ME 8285 Final Project Report
Driver Comparison using Intelligent Driver Model

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1 Abstract

We investigate driver behaviors using an Intelligent Driver Model (IDM) in this report. Specifically, two different type of drivers were studied: normal and aggressive driver. The driving characteristics are mainly parameterized by comfortable acceleration, deceleration, safe time gap, jam distance and desired velocity. By means of simulation, three scenarios were implemented: mild lane-changing, critical lane-changing, and Platooning in changing traffic states. In the lane-changing scenario, it was found out that the aggressive driver experiences higher rate of both acceleration and deceleration, but have smaller velocity bounds. Aggressive driver also tends to have a smaller gap in between cars. In the platooning scenario, the aggressive driver experienced a larger magnitude in both acceleration and deceleration to maintain smaller gap as well. Different traffic conditions were considered for both simulation scenarios.

2 Introduction

There are two types of models when it comes to the problem of traffic congestions: macroscopic and microscopic. Macroscopic uses aggregate measures like density or simulating flow to describe large-scale patterns, whereas microscopic can be understood in the sense of individual vehicle, which forms models in the aspect of time-continuity, the car-following models. Car following theory, the events that occurs in which car follows another without passing it, is used to mimic the interaction between adjacent vehicles in a traffic stream. Well known car following models include the Gazis-Herman-Rothery (GHR) model, the Optional Velocity (OV) model family, and the Collision Avoidance model [1–3].

The Adaptive Cruise Control (ACC) is an automotive system which allows the vehicle to adapt the velocity to the environment. The Intelligent Driver model (IDM) is an ACC model which is characterized by the intuitive and availability of the parameters. The Intelligent Drive Model (IDM) is a deterministic car-following (time-continuous and autonomous) model, with additional clauses to make it accident-free. It is intended for adjusting the driver's longitudinal desired velocity and safety time gap. The IDM has been used for simulating longitudinal vehicle motion and lane changing strategy in different traffic flow conditions (Free, Upstream, Jam, Downstream and Bottleneck) [4, 5]. An extension of the IDM has been studied by considering finite reaction times, estimation errors, looking several vehicles ahead(spatial anticipation) and temporal anticipations [6]. However, this IDM has drawbacks such as the exceeding of the real vehicle deceleration. Moreover, the IDM does not totally guarantee the traffic safety in case of accident scenario in terms of collision number. [7] provided several modifications of the IDM to improve those drawbacks in terms of driver safety and real vehicle capability. Recently, a cooperative intelligent driver model was proposed in [8] to examine the system performance under different proportions of autonomous vehicles.

The objective of this report is analyze different drivers' behavior using the IDM under different scenarios. In addition, sensitivity analysis of a few parameters will be discussed in terms of the driving pattern.

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3 Dynamic Modeling

3.1 Intelligent Driver Modeling

The IDM acceleration a continuous function incorporating different driving modes for all velocities in freeway traffic as well as city traffic. The IDM presented by [4], is shown in the following:

$$a_{IDM}(s_n, v_n, \Delta v_n) = \dot{v_n}(s_n, v_n, \Delta v_n) = a_n \left[1 - \left(\frac{v_n}{v_{0,n}} \right)^{\delta} - \left(\frac{s^*(v_n, \Delta v_n)}{s_n} \right)^2 \right] \tag{1}$$

where the effective minimum gap s^* is determined by

$$s^*(v_n, \Delta v_n) = s_{0,n} + s_{1,n} \sqrt{\frac{v_n}{v_{0,n}}} + T_n v_n + \frac{v_n \Delta v_n}{2\sqrt{a_n b_n}} \tag{2}$$

where a_n is the maximum acceleration of the vehicle n, b_n is the comfortable deceleration of the vehicle n, $v_{0,n}$ is the desired velocity of the vehicle n, v_n is the current velocity of the vehicle n, Δv_n is the approach rate, defined as $v_{n-1} - v_n$, δ is a parameter characterizing how the acceleration decreases with velocity (almost fixed at 4 [9]), the velocity dependent distance $T_n v_n$ which corresponds to following the leading vehicle with a constant safe time gap T, and finally $s_{0,n}$ and $s_{1,n}$ are the actual gap defined by $s_n = \Delta x_n - l_{n+1}$ for car n and its preceding car $n-1$ respectively.

The expression is an interpolation of the tendency to accelerate with $a_n[1-(v_n/v_{0,n})^{\delta}]$ on a free road and the tendency to brake with deceleration $-a_n(s^*/s_n)^2$ when vehicle n comes too close to the vehicle in front. The deceleration term depends on the ratio between the "desired" minimum gap s^* and the actual gap s_n. The desired gap s^* varies dynamically withe velocity and the approach rate. Note the breaking term of the IDM is developed such that accidents are avoided even in the worst case, where the driver of the leading car suddenly brakes with the maximum possible deceleration $b_{max} \geq b$ to complete standstill. Since the IDM does not include explicit reaction times, it is even safe when the time headway paramter T is set to zero [5].

In order to examine how each component of the model controls the result, the model was reordered as directly dependent on v_n and transformed to an ODE system [10]. For demonstration, only 2 cars were examined: n and $n-1$. Let $x_1 = x_n$ and $x_2 = v_n$, then we have the following system:

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}, \quad \dot{x} = \begin{bmatrix} x_2 \\ g(x_1, x_2, q) \end{bmatrix}, \quad with \quad x_0 = \begin{bmatrix} x_1(0) = \hat{x} \\ x_2(0) = \hat{v} \end{bmatrix} \tag{3}$$

where $q = f(T, a, b, v_0, \delta, l, x_{n-1}, v_{n-1}, s_0, s_1)$, $\hat{x}$ is the initial position, and $\hat{v}$ is the initial velocity, and

$$g(x_1, x_2, q) = \alpha_0 x_2^{\delta} + \alpha_1 x_2^4 + \alpha_2 x_2^3 + \alpha_3 x_2^{5/2} + \alpha_4 x_2^2 + \alpha_5 x_2^{3/2} + \alpha_6 x_2 + \alpha_7 x_2^{1/2} + \alpha_8 \tag{4}$$

where

$$\begin{aligned}
\alpha_0 &= \frac{-a}{v_0^\delta} \\
\alpha_1 &= -\frac{1}{4bs^2} \\
\alpha_2 &= \frac{\bar{v}}{4bs^2} - \frac{\sqrt{a}T}{\sqrt{b}s^2} \\
\alpha_3 &= \frac{\sqrt{a}s_1}{\sqrt{bv_0}s^2} \\
\alpha_4 &= \frac{\sqrt{a}s_0}{\sqrt{b}s^2} - \frac{aT^2}{s^2} - \frac{\bar{v}^2}{4bs^2} - \frac{\sqrt{a}\bar{v}T}{\sqrt{b}s^2} \\
\alpha_5 &= \frac{-2\sqrt{a}s_0 s_1 \bar{v}}{\sqrt{bv_0}s^2} - \frac{2as_1T}{\sqrt{v_0}s^2} \\
\alpha_6 &= \frac{-2as_1^2}{v_0 s^2} - \frac{\sqrt{a}s_0\bar{v}}{\sqrt{b}s^2} - \frac{2as_0T}{s^2} \\
\alpha_7 &= \frac{-2as_0s_1}{\sqrt{v_0}s^2} \\
\alpha_8 &= \frac{-as_0^2}{s^2} + a
\end{aligned} \tag{5}$$

q is chosen based on driver's characteristics and it is set prior to simulation. In this report, two sets of q will be chosen to represent a normal driver and an aggressive driver. Note, if the real driver's data were provided, an inverse problem can be formulated in order to find an effective estimation of q.

3.2 Dynamic Modeling: N-car

N-Car IDM can be also simulated with ode solver in Matlab. Consider a vector $\mathbf{x}$ with N car positions, following N car velocities. We can write the N-car system in the following matrix form:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \vdots \\ \dot{x}_n \\ \dot{v}_1 \\ \dot{v}_2 \\ \vdots \\ \dot{v}_n \end{bmatrix} = f\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \\ v_1 \\ v_2 \\ \vdots \\ v_n \end{pmatrix} = \begin{bmatrix} x_{n+1} \\ x_{n+2} \\ \vdots \\ x_{2n} \\ g(x_1, x_{n+1}, x_n - x_{n+1}) \\ g(x_2, x_{n+2}, x_{n+1} - x_{n+2}) \\ \vdots \\ g(x_n, x_{2n}, x_{2n-1} - x_{2n}) \end{bmatrix} \tag{6}$$

where

$$\begin{aligned}
&g(x(i), x(n+i), x(n+i-1) - x(n+i)) = \\
&\alpha_0 x(n+i)^\delta + \alpha_1 x(n+i)^4 + \alpha_2 x(n+i)^3 + \alpha_3 x(n+i)^{5/2} + \alpha_4 x(n+i)^2 \\
&+ \alpha_5 x(n+i)^{3/2} + \alpha_6 x(n+i) + \alpha_7 x(n+i)^{1/2} + \alpha_8
\end{aligned}$$

In the simulation, N was set to be 10. More details will be discussed in the Simulation section.

4 System Specifications

Model parameters of two different drivers are discussed here in this section. We provide 2 different scenarios to analyze the behaviors of drivers: lane-changing and platooning in the congested traffic. Those two scenarios will be discussed in details in later.

4.1 Model parameters for different drivers

The parameters of the IDM is listed in Table 1. Most of the parameters have been discussed in the Modeling section. The parameters v_0, T, a, b have a reasonable interpretation, are known to be relevant, are empirically measurable, and have realistic values. The last column of Table 1 is a typical set of value for a highway vehicle. Note when deceleration exceeds about 5 m/s^2, it is considered as severe braking mode. When deceleration is between 2 and 5 m/s^2, it is considered as large deceleration mode.

Table 1: A Summary of the Parameters Used

Parameter	**Symbol**	**Realistic Bounds**	**A Typical Realistic Value**
Desired Velocity	v_0	[0,35]	24.59 m/s (55 mph)
Safe Time Headway	T	[1,3]	1.6 s
Maximum Acceleration	a	[.5,2]	0.73 m/s^2
comfortable Deceleration	b	[.5,2]	1.67 m/s^2
Acceleration Exponent	δ	—	4
Length of car	l	4 or 5	4 m
Linear Jam Distance	s_0	[0,5]	2 m
Non-Linear Jam Distance	s_1	[0,5]	3 m

We consider 2 drivers: Normal and Aggressive. Here normal means the parameters are picked within the realistic bounds listed in Table 1. The parameters for the aggressive driver are picked based on trial and error. Table 2 lists the parameters for both normal and aggressive driver. Other parameters not listed in Table 2 are set to be the typical values listed in Table 1.

Table 2: Parameters for Normal and Aggressive Drivers

Parameter	**Symbol**	**Normal**	**Aggressive**
Desired Velocity	v_0	25 or 35 m/s	25 or 35 m/s
Safe Time Headway	T	1.5 s	0.5 s
Maximum Acceleration	a	1.4 m/s^2	2.8 m/s^2
comfortable Deceleration	b	2 m/s^2	8 m/s^2

4.2 Driving Strategy for IDM

The *traffic-adaptive driving strategy* [5] was implemented by changing the model parameters depending on the local traffic situation. In general, there are five traffic conditions that are characterized as follows [5]:

- *Free Traffic*: All cars are spaced out enough that they can reach desired velocity easily.
- *Upstream jam front*: It occurs when the driver is headed into congested traffic.
- *Congested traffic*: The driver is greatly restricted, and is moving in a stop-and-go fashion.
- *Downstream jam front*: It occurs when the driver is headed out of congested traffic.
- *Bottleneck sections*: It appears in particular locations along the road where there are physical reasons for decreases in capacity such as lane closings or on-ramps.

To compensate those traffic conditions, the IDM parameters are adjusted as multiplication factors accordingly using the following table given in [5]:

Table 3: Parameters for Normal and Aggressive Drivers

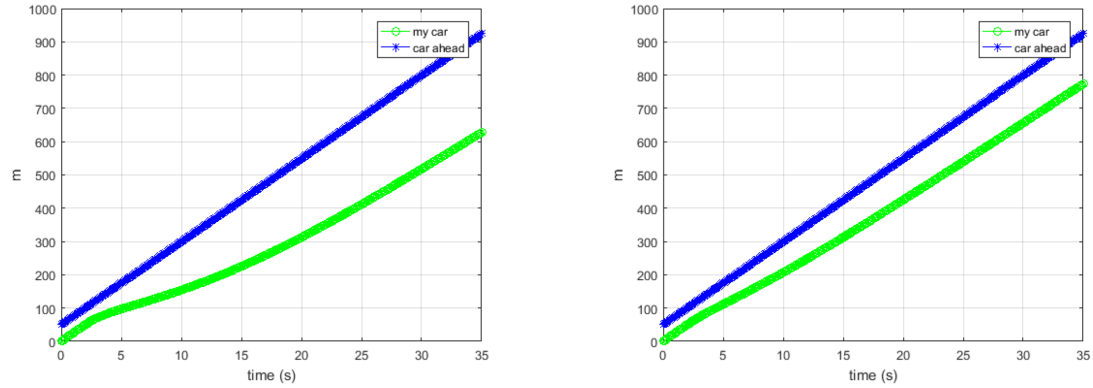
Traffic Condition	λ_T	λ_a	λ_b	**Driving behavior**
Free Traffic	1	1	1	Default/Comfort
Upstream jam front	1	1	0.7	Increased safety
Congested traffic	1	1	1	Default/Comfort
Downstream jam front	0.5	2	1	High dynamic capacity
Bottleneck sections	0.7	1.5	1	Breakdown prevention

For example, $\lambda_T = 0.7$ denotes a reduction of the default safe time gap T by 30% in bottleneck situations. We will use those values to simulate a platooning in a congested traffic for different drivers in the next section.

5 Simulation Study

5.1 Lane-changing Simulation

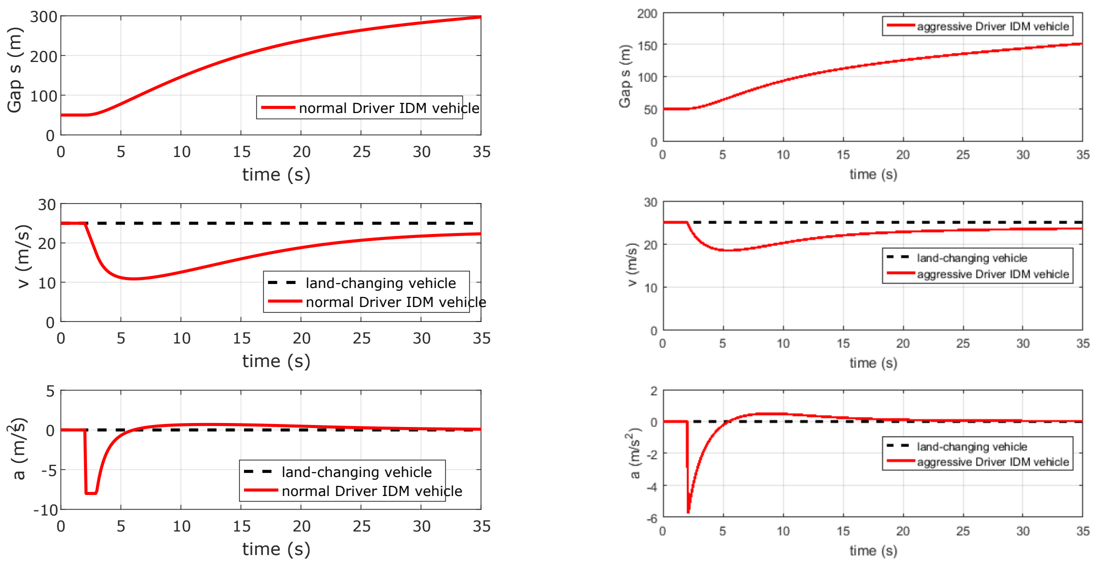
We simulate lane-changing scenarios for both drivers. The preceding car cuts in suddenly at $t = 2sec$ at 30 meters ($s(0) = 30m$) in front of both drivers. Fig. 1 and 2 are simulation results for both drivers. Since the corresponding time headway $s(0)/v(0) = 1.2s$ is less than the desired minimum time headway 1.5s for the normal driver, we see the deceleration of normal driver reaches the deceleration limit at 8 m/s^2 (the maximum value of deceleration is assumed to be physically possible at 8 m/s^2). On the other hand, the minimum deceleration of the aggressive driver was about 5.5 m/s^2, which is less than its own comfortable deceleration limit.



(a) Normal Driver and its preceding car displacement. (b) Aggressive Driverand its preceding car displacement.

Figure 1: Scenario 1: Response of a normal and aggressive driver and their preceding car displacement using IDM.

Comparing these two drivers' velocity and acceleration profiles, it can be observed that the aggressive driver has a higher rate of acceleration (jerk), but it does give a smaller Δv (velocity bounds) when correcting its velocity to keep the desired gap.

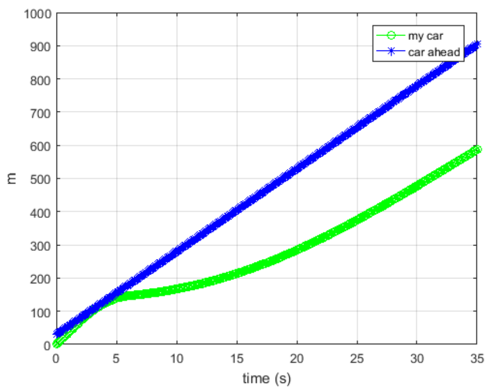


(a) Normal Driver Response. (b) Aggressive Driver Response.

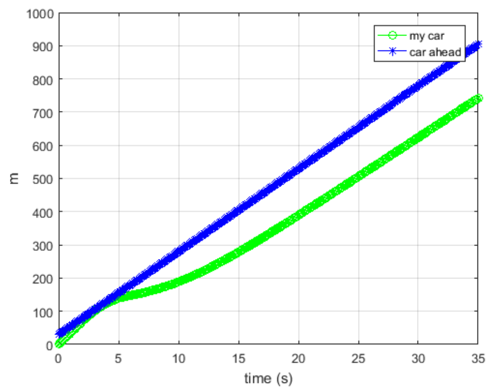
Figure 2: Response of a normal and aggressive driver using IDM to the lane-changing maneuver of anothoer vehicle immediately in front of the considered vehicle. The initial velocities of both vehicles is 25 m/s, and the initial gap is 50 m.

Also, the aggressive driver has a smaller gap as time progresses. Another interesting point is that the velocity of both drivers slowly converge to the velocity of the preceding car, which is realistic. We denote this lane-changing scenario to be mildly critical because both drivers have reached the deceleration limit for a short period of time.

A seriously critical situation is depicted in Fig. 3 and 4. While the 'cut-in' results in the same initial gap $s(0) = 30m$, both drivers are approaching rapidly at 35 m/s. Therefore, an emergency braking is mandatory to avoid a rear-end crash. For this case, both drivers have similar gap, velocity and acceleration profiles. We can see both drivers nearly crashes its preceding car, and both have to keep maximum deceleration for more than a few seconds. The aggressive driver actually was able to decelerate and accelerate quicker, and it resulted a smaller gap as time progresses. However, this means the aggressive driver is tolerant of high acceleration, and this might reduce comfortableness. This critical scenario should be avoided because it requires drivers to stay at deceleration limit for a while (comfortableness reduction).

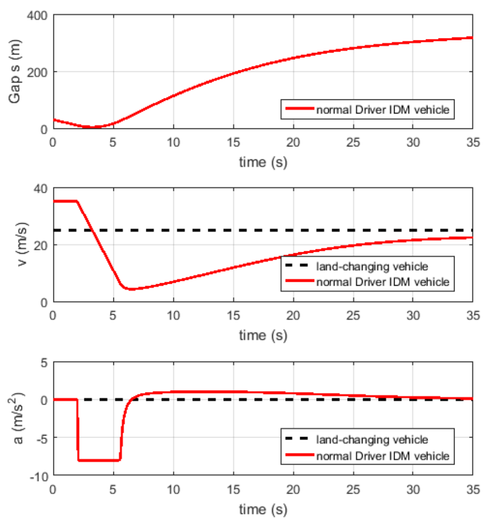


(a) Normal Driver and its preceding car displacement.

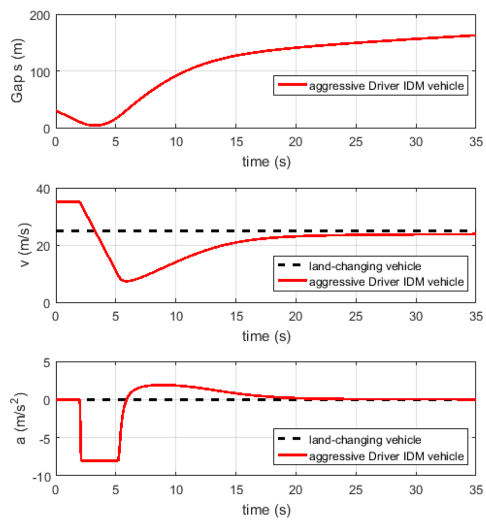


(b) Aggressive Driverand its preceding car displacement.

Figure 3: Scenario 2: Response of a normal and aggressive driver and their preceding car displacement using IDM.



(a) Normal Driver Response.



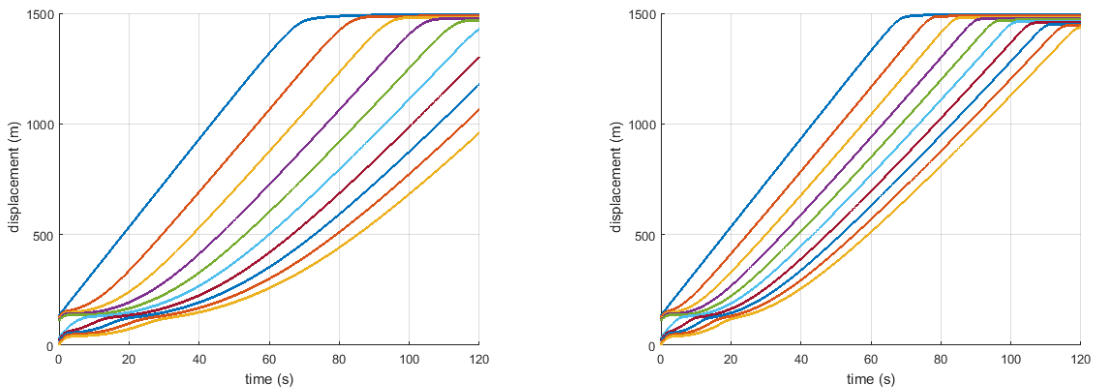
(b) Aggressive Driver Response.

Figure 4: Response of a normal and aggressive driver using IDM to the lane-changing maneuver of another vehicle immediately in front of the considered vehicle.The initial velocity of the lane-changing vehicle is 25m/s, while the initial velocity of the considered vehicle is 35m/s. This is a "strong critical" situation.

5.2 N-Car Simulation in Changing Traffic States

We also simulate a 10 car platooning in a changing traffic condition to see how both drivers respond. Note all the drivers are either normal or aggressive in the simulating environment; there is no mix drivers in this simulation. In order to simulate multiple stages of traffic, the cars were separated into two groups. The front group's speed (20 m/s) was lowered and the cars were pushed closer together to begin with. The back group has a faster speed (25 m/s) to begin with, so they caught up with the front group quickly, making this scenario to be a traffic jam. However, since there is no limit on first car, it was able to speed up to the desired speed (still 20 m/s in this case) and followed up others. Eventually, there is another slow car on the road that the first car cannot pass. It has to slow down, again follow by both groups. The initial gap between front group and back group is about 80 m.

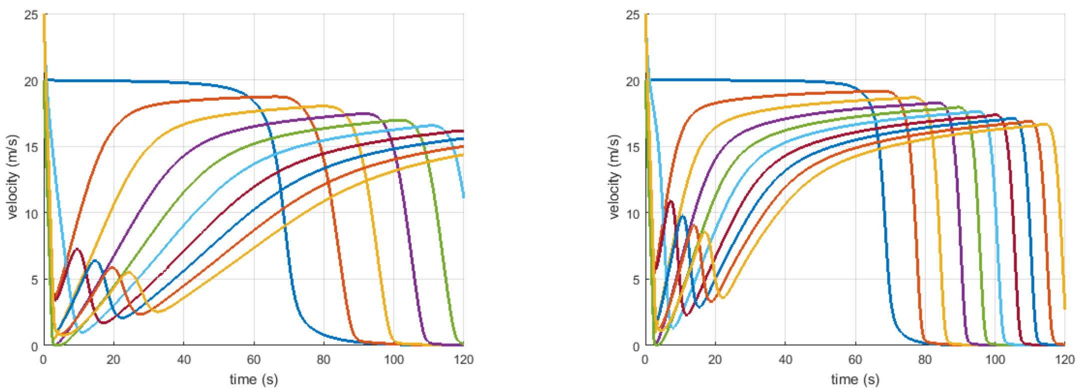
Fig. 5, 6 and 7 show the simulation results for both drivers. Both drivers have similar results in displacement, velocity and acceleration. In terms of velocity, we can see the last car (light blue) in the front group have almost reached a zero velocity to prevent crash. The minimum velocity of each car decreases with the order of car in the front group in the first 20 secs. Interestingly, the minimum velocity of each car increases with the order of car in the back group in the first 20 secs. This makes sense as the first car of the back group approaches to the front group, it needs to decelerate faster than the later car. All the velocity decreases to zero over time because there is another slow car on the road that is in front of the car.



(a) Normal Driver Response: Displacement

(b) Aggressive Driver Response: Displacement

Figure 5: The cars begin in a jam situation, move into a downstream, then free state, before entering into an upstream

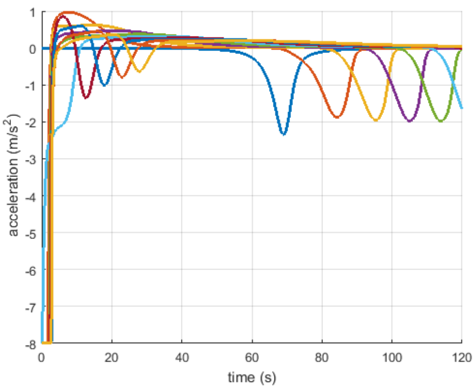


(a) Normal Driver Response: Velocity

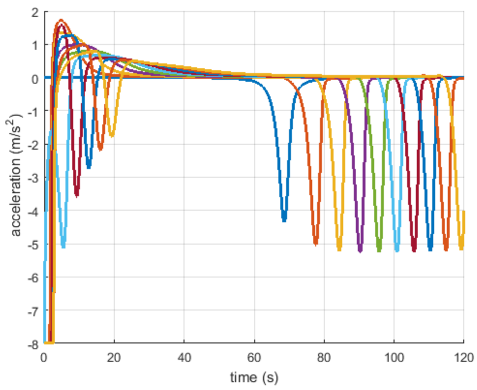
(b) Aggressive Driver Response: Velocity

Figure 6: The cars begin in a jam situation, move into a downstream, then free state, before entering into an upstream

Fig. 7 shows the acceleration profile for both normal and aggressive drivers. It can be seen the aggressive drivers have larger acceleration and deceleration in all the stages of the changing traffic states. Both drivers have reached the maximum deceleration limit in the 5 secs due to sudden upstream jam front.



(a) Normal Driver Response: Velocity



(b) Aggressive Driver Response: Velocity

Figure 7: The cars begin in a jam situation, move into a downstream, then free state, before entering into an upstream

6 Conclusion

An Intelligent Driver Model (IDM) was studied and simulated for 2 types of driver: normal and aggressive. The IDM was transformed into an ODE system for quick simulation purpose. N-car platooning was developed and simulated for both types of drivers. 3 scenarios were simulated to compare drivers' behavior: mild lane-changing, critical lane-changing, and 10-car platooning in the changing traffic states. In all scenarios, we can see that the aggressive drivers experience a higher rate of acceleration, which results in a smaller Δv change when trying to catch up after deceleration. In terms of the gap between cars, the aggressive drivers have smaller gap. It is interesting to find out that being aggressive does not translate to being dangerous on the road, it just means the aggressive driver is more tolerant for high acceleration or deceleration change. Of course, this is based on the assumption that aggressive drivers fully pay attention to what is happening on the road. In reality, we like to keep the gap distance large enough in case our reaction is delayed by distractions.

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