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# Summary

Among so many rules of the freeways, the Keep-Right-Except-To-Pass rule is used more and more commonly in right-hand traffic and there is a greater necessity to fully study its performance under different traffic conditions.

We designate the traffic flow and safety as the two basic measures of this rule and analyze their variation under the effect of posted speed limits. We develop the model of acceleration, combined with a number of existing ones, to model the performance of the rule using the primary measures, namely traffic flow and safety.

We then introduce the influence of overtaking in order to optimize the model in light and heavy traffic and compare it with other alternative rules that might be more effective. After that we discuss the application of our model in left-hand traffic considering two major factors that may need us to do add variations or more requirements, which is the Coriolis Effect and the vehicle design.

Finally we simulate our model in VISSIM to discuss whether our model works fine in reality. When considering intelligent system, we assume that there are three human factors and draw a conclusion that in heavy traffic human judgment is likely to behave better than artificial intelligence. Our model focuses more on macroscopic level, so it’s not refined by some microscopic conditions, which make our model applicable in a wider range of situations.

# Keep-Right-Except-To-Pass, Better or Not?

# Content

# 1 Introduction

There are two kinds of basic traffic across the world, namely right-hand traffic and left-hand traffic, which are used according to regulations of different countries and in each one of them there are rules trying to ensure the best condition of the traffic.

In countries where the right-hand traffic is applied, some more specific rules are used on multi-lane freeways, for example, a so-called Keep-Right-Except-To-Pass rule generally requires all drivers to keep to the right-most lane of the freeway unless overtaking, which also requires them to move one lane to the left and return to the previous lane after passing.

Overtaking is a rather common phenomenon on freeway. It allows a number of faster cars to pass slower ones to avoid being limited, so they are able to travel through the whole journey without speed loss. The main approaches that are used to study overtaking are cellular automata modeling and differential equation modeling. [1]

## 1.1 Objectives

However, we want to find out the effect of such rule on the performance of freeway traffic since there may still be dispute upon whether such rule has improved the traffic in certain ways or whether there exists a better rule in traffic controls.

Our goal is to find and analyze the optimal rule in light and heavy traffic. We thus need a metric with which to evaluate traffic flow, safety and other factors. We firstly build and analyze a mathematical model to evaluate those factors above in keep-right-except-to-pass rule. Then we compare this rule with keep-right-without-overtaking rule and free-driving rule. We also apply the optimal rule in countries where driving automobiles on the left is the norm with some changes. Lastly, we revise the optimal rule considering (without considering human judgment for compliance) vehicle transportation on the same roadway was fully under the control of an intelligent system.

## 1.2 Combination of Microscopic and Macroscopic Model

Microscopic and macroscopic models are two general methods in analyzing traffic situations. In this paper, both microscopic and macroscopic model are applied. Microscopic models focus on individuals, thus involving condition of a single driver and vehicle and their relation to the objects next to them, while macroscopic models consider thousands of vehicles at a time and model them as fluids or with other physical analogies.[2] On one hand, the current rules, which are the only requirement that could be applied on individuals, such as the Keep-Right-Except-To-Pass rule have determined in details how an individual driver behave in typical ways, on the other hand, a large amount of action taken by all drivers will finally lead to macroscopic change on the freeway. With all being discussed, there is a necessity to take both models into account.

# 2 Terminology

**multi-lane freeways:** A one-way traffic road with at least 2 lanes.
**traffic stream:** A road that vehicles either follow others or overtake them.
**flux ( $q$ ):** The number of vehicles passing a given line over a given interval of time. We will measure this in vehicles per hour.
**velocity ( $v$ ):** The average rate at which the flow of traffic is moving. We will measure this in kilometers per hour.
**density ( $\rho$ )**: The number of vehicles per unit of distance. We will measure this in vehicles per meter.
**overtaking probability( $p$ ):** The average probability of vehicles overtaking. It should be less than 0.5, since the probability of the speed of the latter vehicle greater than the former vehicle is 50%.

**safety distance( $s$ ):** The distance allow the drivers to brake safely in incidents.

**vehicle length ( $l$ ):** The average length of all vehicles. Based on data, we decide to set l equal to x meter.

$\boldsymbol{v_{min}}$ **:** The minimum velocity that the traffic stream can at least attain in a given freeway.

$\boldsymbol{v_{max}}$ **:** The maximum velocity that the traffic stream can attain in a given freeway.

$\boldsymbol{\rho_{max}}$ **:** The maximum density of the traffic stream, at which point all vehicles follow the vehicles ahead by safety distance.

# 3 Simplifying Assumptions

In fact, to fully model the real traffic situations, a great number of specific variables need to be considered, including subjective decisions made by drivers which are hard to anticipate and predict. Therefore in this paper, we make the following assumptions to simplify the models.

- In the overtaking model, every car must conduct overtaking whenever there is a chance and the situation on freeway meets all the needs of what it takes to conduct overtaking. For example, when a faster car is approaching a slower car moving ahead and is within safety distance between two cars, the driver in the faster car will surely make overtaking instead of slowing down unless objective condition, such as the faster car being overtaken at the moment, forbid him/her to do so.
- We do not take into account the situation where the traffic is completely blocked and the total flux is close to zero, since under such circumstances the performance of the freeway is seriously damaged and no other action could be taken but following the cars ahead, which is beyond our discussion on the proper and normal functioning of rules on freeways.
- The freeway remains normal condition. That is, no extreme weather takes place, such as strong wind and wet roads on rainy days that will directly cause the motion changes of vehicles.
- All vehicles obey the basic rules on freeway. For example, a vehicle being overtaken will cooperate until overtaking is finished instead of speeding up suddenly.
- Vehicles are all cars of the same type.

# 4 The model

## 4.1 Basic Formula for describing traffic flow

When studying traffic flow in macroscopic model, three fundamental factors are usually considered, namely the flux $q$, which means the number of vehicles passing a certain point per unit of time, the average velocity of cars $v$ and the density of cars $\rho$. According to Haberman, "a road is homogeneous such that the vehicle velocity depends on traffic density and not on time and position along the road… flow only depends on the density"[3], we define the flux is the function of $\rho$ and $v$, that is

$$q = \rho v \quad (1)$$

which is suitable to all condition of the roads.

Based on the conservation of vehicles, that no vehicles are created or destroyed, which means the vehicles entering the freeway will surely leave the freeway later. Thus, the following formula derives, which is called continuity equation:

$$\frac{\partial \rho(x,t)}{\partial t} + \frac{\partial q(x,t)}{\partial x} = 0 \quad (2)$$

There are many models to study the relationship between traffic density and speed, for example: the Greenshield model, the Greenberg model, the Underwood model, the Drew model, the Drake model, etc.[4] Since our goal is to analyze the performance of the Keep-Right-Except-To-Pass rule in both light and heavy traffic using total traffic flow and safety as metrics, we need to deal with both situations separately.

It's a common sense that, the average speed of vehicles decreases as the density of vehicles increases, because the tighter they get, the slower they move and harder they overtake others. The problem then lies in the difference of such relationships between light and heavy traffic. According to Dirk Helbing, "As the density of vehicles increases, their interactions cause a transition into a highly correlated state in which all vehicles practically move with the same speed, analogous to the motion of a solid block"[5], we realize that compared to heavy traffic, vehicles in light traffic move more freely and become less correlated with other vehicles. Therefore, the range of application of our model isn't negligible.

## 4.2 The Greenshield model

Greensield postulated a linear relationship between speed and density based on measurements[6], which is simple and has a number of field data supporting:

$$\bar{v} = v_f\left(1-\frac{\rho}{\rho_{\max}}\right) \quad (3)$$

where $\rho$ and $\rho_{\max}$ are the density and jam density (in veh/km) and v and $v_f$ are the speed and free-flow speed (in km/h). Approximately, we assume $v_f$ as the maximum speed of posted limit.

## 4.3 The model for overtaking

The basic overtaking procedure can be described as follows. A fast vehicle A with a speed va gains on a slow vehicle B with a speed $v_b$ ($v_a > v_b$). When the distance between them decreases to a safe length, vehicle A slows down (although its speed is still greater than $v_b$)and moves to the side of vehicle B, accelerates, overtakes vehicle B, and finally regains its original speed $v_a$ .[4] However, in this paper, we are studying how the rule of vehicles, which cause masses of individuals acting in the same way, influences the traffic as a whole, so details in the way a certain vehicle overtakes another doesn't matter that much. What matters is the time saved and the danger caused by overtaking.

Therefore, we make some additional assumptions as follows:

1. Since the driver will conduct overtaking whenever there is a chance and situations permit and the speed is already greater than the slow one's, the fast vehicle doesn't have to slow down.
2. Since the driver doesn't have to slow down, to further simplify the model, the time needed to accelerate can be neglected. So the new procedure is simple: when the fast vehicle start overtaking, it change to the left lane (during which the time needed is ignored) while the speed change from $v_1$ to $v_2$ immediately. Then the fast vehicle passes the slow vehicle in the uniform linear motion and return to the right lane in the same way in reverse.
3. Since the speed of the faster vehicle is still greater than the slow vehicle and the slow vehicle will cooperate with the overtaking, we ignore the safety length between two vehicles after overtaking.

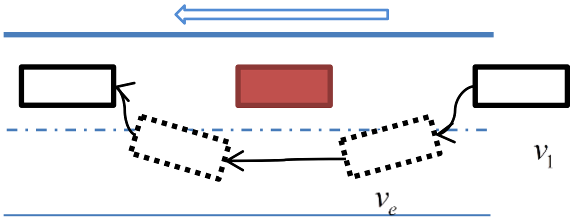


**Figure 1**: The real overtaking procedure.

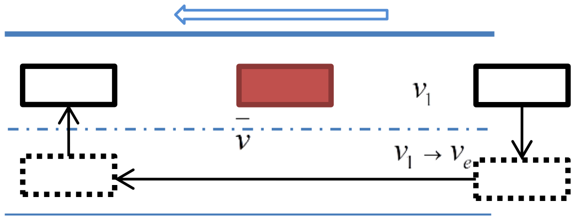


**Figure 2**: The simplified overtaking procedure.

After simplifying the overtaking model we are able to calculate the time saved at a time by overtaking. Let $\Delta t$ be the time saved every time an overtaking is conducted, ve be the uniform velocity when passing. Let t1 be the time it takes for the fast vehicle to overtake the slow vehicle. Thus we obtain the following equation:

$$\left(v_e - \bar{v}\right)t = 2l + s \qquad (4)$$

The variable $\bar{v}$ is the velocity of the slow vehicle, statistically we let it be the average velocity of the traffic. If no overtaking is conducted, that is, the fast vehicle keeps following the slow vehicle, it has to slow down to the speed equal to the vehicle moving ahead. Derives the following equation:

$$v_e t = \bar{v}t + \bar{v}\Delta t \qquad (5)$$

From equation (5) and (6) we get the value of $\Delta t$:

$$\Delta t = \frac{2l + s}{\bar{v}} \qquad (6)$$

The value of $\Delta t$ stands for the time saved for one vehicle to cover the whole journey, we can imagine that when thousands of vehicles do overtaking, it save a large amount of time for all vehicles to travel the whole freeway. In other words, the motion of the traffic somehow accelerates. Therefore, we here define another variable $a$ as the acceleration of the traffic.

To discuss the variable *s*, we need to divide it into two parts. The first part should be the length which the vehicle passes during response time, while the second part is the length of deceleration.

$$s = vt_{react} + \frac{v^2}{a_{brake}} \qquad (7)$$

## 4.4 The Model of Acceleration

When we discuss an object's motion, the position of centroid in a way reflects the mass distribution of an object. The mass distribution can further be described as the density of the object. Similarly, as we study the density of traffic on a given freeway, we are actually working on the distribution of vehicles. Taking a section of freeway into consideration, if we assume all vehicles within this section obey a certain distribution, such as uniform distribution, all of the vehicles in this section can be compared to an object, the centroid of which is on the midpoint of the road. Because the Keep-Right-Except-To-Pass rule requires all drivers to move back to the right lane, the total mass of the object remains the same.

Observing the phenomena without overtaking, and ignoring the boundaries conditions, we find that the over a period of time *t*, the center of mass of the traffic stay in the midpoint. However, when overtaking happens, more vehicles are able to go to the front over the same period of time. The center of mass thus relatively move a little bit forward compared to the situation where no overtaking takes place. Such change happens in any section of freeway. In fact, as number of vehicles at the back of the section decreases, more vehicles in the back section are given chances to fill the vacancy. In Fig.1 below, where the color depth represents the density of vehicles, demonstrates the change of the center

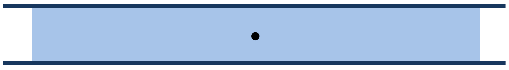

**Figure 3:** The density distribution without overtaking.

**Figure 4:** The density distribution with overtaking.

Let d be the shift of the center of mass, the function is given by:

$$d = \frac{1}{2}at^2 \quad (8)$$

thus the new average velocity of the traffic can be described as:

$$\bar{v} = v + at \quad (9)$$

where *t* represents the real time duration excluding the overlapped amount of time, so we assume the number of vehicles that overtake at the same time obeys the Poisson distribution.

Let *p* be the possibility of overtaking, the total amount of time saved by overtaking $t'$ is given by:

$$t' = pq\Delta t \quad (10)$$

And *d* is given by:

$$d = \frac{(2l+s)\,pq}{q} = (2l+s)\,p \quad (11)$$

Thus we gain:

$$t = \frac{pq\Delta t}{p^2 q} \quad (12)$$

where $p^2 q$ represents the number of vehicles overtaking at the same time in average.

Finally we have the function of acceleration:

$$a = \frac{2p^3v^2}{2l+s}$$

Discussion about this acceleration model emphasizes on heavy traffic situations. Light vehicle traffic distribution is not uniformly distributed. After we plot in MATLAB for lots of times we finally find an optimal variable factor which is $e^{-2p^3t}$ to improve this model. We can further define *a* as:

$$a = \frac{2p^3v^2}{2l+s}e^{-2p^3t} \quad (13)$$

## 4.5 The Model of Traffic Flow

According to (1), the flux *q* can be defined as:

$$q = \rho(v)v$$

Therefore, the equation of traffic flow derives using (3) and (8):

$$q = (v + at)\rho_{\max}\left(1 - \frac{v + at}{v_{\max}}\right) \quad (14)$$

where the variable *a* is described in (12).

We assume when $\rho = \rho_1$, the vehicle overtaking cannot return to the original lane, since the average distance between vehicles in the right lane is less than safety length in the left lane. When $\rho > \rho_1$ , vehicles in the left lane begin to accumulate, where we can still apply Eq.(14). While the equation for free multi-lane without overtaking rule remains as follows:

$$q = v\rho_{\max}\left(1 - \frac{v}{\max}\right) \quad (15)$$

## 4.6 Safety Definition

In 1993, Monash University simulated accident rate's approximate function of velocity gradient in roads in Australia and they got:

$$I = 500 + 0.8\Delta V^2 + 0.014\Delta V^3$$

where I represents the accident rate ( $times/10^5 vch \cdot km$ ) and $\Delta V$ represents the velocity gradient(*km/h*).[7]

Later, British researcher A.Buruya developed EURO model defined as follows:

$$\Delta \ln(I) = \frac{1.536\Delta V}{V}$$

where I represents the average accident rate per year ($times/10^6 vch \cdot km \cdot y$), *V* represents average velocity (*km/h*), $\Delta V$ represents the velocity gradient(*km/h*).[7]

Based on the previous research, Bo developed a new model to define the accident rate I, which is given by:

$$I = V^{2e^{-9}V^{3.264}} - \left(1 - \frac{V}{\overline{V}}\right)$$

where $\overline{V}$ stands for the average velocity.[7]

However, this model neglects the velocity distribution in a given section of the road, which could be defined as a normal distribution:

$$y = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(v - \overline{v})^2}{2\sigma^2}} \quad (16)$$

where $\overline{V}$ stands for the average velocity and $\sigma$ is the standard deviation of the distribution.

According to statistics (see Appendix), as the average velocity approaches 80km/h (50), $y_{\max}$ gets to about 0.012($10^6$ vch), so $\sigma$ can be calculated to be 33.245.

Therefore, we define $\xi$ as accident rate which is given by:

$$\xi = I(V)y(V) \quad (17)$$

Then we plot a curve of the relationship between $\xi$ and *V*:

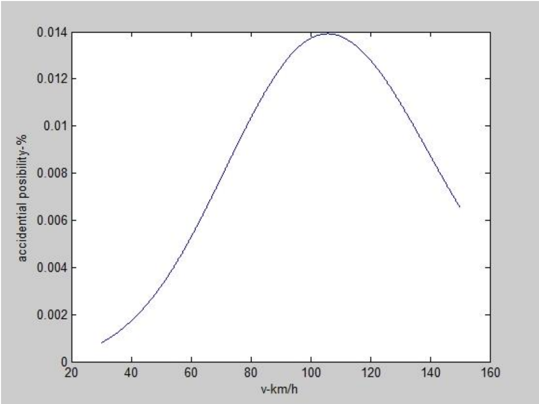


**Figure 5:** The $\xi$-$V$ curve

## 4.7 Analysis of Our Model

We analyzed our model in MATLAB by plotting the curve of Eq.(14) after defining the values of a few variables.

- Response speed depends on several factors so there can be no single, universal reaction time value.[8] Since we assume the objective conditions are the best they can get, we set $a_{react}$ as 0.7 seconds.
- According to the traffic rule on freeways in China, safety distance at 100km/h should be 100m,[9] so we define $a_{brake}$ as $8.89\,km/s^2$.

As shown in figure (6) (7) (8) (9), we traffic flow in relationship with v, which also varies based on freeway conditions (light and heavy traffic).

In figure 6, we found that in heavy traffic, the flux of no-overtaking rule (the green line) is obviously greater than Keep-Right-Except-To-Pass (KRETP) rule, which means that our model has proven that KRETP rule is superior to free multi-lane without overtaking rule. As for the safety, the density of free multi-lane without overtaking rule is less than the KRETP rule when compared in the same speed which leads to larger safety distance and thus the situation becomes safer. But generally speaking, to gain the maximum flux the speed of blue and green curve should be 65km/h and 80km/h respectively. Based on the curve of accident rate, the KRETP rule is safer.

Figure 7 indicates that in light traffic, the free multi-lane without overtaking model is exactly the same as the KRETP rule. It makes sense because although the rate of overtaking is greater, we can still see less vehicles conduct overtaking.

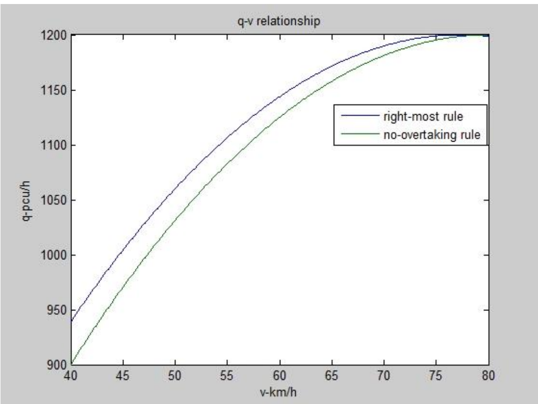


**Figure 6:** Situation in heavy traffic, where $40<v<80(km/h)$, $p=0.2$, $v_{\max}=160$km/h. We simulate the traffic for 100s ($t=100$).

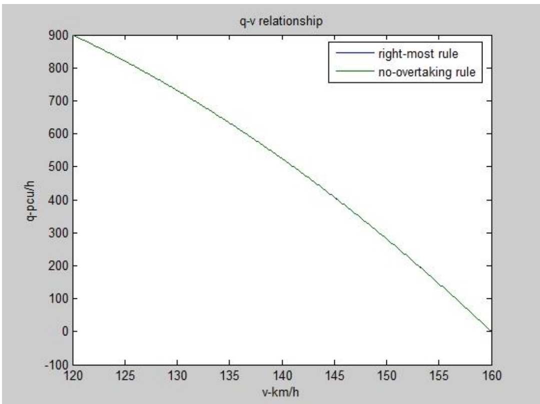


**Figure 7:** Situation in light traffic, where $120<v<160(km/h)$, $p=0.4$, $v_{\max}=160$km/h. We simulate the traffic for 100s ($t=100$).

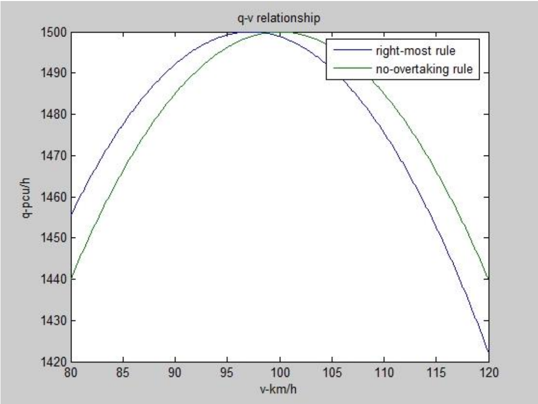


**Figure 8**: Situation in light traffic, where $80<v<120(km/h)$, $p$=0.2, $v_{\max}$ =200km/h. We simulate the traffic for 100s ($t$=100).

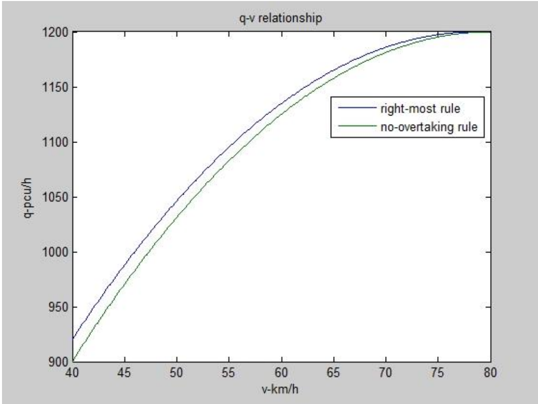


**Figure 9**: Situation in light traffic, where $40<v<80(km/h)$, $p$=0.1, $v_{\max}$ =160km/h. We simulate the traffic for 100s ($t$=100).

In figure 8, we can find out that when $v_{\max}$ grows larger, the point of intersection shifts right, which indicates that raising posted speed limit has positive effect on the KRETP rule. Also, the maximum of flux has increased at the same time! In the suspect of safety, raising speed straightly causes the safety to reduce. If we take the minimum posted speed limit into account, it can help to increase the average speed of normal distribution to the high place in figure 8, which helps to keep the flux in high place.
In figure 9, $p$ is smaller when compared with figure 6. We can see from the picture when the traffic grows heavier KRETP rule will less likely to show its advantage. That's because the rate of overtaking is becoming smaller and smaller.

# 5 Application in Left-hand Traffic

Today, Nearly 65% of the world's population lives in countries with right-hand traffic and 35% in countries with left-hand traffic.[10] Generally speaking, the rules in the right-hand traffic could be perfectly applicable to the left-hand traffic if the entire system is of exact axial symmetry. Nevertheless, statistics shows that right-hand dominates in global traffic. The reason why there are differences between them should be considered in both external and internal cause.

## 5.1 Coriolis Effect

The Coriolis Effect is a deflection of moving objects when they are viewed in a rotating reference frame. The earth itself is an rotating object so it influences all objects attached to it by changing their motion. Such phenomenon as the river direction could be felt when a long period of time passes. Any land feature in the Northern Hemisphere turns counter-clockwise, while in the Southern Hemisphere they turn in clockwise. Then the trace of a free moving object will turn in opposite direction, which usually in Northern Hemisphere is right.
If the Coriolis Effect on vehicles is taken into account as an external cause, our solution cannot be carried over without changing. Yet the effect may be trivial, since the main constraint on the motion of a vehicle is related to the driver, which appears on the steering wheel and thusly the friction the ground provides. The friction itself is almost irrelevant to the Coriolis Effect.
However, any tiny change gets significant when applied to a large amount of objects. Comparing the traffic to fluids, such as a river, we have to take into account the effect on macroscopic level.
Our solution is based on right-hand traffic, where all vehicles travel on the right side. Under the effect of Coriolis force, the traffic flow shows a tendency to move a little righter in Northern

Hemisphere, which results in a higher probability of crashing into the road shoulder and lower probability of overtaking in Keep-Right-Except-To-Pass rule. If the traffic is changed to the left side, where a lower probability exists of hitting the shoulder and the probability of overtaking gets higher in Keep-Left-Except-To-Pass rule, the overtaking probability *p* must be recalculate or redefine, for the average value of *p* slightly has increased. Therefore, there may be a change in the total flux of the traffic flow and the safety factor changes according to the proportion of accident rate of overtaking to hitting the shoulder.

## 5.2 Vehicle Design

In order to completely carry our solutions over without changing, the structure inside the vehicle must be axial symmetric as well. Vehicles are usually manufactured in left-hand drive (LHD) and right-hand drive (RHD) configurations according to the side vehicles travel, because in right-hand traffic, where overtaking usually occurs on the left side, the sight of drivers should allow the drivers to see clearly the road to the left, thus there are more chances to keep eyes on the oncoming vehicles and prevent accident from happening.
Assuming a left-hand drive vehicle is moving in left-hand traffic, the position of driver in the vehicle is on the left side. In this situation, the driver's sight on the oncoming vehicles is somehow blocked and the driver needs to estimate the width of the vehicle when driving and overtaking.
However, our solution doesn't involve the difference between left-hand drive and right-hand drive vehicles, so it could be carried over without alterations.

# 6 Application in Intelligent System

In the future, artificial intelligent will probably play a significant role in daily life. There are many high-tech companies working on intelligent vehicle system and how to apply artificial intelligence on the highway system is a problem. Artificial intelligence system excludes the human factor, in order to make achievement of completely replacing human judgment. Our analysis of the model largely simulates the flux influenced by the speed of the actual traffic. But to use it as a complete artificial intelligence system, there still exists some differences as follows:

1. In reality, whether the drivers will conduct overtaking depends not only on objective conditions, but also on the willingness of the driver at the moment, which is hard to predict and simulate. For example, the driver will consider slowing down the speed when he/she finds there are too much cars ahead or when he/she has to talk to the passengers on the cars. This will leads to the change of some of our variables, especially *p*, the possibility of overtaking. Since as shown in Eq.(13):
$$a = \frac{2p^3v^2}{2l+s}e^{-2p^3t}$$
the average acceleration of the traffic is partly determined by p. So as the driver is willing to slow down instead of overtaking, the probability of overtaking will decrease a bit compared to a complete intelligent system, so we have to raise the value of p accordingly to fit the real situation with human factor. Therefore, if we replace human judgment with an intelligent system, a more complicated function to simulate p is needed instead of only using statistics.
2. We use VISSIM to simulate the real situation in intelligent system using our model which resulting in the following data. The total amount entering represents the input of vehicles to the freeway, the data is obtained at a certain point of the freeway over a given period of time. We can see from the table when the input ranges from 8000 to 10000, right-hand rule traffic somehow equals to the situation in traffic of no rules, but when the input is reach 11000,

right-hand rule traffic is apparently inferior to traffic of no rules.

| Total Amount Entering(vch) | Left-hand traffi (vch) | | Right-hand traffic (vch) | | no rules (vch) | |
|---|---|---|---|---|---|---|
| | left lane | right lane | left lane | right lane | left lane | right lane |
| 300 | 7 | 0 | 0 | 7 | 4 | 3 |
| 2000 | 32 | 8 | 10 | 30 | 21 | 19 |
| 5000 | 59 | 50 | 46 | 63 | 55 | 54 |
| 7000 | 60 | 63 | 50 | 59 | 62 | 63 |
| 8000 | 61 | 59 | 55 | 67 | 63 | 64 |
| 9000 | 72 | 70 | 61 | 65 | 62 | 64 |
| 10000 | 65 | 56 | 59 | 70 | 64 | 63 |
| 11000 | 65 | 63 | 41 | 54 | 64 | 62 |

**Table 1:** Simulation in VISSIM, the traffic flow distributes in different rules.

From VISSIM simulation, we can find the right-hand traffic rule is congested, because artificial intelligence still cannot effectively identify the traffic jam situation, blindly follows the existing rules, but in fact human won't. However, if no traffic jams can be seen, namely the 8000-10000 input, the right-hand rule traffic is still better than traffic of no rules, which still accords with our model.

# 7 Conclusion

We mainly analyze from the macro how the various factors of different rules impact on traffic flow, safety, speed. We consider the difference between artificial intelligence and human affects, and simply describes the right and left of the driving in history and their science basis. Our model is just around the discussion on constant-speed overtaking. We believe that the complexity of overtaking model little effect on the overall model. Our model is mainly focused on the macroscopic level and therefore suitable for multi-lane freeways.

In different rules, we focus only on right-most rule and no-overtaking rule.

In the suspect of traffic flow, heavy traffic in the right-most rule is better than no overtaking rule , but with heavier traffic situation , this advantage is gradually disappearing. In light traffic, the right-most rules are almost entirely consistent with no overtaking rule, if one has to win, then the rule of no overtaking is superior.

In terms of security, we have introduced an accident rate and velocity curve describing the relationship between the accident and the traffic. After we discuss it in detail, the relationship between speed and accident rate is far greater than the relationship between the accident rate and the car. So the accident rate is mainly to measure the speed. The right-most rule of the heavy traffic is in higher security. When it reaches the maximum flow, right-most rule has less speed than no-overtaking rule, and both are on the rising portion of speed and accident rate portion of the curve. So the right-most rule is safer. In light traffic, the two curves almost coincide, therefore with almost the same level of security .Overall, the right-most is a higher security rules.

In terms of speed, maximum speed limit can improve overall traffic, minimum speed to make the majority of cars driving at the speed of the highest traffic flow, which can enhance the performance of road transport. But higher the maximum speed limit is the worse security it will become.

If you want to balance the relationship between security and traffic, for the right-most rules you need to try to raise the maximum speed limit, but not too high, to make the average speed settle in a lower part of the rising proportion of the *q*-*v* curve. Adjust the minimum speed limit so that the average speed locates in the point of intersection of *q*-*v* curve and *Safety*-*v* curve. As for the no overtaking rule, the maximum speed limit has little influence on it. We can just adjust the minimum speed limit so that the average speed locates in the point of intersection of *q-v* curve and *Safety-v* curve.

In the left-driving rule, we mainly discuss the impact of the Coriolis force and the steering wheel design on the rule.

On Artificial intelligence we mainly discuss it in three aspects.

We assume that there are three human factors:

The first is the possibility of people failing to conduct overtaking when there is a chance. In the case of heavy traffic it helps to reduce the pressure. It may also increase the pressure. If the traffic is very blocked, this will help reduce the pressure on the traffic. If not, it will increase the pressure.

Then a man who encounters a traffic jam will possibly slow down the speed. There is no good data for this situation and therefore we cannot find the fitting function and also cannot discuss how this human awareness impacts on the traffic.

Finally, the people in the traffic jam will automatically avoid the blocked car. But artificial intelligence is not able to recognize the situation and drive straight to the blocked car. We present a table of VISSIM simulation, artificial intelligence response worse to the traffic jam than human being does. Overall, right-most rule under heavy traffic flow is superior to the no-overtaking rules, consistent with the conclusion of our model.

# Appendix

To simulate the real situation, we refer our value to the National Transportation Statistics in United States. We plot the following using the table given on the website. [11]

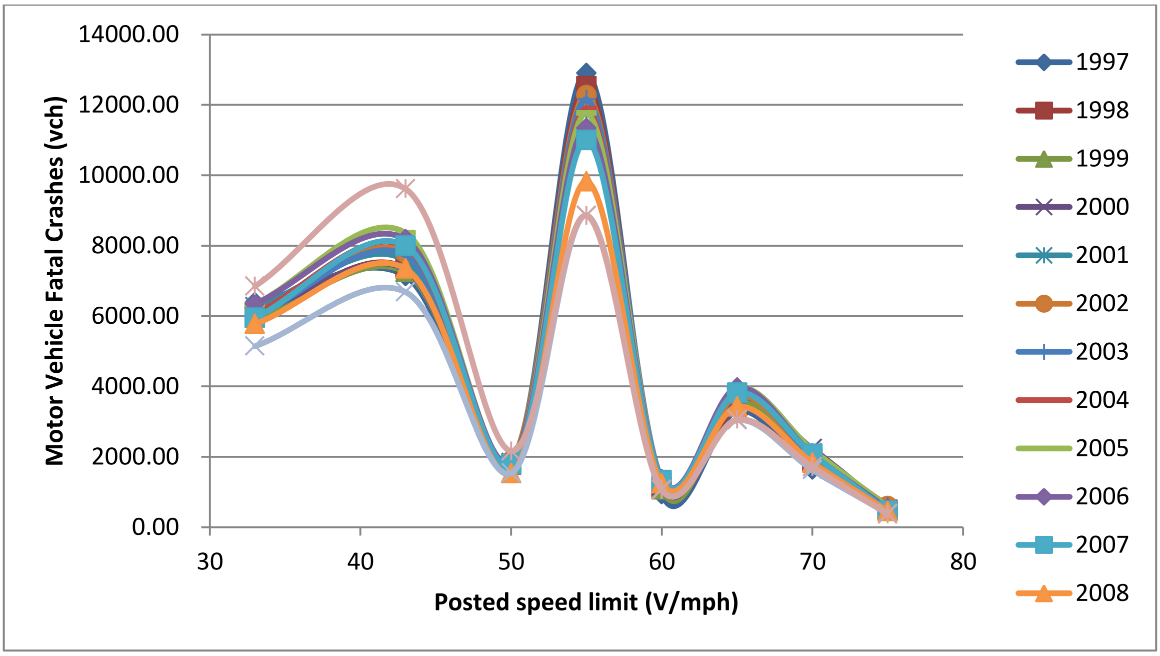


**Figure 10**

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