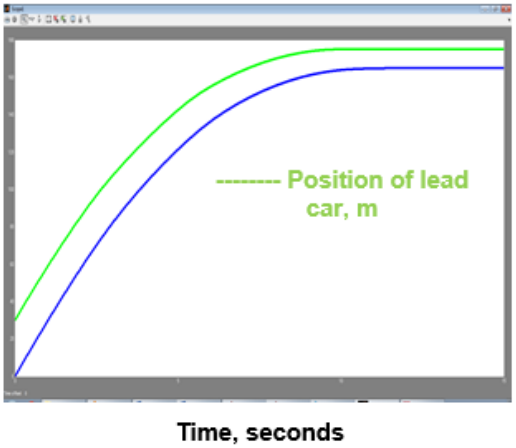

Fig. 8 Positions of follower and lead cars

IV. CONCLUSION

In this paper car follow philosophy is discussed along with various car follow models. Intended car follow model will be useful to estimate the desired speed of follower vehicle and its trajectory with respect to vehicle ahead. By implementing the a car follow model for estimating the speed of follower vehicle with respect to that of vehicle ahead is presented. The mathematical equations of the proposed model are developed. The proposed model results are verified by using MATLAB program as well as using same in SIMULINK model.

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Dr. K. Manjunatha Chari received his Ph.D from JNT University, Kakinada, and he completed M.Tech from JNT University, Hyderabad. He is having 18 years teaching experience and 3 years of Industry experience. At present Dr.K.Manjunatha Chari is working as Professor and Head of the ECE Department in GITAM (Deemed to be University) Hyderabad, Telangana. He published many papers in his field of interest viz. Signal and Image Processing.