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Problem Chosen

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2014 Mathematical Contest in Modeling (MCM) Summary Sheet

Keep right, it counts!

Problem Clarification: Analyze and establish a traffic model which must balance traffic flow, safety, speed limits or other factors to simulate traffic flow with a particular rule. Judge whether the keep-right-except-to-pass rule is efficient for traffic flow or not. Examine if our model is still suitable to the rule with a simple change of orientation. Involve the intelligent transportation system and compare the results with earlier one. Besides, relevant sensitivity analysis is suggested.

Assumptions: (i) The freeway is straight without any ramps and barriers. (ii) The displacements, velocities and time are discrete. (iii) The changes of velocity and lane take place instantaneously. (iv) All vehicles will reach the upper limit of velocity when overtaking or the way is empty, while they will slow down over time when in traffic jam in order to avoid crash. (v) When a vehicle overtakes another vehicle, it's only allowed to pass one vehicle ahead during once overtaking.

Model Design and Justification: Considering the specific simulation of traffic flow with the rule, the traffic flow model is built based on cellular automata. The effectiveness of the rule was examined by training the traffic flow model in different traffic conditions. Meanwhile, the gray clustering model is involved to evaluate the safety conditions in different situations, because there is no security coefficient in our traffic flow model. The traffic flow model is enhanced by adding some constraint conditions so that it can simulate the situation of the rule with changed orientation and the intelligent transportation system.

Results and Sensitivity Analysis: (i) The keep-right-except-to-pass rule is effective in promoting better traffic flow. (ii) After traffic management optimization, the traffic flow becomes much more efficient. (iii) Our solution can be carried over only with a simple change of orientation. (iv) As for a particular freeway, the variety of vehicles will have different impacts on traffic flow in a short term, whereas it will reach to a similar saturation point in a long period of time.

Strengths and Weaknesses Discussion: The traffic flow model based on cellular automata can authentically make simulations of acceleration, deceleration and overtaking of vehicles. The gray clustering model can preferably remedy the limitation that the safety coefficient is difficult to define. However, when facing some realistic conditions, our model will be difficult to simulate. In addition, the situations in our model are complicated, and it caused great difficulty for computer programming.

Contents

1 Introduction

A variety of driving psychology leads directly to the overtaking or following in the convoy when driving on the freeway (Dr. Leon James, 1997). It means that overtaking would take place in any case as drivers' attitude would change with time and traffic condition. Therefore, the performance of overtaking in light and heavy traffic must change a lot. We analyze the performance by setting up mathematical model aimed at the countries where driving on the right hand.

Not all the countries in the world drive on the right hand, countries like Japan, Australia and Great Britain and so on drive on the left hand. Driving on different sides of the road has a long history (Dan Stone, 2013) but it can't convince us that whether the rule driving on the right or left is truly effective or not. Differences and similarities between right-hand and left-hand traffic also need further analysis.

As the problem has indicated that the current overtaking rules only depends on human judgment. Driver behavior, attitude and experience will deeply affect the traffic condition as they may lean to overtake or even break the traffic rule (Dr. Leon James 1997). An advisable approach to avoid the subjective factor is employing intelligent system. However, how ITS would help change the traffic condition and what it would change the result of our earlier analysis are still unknown.

In this paper, we introduce cellular automata to simulate overtaking in light and heavy traffic. Combine with under- or over-posted speed limits, the type of vehicle; we give precise and appropriate assumptions and parameters to make simulation more convinced and realistic. The characteristic that Cellular automata model can ensure the simulation take place in absolute security might be an advantage in real traffic system but not in this problem. We compensate traffic safety by taking advantage of grey clustering evaluation.

Compare traffic flow and traffic safety without the rule with flow and safety following the rule, we can examine whether right-hand traffic is effective or not. We convince that driving on the left hand is similar with the right so that we can make use of the model in right-hand traffic to deal with the left-hand traffic problem.

Intelligent transportation system is now still in research so that we can only make use of existing findings to get an expectation result. We analyze and predict the changes in earlier result when introduce ITS into traffic flow model.

Sensitivity analysis aims at multi-lane and multi-lane, is performed to test the affection multi-lane and multi-velocity would bring to the traffic flow.

2 Assumptions

- There are no barriers such as toll-gates, traffic lights and construction sections on the freeway. In addition, the freeway is straight and flat without any ramps.
- We neglect the influence of weather changing and the distinction of day and night.
- The displacements, coordinates, velocities and time are discrete, and the changes of the velocity and the lanes changing of vehicles are instantaneous. What's more, both the unit and interval of time is one second.
- All drivers in our model are greedy and rational. In other words, all drivers want to reach the upper limit of velocity when the way is clear or overtaking, while they will also slow down timely when there is traffic jam for avoiding crash.
- When vehicles overtake another vehicle, they are allowed to pass only one vehicle ahead during once overtaking.

3 Terminology and Definition

parameter	definition
p	the probability that one vehicle enter into the observation road
y_u	the ordinate of the lane u
d_j	the distance between the vehicle j and vehicle k
$v_j(t, y_u)$	the velocity of vehicle j on lane u at time t
$v_j(t)$	the velocity of vehicle j at time t
$x_j(t)$	the abscissa of vehicle j at time t
$y_j(t)$	the ordinate of vehicle j at time t
$Q(t)$	the quantities of the vehicle that passed the terminal of the observation road at time t
$D(t)$	the density of traffic at time t
$N(t)$	the number of the vehicles which are on the observation road at time t
L	the length of the observation road
$v_{i\max}$	the maximal velocity of type i vehicle

4 Traffic flow &traffic safety model

4.1 Traffic flow model

4.1.1 Model background

General description of traffic flow model can be divided into microscopic and macroscopic. As macroscopic one focus on the quantity change of vehicles but neglect the specific behavior of vehicles on lane, we employ microscopic traffic flow model and introduce cellular automata to simulate the realistic traffic flow.

Before going into detail, a concept must be declared. The basic traffic properties are quantitative while driver behavior is qualitative, the former can be quantified but the latter can't so that we don't take driver behavior into consideration. Since microscopic model often describes the motion of molecule, atom and other corpuscles in the natural, we note space, time and speed and so on are discrete, and each cell represents a vehicle or is empty in cellular automata model (Wagner, Nagel, & Wolf, 1997).

In this model, we examine tradeoffs between traffic flow and safety, the role of under- or over-posted speed limits and the type of vehicle. Consider the different types of vehicles and the under- or over-posted speed limits in realistic world. We distinguish car's variety by its over-posted speed limits so that it can be quantified.

We involve two-lane, two-speed, variable speed and safe distance to make model more understandable. Before further analysis, we first discuss the traffic flow in two-lane freeway and do relevant simulation.

Model operating rules

1. All the lane changing, coordinates, velocities and time are discrete.
2. The time interval of model operating is one second, and after one second, all vehicles' coordinates and velocities will be replaced.
3. The changes of the velocity and the lanes changing of vehicles are instantaneous.

The Definition of vehicle k

We know that N means the total number of all vehicles. In our study, we regard one vehicle as a particular object and marked as number j, and every vehicle can be vehicle j. Then we define that the vehicle which is nearest ahead the vehicle j on the same lane is the vehicle k. Due to the vehicle k might change during the traffic flow. We suppose that with respect to vehicle j we need to redefine the vehicle k per second.

Driving patterns with different rules

• With the right-most rule (right-most rule is keep-right-except-to-pass rule) :

The right-most rule is easy for us to understand, it requires drivers to drive in the right-most lane unless they are passing another vehicle, in which case they move one lane to the left, pass, and return to their former travel lane. In our multi-lane model, we assume that all vehicles should drive in the right-most lane when they do not overtake, that means if there are four lanes in the freeway, it will be three overtaking lane and just one traffic lane. In addition, if a vehicle completes the overtaking, it should return to the right-most lane immediately, and it is allowed to pass only one vehicle ahead during once overtaking in our model.

• Without the right-most rule:

Actually, in our analysis, the so-called "without the right-most rule" still has some laws. We can't let all vehicles drive randomly, so we need to establish a driving rule without the right-most rule.

Without the right-most rule, we suppose that every vehicle can drive in any lanes, and when one vehicle is passing another vehicle, in which case it can feasibly move one lane to the right or to the left. In addition, the vehicle which is overtaking is also allowed to pass only one vehicle ahead during once overtaking in our model

4.1.2 Multi-lane traffic flow model

We employ two mechanisms which separate model into two parts, one is entering observation section and the other is driving observation section.

The mechanism of vehicles entering observation section

In order to clearly indicate the light load and heavy load cases of the traffic, we use probabilities to distinguish those two situations. First, we assume that there will likely be one vehicle running into the observation road per second. However the probability of the vehicles entering observation road is uncertain. In other words, if we want to show the light load traffic flow, we just need to adjust the probability to a low level, such as $p = 0.1$.

If we want to reveal the heavy load traffic flow, we just need to adjust the probability to a high level, such as $p = 0.9$.

Secondly, we also need stipulate rules to the lane which the vehicle will be on when it entering the observation road. In the right-most rule, all vehicles should be on the most-right lane, while without particular rules, we assume that the vehicle will randomly appear on the lane, and the probabilities are equal. Thus we complete the mechanism of vehicles entering observation road.

Vehicle driving mechanism in observation section

In our driving mechanism, we assume that all drivers want to reach the maximum velocities, but in order to avoid crash, when it's unable to overtake, vehicles will slow down and zero crash will happen.

We take the vehicle j in multi-lane situation to explain the vehicle driving mechanism in observation road. At time t, we can get the velocity and the coordinate of the vehicle j, among them we assume that the ordinate of the lane that vehicle j located is y_1 and the ordinates of other lanes are y_u, $u = 2,3,\cdots,m$. Now we show our detail vehicle driving mechanism in different rules.

- Without the right-most rule (Figure 1) :

Situation1: If $d_j \geq v_j(t,y_1) - v_k(t,y_1)$

At time t: $v_j(t) = v_j(t)$ & $x_j(t) = x_j(t)$ & $y_j(t) = y_1$ which means the velocity and the lane of vehicle j remain unchanged.

At time $t+1$: $v_j(t+1) = v_j(t)$ & $x_j(t+1) = x_j(t) + v_j(t)$ & $y_j(t+1) = y_1$ which means the change of abscissa, but the velocity and lane are still the same .

Situation2: If $d_j < v_j(t,y_1) - v_k(t,y_1)$ & $d_j \geq v_j(t,y_1) - v_k(t,y_{\hat{u}})$

At time t: $v_j(t) = v_j(t)$ & $x_j(t) = x_j(t)$ & $y_j(t) = y_{\hat{u}}$ which shows that vehicle j changes its lane to lane $\hat{u}$,the velocity and abscissa remain unchanged.

At time $t+1$: , $v_j(t+1) = v_j(t)$ & $x_j(t) = x_j(t) + v_j(t)$ & $y_j(t) = y_{\hat{u}}$ which means the changes of abscissa and the velocity is still same, what's more, the lane is lane $\hat{u}$ and the vehicle j will not change the lane until it once again encounters this situation.

Situation3: If $d_j < v_j(t,y_1) - v_k(t,y_1)$ & $d_j < v_j(t,y_1) - v_k(t,y_u)$

At time t: $v_j(t) = v_k(t)$ & $x_j(t) = x_j(t)$ & $y_j(t) = y_1$ which means that the velocity of vehicle j is down to $v_k(t)$, the abscissa and lane remain unchanged.

At time $t+1$: , $v_j(t+1) = v_j(t)$ & $x_j(t) = x_j(t) + v_k(t)$ & $y_j(t) = y_1$ which means the change of abscissa, but the lane are still the same.

Therefore, we can obtain the critical value of safety distance is:

$$d_j = v_j(t,y_1) - v_k(t,y_1)$$

- With the right-most rule (Figure 2) :

The situations are almost the same, but there are still some differences between the traffic with the right-most rule and the traffic without the right-most rule:

Difference1: In the right-most rule, all vehicles should be in the right-most lane when they enter the observation road.

Difference2: Without the right-most rule when vehicle j changes the lane to lane $\hat{u}$, it will not change the lane until it once again encounters the situation2. However, in order to complete the overtaking, the vehicle j should change the lane to overtake the ahead slow vehicle. And when vehicle j pass the slow vehicle, it should change the lane to the right-most lane again.

Difference3: In the right-most rule, the vehicle only can move to left lanes to complete the overtaking while it's dispensable without the right-most rule.

In addition, the critical value of safety distance is still:

$$d_j = v_j(t, y_1) - v_k(t, y_1)$$

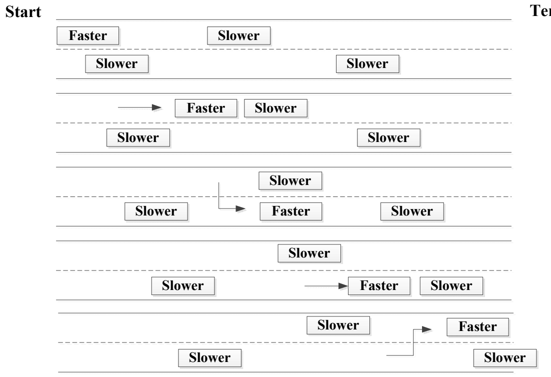

Figure 1 Overtaking without the rule

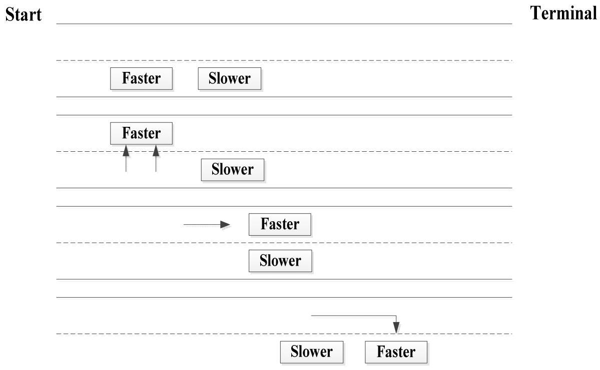

Figure 2 Overtaking in the rule

4.1.3 Simulation

In order to analyze the traffic conditions in different rules, we calculate the total traffic volume in a certain period time in different rules. Through comparing those results, we can draw our conclusion whether the right-most rule is efficient.

In our model, we regard the observation period of time as a certain period time that is from vehicle j entering the observation road to vehicle j leaving the observation road. In addition, the cross section that records the traffic volume is the terminal of the observation road.

Thu the total traffic volume(Zamith et al., 2010) expressed as:

$$\sum_T Q(t) \tag{1}$$

Where T means the observation period of time, and $Q(t)$ means the quantities of the vehicle that passed the terminal of the observation road at time t.

We also want to get the density of traffic(Zamith et al., 2010):

$$D(t) = N(t)/L \tag{2}$$

Where $D(t)$ means the density of traffic at time t, $N(t)$ means the number of the vehicles which are on the observation road at time t, L is the length of the observation road.

The simulation takes place in an observation road. As mentioned above, each cell represents a vehicle of velocity $v_{\min}$ to $v_{\max}$ or is empty (Rickert, Nagel, Schreckenberg, & Latour, 1996), $v_{\min}$ is under-posed speed limits and $v_{\max}$ is over-posted speed limits. To simplify the model, we denoted $v_{i\max} = 1, 2, \cdots, 6$ and $v_i \in [1, v_{i\max}]$, where i is the type of vehicle and $i = 1, 2, \cdots, 6$, $v_{1\max} \cdots v_{6\max}$ are referred as the realistic velocity $60km/h,\ 80km/h,\ 90km/h,\ 100km/h,\ 110km/h,\ 120km/h$, v_i is discrete integer and represents the velocity of type i vehicle. "The length of each cell is 7.5m which is interpreted as the length of a vehicle plus distance between vehicles in a jam" (Wagner et al., 1997), we regard it as a unit length in model simulation.

We do simulation both on the condition without the rule and follow the rule.

Table 1 Position and velocities of cars in 2-lane multi-velocity simulation

Time	Lane	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
151	L																				
	R		1		1				1		1	2				1					
152	L	2				5															
	R	1	3	1		1				1		1		2			1				
153	L					5					5										
	R	4	1	2	1	3	1				1		1			2		1			
154	L					2															
	R			1	3	1		1	3		5	1		1		5		2	1		
155	L								4											2	
	R		3		1		1	2	1			3	1		1	5				1	5
156	L					3				2											5
	R					1		1		1			4	1	3	1					1
157	L								3								4				
	R						1		1		1	2			1		1	3			
158	L											3									4
	R							1		1		1		2		1		1			3
159	L																				
	R								1		1		1		3	2	1		1		
160	L																	2			
	R									1		1		1			2	1		1	

Note: L denotes the left lane while R denotes the right lane

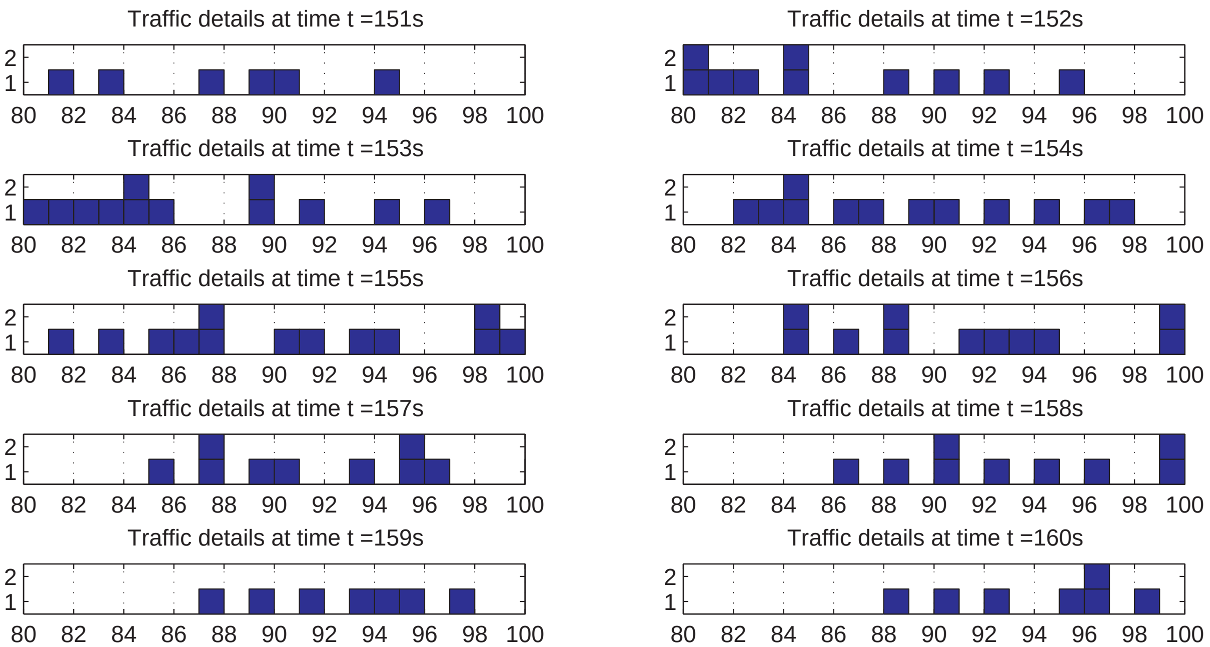

Figure 3 Position of cars of cars in 2-lane multi-velocity simulation

Note: In other simulations which is akin to this there will not be simulation figure like Figure 3 any longer at the mercy of the conciseness of this article.

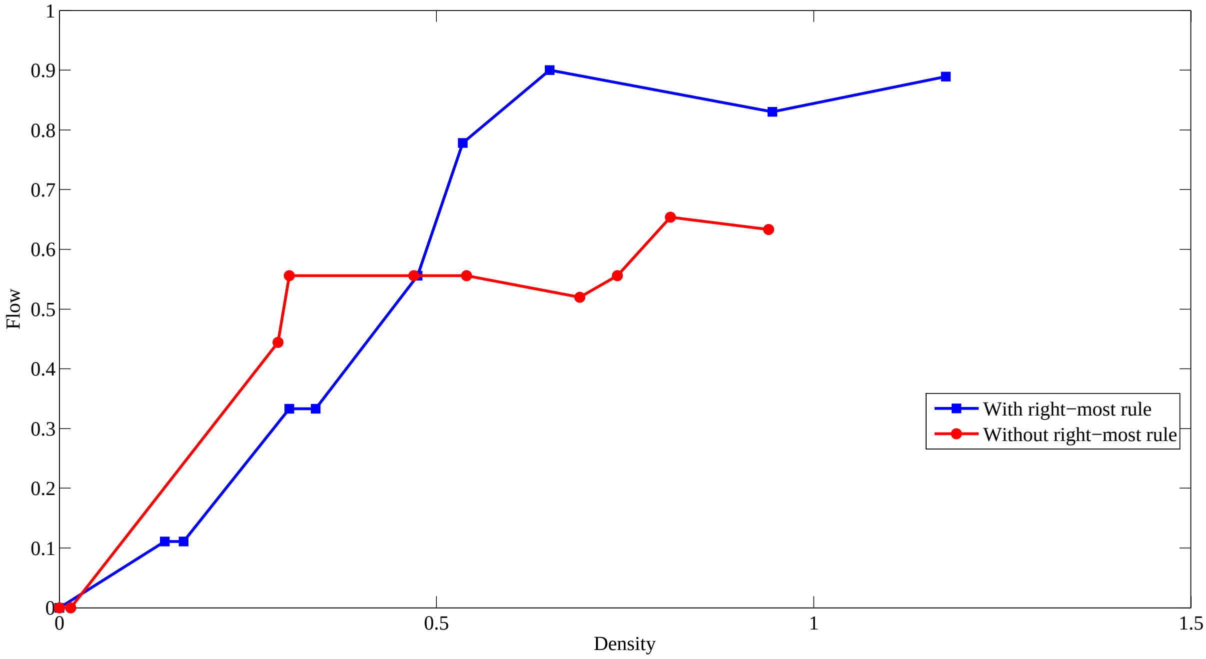

Figure 4 Comparison between with and without right-most rule

The figure above shows that the different changes of traffic condition in different rules with the increasing of density, and when the density reaches to a critical value, the flow becomes basic saturated. We can clearly find that when the density value is low, the traffic condition without right-most rule is better than the traffic condition with right-most rule; but when the density value increase to a high level, the result is reserve. However, in general, the traffic condition with right-most rule is better than the traffic condition without right-most rule, because the traffic condition with right-most rule has a higher maximum value of flow and a higher critical value of density.

But why when the density reaches to a critical value, the flow becomes basic saturated?

According to our assumptions, all drivers in our model are rational; they will slow down timely when there is traffic jam for avoiding crash, so there is no crash in our traffic model. Thu, the traffic flow will not be inactive, in other words, the flow will not decrease when density is increasing, but reach to a steady state value.

4.2 Traffic safety level

4.2.1 Grey clustering evaluation

Our traffic flow model is established under safe condition without traffic accident. However, traffic accident is everywhere around the world. In recent years deaths in U.S. caused by motor vehicle are more than 30 thousand per year (Wikipedia, List of motor vehicle deaths in U.S. by year, 2014). Traffic safety must be paid more attention.

Traffic accident is in relation to driver, vehicle and lane (Hong-guo Xu, 2007). As driver behavior is a qualitative variable, we intentionally avoid in this model. Cellular automata traffic flow model insures the vehicle in safe condition so that we concentrate on discussing the effect caused by lane conditions.

Grey clustering evaluation is common used in evaluating the traffic safety degree as the characteristic of information is generally incomplete. In this paper, we introduce grey clustering evaluation to graduate some respective cities in the U.S..

First of all, we build up whitening matrix which consists of evaluation items (total items is n) and evaluation index items (quantity is m) denote as D_{ij} where $D_{ij}=(d_{ij})_{n\times m}$ (Fengyi Dong, 2010).

We graduate traffic safety condition into four degrees and refer as A (excellent), B (good), C (average) and D (bad). Accumulative frequency percentage of level A to D separately note as $\lambda_1=20\%$, $\lambda_2=40\%$, $\lambda_3=60\%$, $\lambda_4=80\%$. Then we can get white weight function and figures about four degrees below(Fengyi Dong, 2010).

$$f_A(x)=\begin{cases}1 & x<\lambda_1\\ \dfrac{\lambda_2-x}{\lambda_2-\lambda_1} & \lambda_1\le x\le\lambda_2\\ 0 & x>\lambda_2\end{cases}\qquad f_B(x)=\begin{cases}0 & x<\lambda_1\\ \dfrac{x-\lambda_1}{\lambda_2-\lambda_1} & \lambda_1\le x\le\lambda_2\\ \dfrac{\lambda_3-x}{\lambda_3-\lambda_2} & \lambda_2\le x\le\lambda_3\\ 0 & x>\lambda_3\end{cases}$$

$$f_C(x)=\begin{cases}0 & x<\lambda_2\\ \dfrac{x-\lambda_2}{\lambda_3-\lambda_2} & \lambda_2\le x\le\lambda_3\\ \dfrac{\lambda_4-x}{\lambda_4-\lambda_3} & \lambda_3\le x\le\lambda_4\\ 0 & x>\lambda_4\end{cases}\qquad f_D(x)=\begin{cases}0 & x<\lambda_3\\ \dfrac{x-\lambda_3}{\lambda_4-\lambda_3} & \lambda_3\le x\le\lambda_4\\ 1 & x>\lambda_4\end{cases}$$

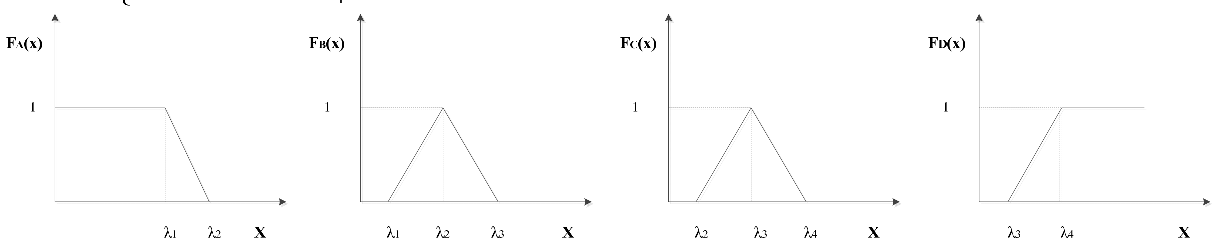

Figure 5 Four degree of traffic safety condition

Then, we calculate clustering weight with the function(Hong-guo Xu, 2007):

$$\eta_{jt}=\lambda_{jt}\Big/\sum_{j=1}^{m}\lambda_{jt} \tag{3}$$

Where η_{jt} means clustering weight of the t grey of item j , λ_{jt} is referred as whiting value of the t grey clustering grade abut item j .

The clustering evaluation value (Hong-guo Xu, 2007) is defined as

$$\sigma_{it}=\sum_{j=1}^{m} f_{it}(d_{ij})\eta_{jt} \tag{4}$$

4.2.2 Application in specific five cities

Traffic safety can be easily influenced by qualitative reason outside like lane condition, driver behavior or even economy of a specific city. To examine the rule effect, we choose five cities (some of them don't obey the rule but the rest do obey) in the U.S. (Figure 6) where the design of freeway and economic level is similar, and then comparing their safety degree.

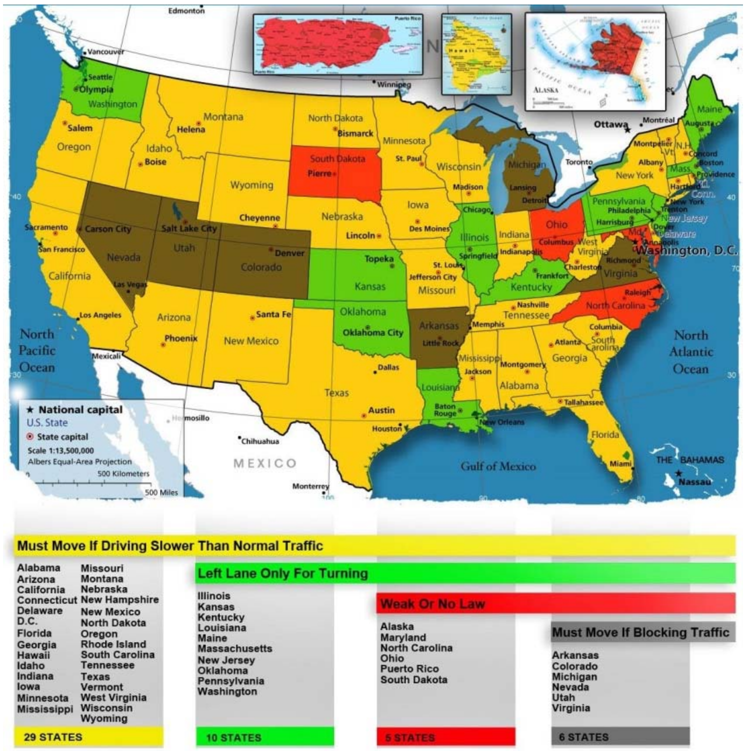

Figure 6 Different rules in U.S.

From figure above, we find that there are four kinds of rules in U.S. We believe that traffic safety would change a lot in different rules. We pick up five cities (Illinois, New Jersey, Minnesota, North Carolina and South Dakota) from each kind of rule and get corresponding safety degree. We list the results below (Table 2):

Table 2 Traffic levels of different cities

Region	Illinois	New Jersey	Minnesota	North Carolina	South Dakota
Level	Good	Excellent	Excellent	Bad	Good

Table above list the traffic levels of five cities. Illinois, New Jersey and Minnesota obey the rule of driving on the right hand; North Carolina and South Dakota don't follow the rule. Their traffic levels show that cities in the rule are safer in traffic than where without the rule. It means the rule is truly effective.

Combined the simulation in traffic flow with levels in traffic safety we confirm the keep-right-except-to-pass rule is not only effective in promoting better traffic flow, also effective in improving better traffic safety.

4.3 Sensitivity Analysis

Traffic flow is relative to the number of lane and the velocity of vehicle. To discuss the affection multi-lane and multi-velocity would bring to the traffic flow, we make sensitivity analysis separately.

- Multi-lane

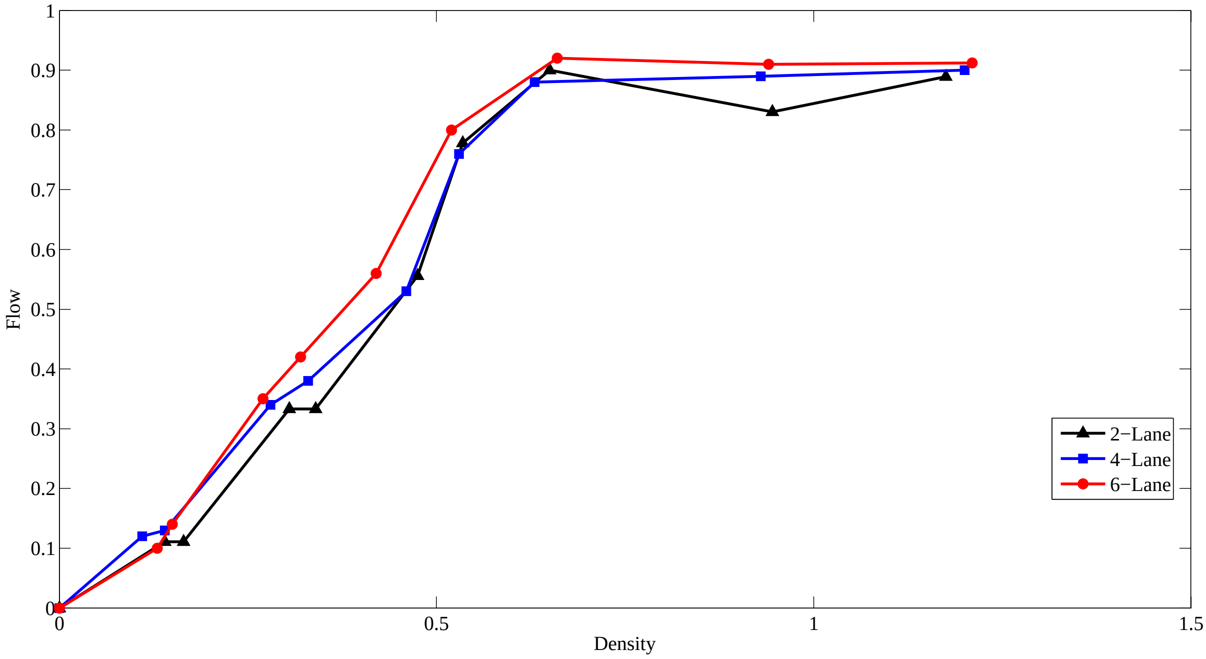

Figure 7 Multi-lane traffic comparisons under 6-velocity driving after optimization

The figure above shows the sensitivity analysis of the multi-lane traffic conditions. Because the 2-lane, 4-lane and 6-lane all have been optimized, the results are almost the same. Another perspective to the result, actually, 4-lane is equal to two 2-lane, and 6-lane is equal to three 2-lane, thus, it's easily to understand the results.

- Multi-velocity

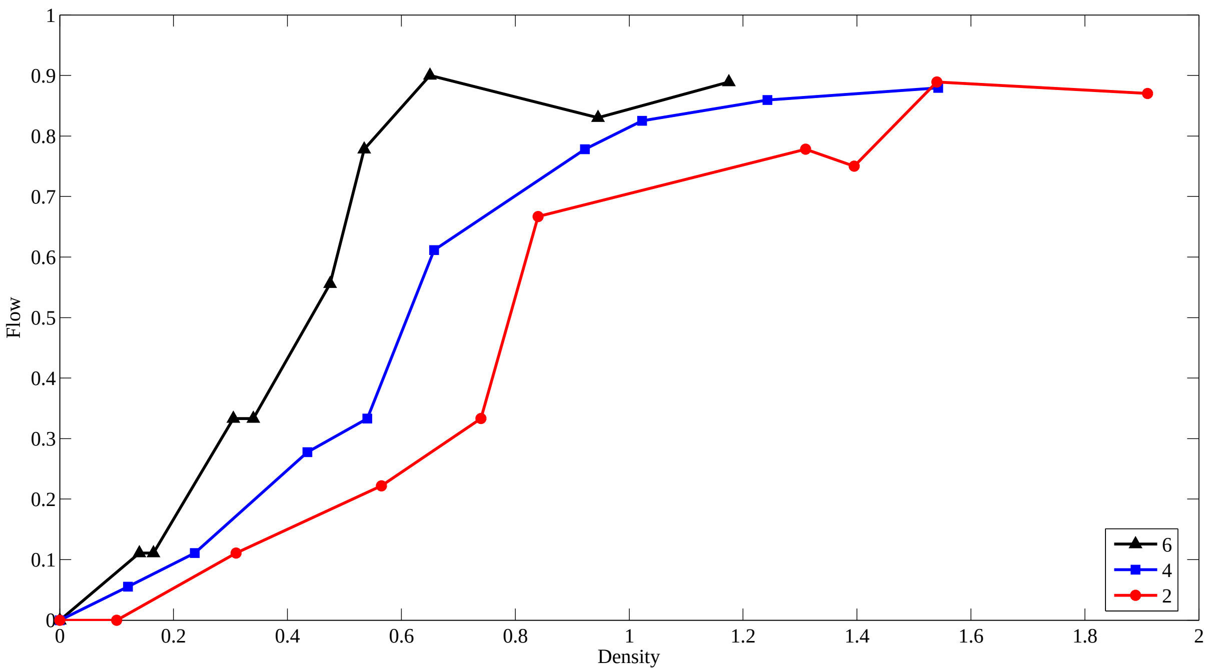

Figure 8 Multi-velocity driving comparison of 2-lane traffic

The figure above shows the sensitivity analysis of the multi-velocity traffic conditions. We can find that when the density value is low, the traffic condition of 6-velocity is the best, the traffic condition of 4- velocity is in the second best, and the traffic condition of 2-velocity is the last. However, with the increasing of density, these traffic flows will reach to saturation points sequentially. It is worth mentioning that theses saturation points of flow are nearly the same.

4.4 Traffic management optimization of multi-lane

We have already simulated both cases of traffic flow in right-most rule and without this rule. The result demonstrates that the traffic flow in right-most rule is better than the traffic flow without this rule, and we can draw a conclusion that the right-most rule is efficient in traffic flow.

However, we find that when we analyze the number of lane, especially multi-lane, in different traffic conditions: the more lanes, the more wasting of lane resource. No matter how many lanes on freeway, there is still only one lane is traffic lane and others are all overtaking lanes. Thus, we put up with a lane planning method which firstly separates the vehicles to several levels according to their maximum velocities, and then assign those vehicles to the corresponding level traffic lanes. In addition, under the different levels, there are corresponding level traffic lane and overtaking lane. In order to express clearly, here is a schematic diagram as follow:

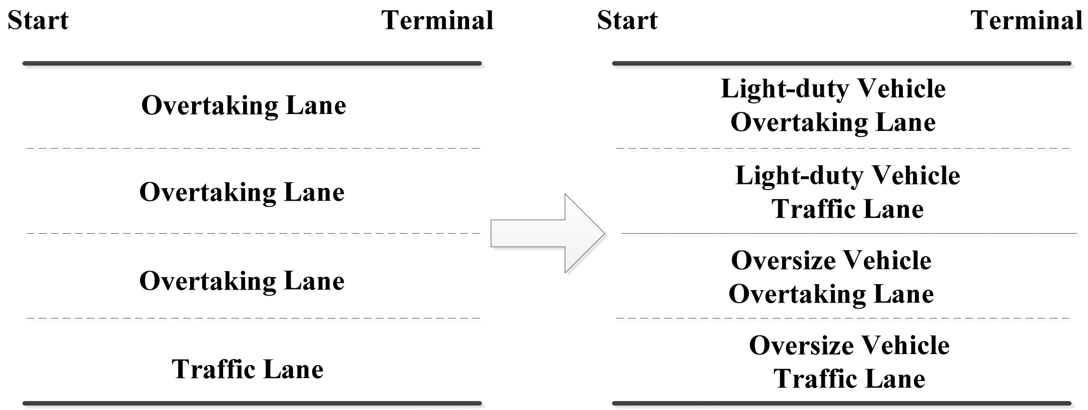

Figure 9 Traffic management optimization of multi-lane

The picture above shows an optimization scheme of four-lane, two-level freeway. We can see that there are two levels lane on right-side freeway, and each level has traffic lane and overtaking lane. Because the velocities of oversize vehicles are always lower than the light-duty one, we can judge the velocity of a vehicle through its size. Thus, the traffic flow will be more effective when we can make use of multi-lane.

• Simulation

To examine the optimization result, we compare the simulation before and after optimization.

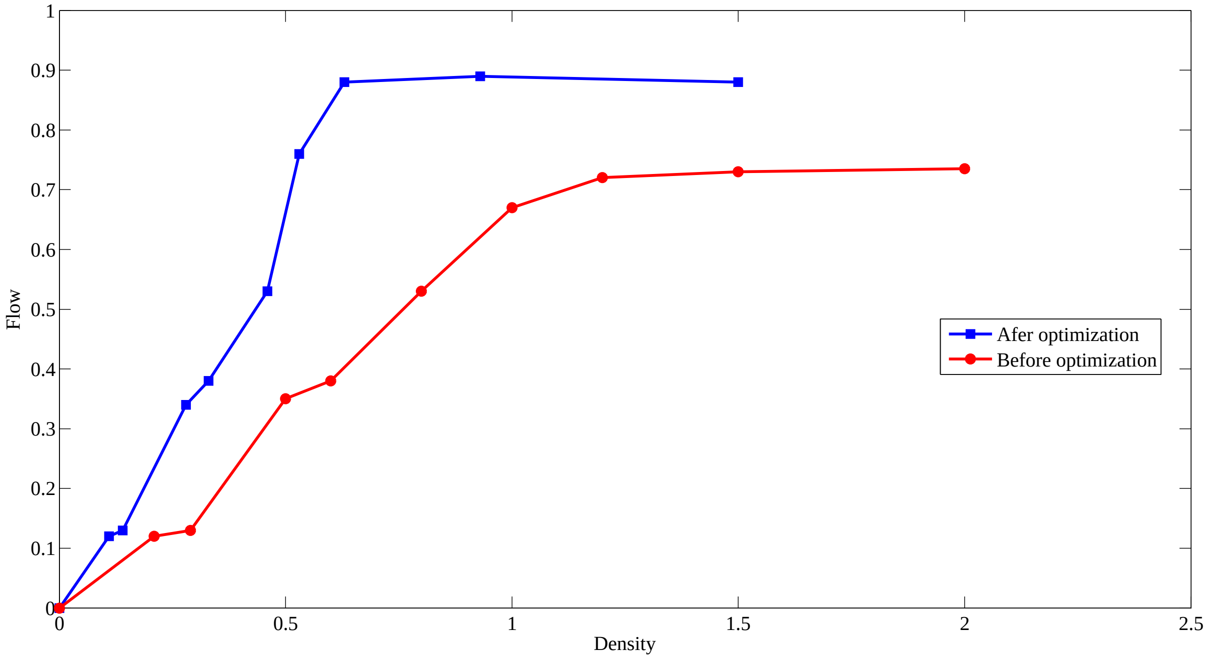

Figure 10 Before and after optimization of 4-Lane traffic

From the above figure, we can find a tremendous promotion of the traffic condition after the lane optimization. Thu we can easily draw a conclusion that the lane management optimization can make the traffic flow much more efficient.

5 Application in countries where driving on the left

"Today, about 65% of the world's population lives in countries with right-hand traffic and 35% in countries with left-hand traffic. About 90% of the world's total road distance carries traffic on the right and 10% on the left" (Figure 11) (Wikipedia, Driving standards historic, 2014). Driving on the left hand and right hand are two cultures which consist of long history and human behavior. Multi-culture country like the U.S. allows both right-hand traffic and right-hand traffic.

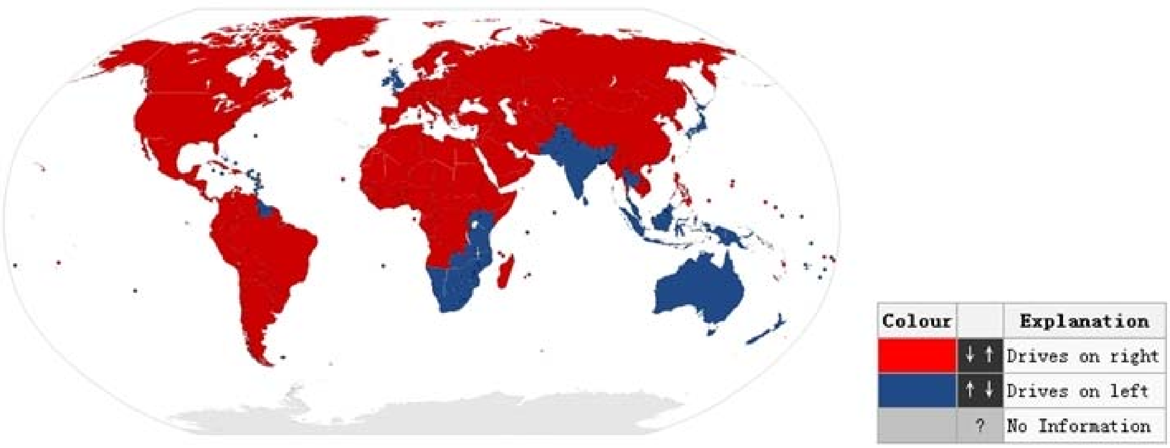

Figure 11 Distribution of right-hand traffic and left-hand traffic

Overtaking rule in left-hand traffic country should be expressed as: drivers to drive in the left-most lane unless they are passing another vehicle, in which case they move one lane to the right, pass, and return to their former travel lane.

We convince the model in right-hand traffic can also be adopted in left-hand traffic after a simple change of orientation. Therefore, we make simulation with multi-lane traffic flow model. When discussing traffic safety, we should pay the equal attention on qualitative analysis due to the different position of driver's seat.

5.1 Traffic safety

Traffic safety between right-hand traffic and left-hand traffic may have large difference as the position of driver's seat has changed. Driver behavior also helps determine the difference of traffic safety. We can get causes by analyzing physical characteristics and habits of human.

Researcher J. J. Leeming has found that left-hand traffic may have less traffic accident than right-hand traffic though the research sample is small (Wikipedia, Right- and left-hand traffic, 2014). We would like to list the causes below:

- "People are commonly right-eye dominant" (Wikipedia, Right- and left-hand traffic, 2014). It means right eye have a wider view and perform a better use so that people can easily notice surroundings and other vehicles in side mirror.
- Right hand can protect us better than left. Generally, right hand is stronger and more flexible than left one so as to provide a better buffer when accidents happen. Strength of right hand obviously becomes an advantage for people driving on the left hand but less flexible of left hand increase the difficulty of performing car shifter.(Wikipedia, Right- and left-hand traffic, 2014)
- Habits. People grow up in different circumstance so that an experience driver in right-hand traffic won't be accustomed to left-hand traffic.

5.2 Traffic flow simulation

In this section, we make simulation of left-hand traffic by employing the model of right-hand traffic which has been made a simple change of orientation. We only analyze and simulate two-lane traffic flow model as the model is also appropriate for multi-lane traffic flow.

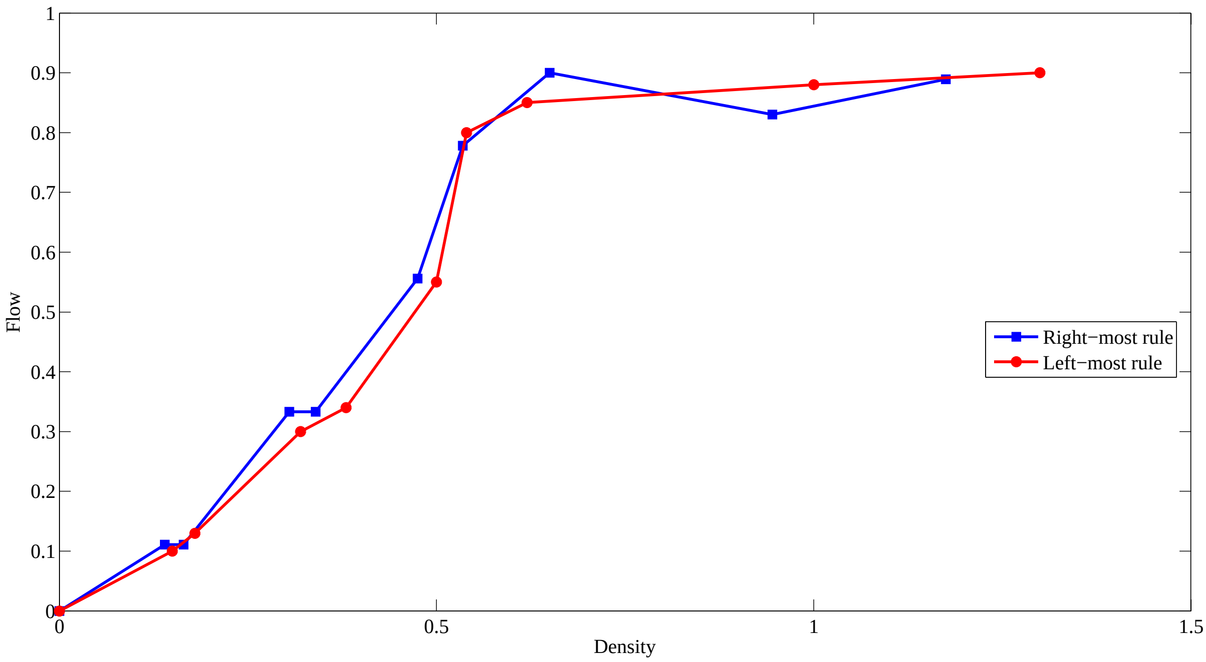

Figure 12 Right-most rule traffic vs. left-most rule traffic

From the above figure, we can find that the traffic conditions are almost the same with the different rules. In other words, the traffic flow condition of right-most rule is as same as the traffic flow condition of left-most rule.

With the limitation of model, our result can't show the differences between the traffic flow condition of right-most rule and the traffic flow condition of left-most rule. Nonetheless, in real life, there might be some differences. For example, most people are right-hander, and it will be more flexible to shift by using the right hand, thus the driver seat should be set no the left, in other words right-handers are more applicable to the right-most rule.

6 Intelligent transportation system

6.1 Background

The cooperative control of multi-agent system can be described as: a single agent which has independent abilities of perception, decision-making and communication can plan next step by partly perceiving the information from neighbor agents. And based on the mutual coupling and interaction of the multi-agent network, the cooperative control of multi-agent system can complete some collaborative tasks of crowd behavior which a single agent cannot complete. (ITS, About ITS, 2014)

Thus, the cooperation of multiple individuals can complete missions beyond their ability, which makes the overall capacity of multi-agent system better than the sum of individual abilities. (ITS, About ITS, 2014)

In the field of transportation, the cooperative control of multi-agent system called Intelligent Transport System (ITS) which improves transportation safety and mobility and enhances national productivity through the integration of advanced communications technologies into the transportation infrastructure and in vehicles. "ITS encompass a broad range of wireless and wire line communications-based information and electronics technologies."(ITS, About ITS, 2014)

Design of vehicle

Sensor and acceptor are necessary part of a vehicle in intelligent transportation system. People who research the design of vehicle concentrate more on the connection of vehicle to vehicle. Communication system between vehicles is built up in precondition of privacy protection. Information change is based on dynamic wireless which contains based data (including position, velocity and location). Communication between vehicles can also help vehicles to sense the risk and barrier in 360 degree to ensure the traffic safety and improve traffic fluency.(RITA, Connected Vehicles Applications, 2014)

Road network

To set up road network, first, vehicles must contain sensors and accepters. Secondly, there should be enough base stations both sides of the road and base stations is responsible for gathering the information and dealing with based data. Road network is much more complicated than vehicle to vehicle communication system as dynamic wireless does not only exist between vehicles, also between base stations to vehicles.

6.2 ITS Main Targets

- Insure the safety of surface transportation
- Promote the mobility of surface transportation
- Contribute to national economic growth

6.3 Comparison

Firstly, in our multi-lane traffic model, we just consider the straight road without any ramps or toll-gates. However, in the real situation, ramps or toll-gates certainly impact on traffic conditions. If we involve these interference factors to our model, the result of our simulations will be changed. However in ITS, it can still remain unchanged since ITS technologies include electronic toll collection, which means that there weren't be toll-gates on freeway anymore, or any other automatic systems.

Secondly, our model can achieve the transportation safety level as same as the ITS. In fact, there is no crash in our simulations because the limitation of our model. However, if ITS can achieve the fully automatic intelligent control, it also will be no crash in realistic situation.

Last but not the least, we ignore the economic effect in our model. Compared with the ITS, our model is not involved with economy from beginning to end. However, in practical situation, some frequent phenomena such as traffic jams which might cause huge losses in economy. In ITS, no matter how much traffic density is, it can ensure the road always in fluent and contribute to the increasing of economy.

6.4 Expectation Result

As intelligent transportation system is now still in research so that we can only make use of existing findings to get an expectation result. We analyze the changes between earlier result and ITS result by compare their simulation.

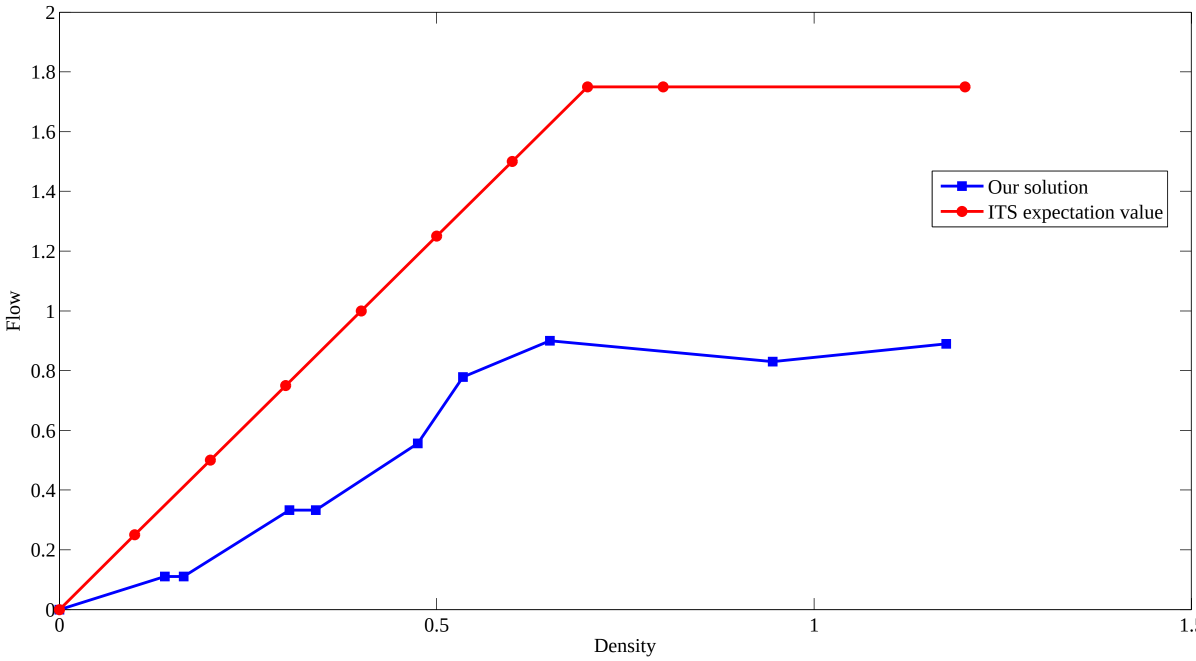

Figure 13 ITS traffic vs. non-ITS traffic based on our solution

The above figure shows the expectation result of ITS and our model result. At present, it's impossible to simulate the real traffic condition of the fully automated intelligent transportation. Therefore, we just put forward the expectation traffic condition of ITS by synthesizing main factors. Although our traffic model can avoid crash, it still has a gap to reach the intelligent level of ITS.

7 Strengths and Weaknesses

7.1 Strengths:

• Our traffic flow model can describe the traffic flow from the microscopic traffic conditions, and can preferably make the simulations of acceleration, deceleration and overtaking of vehicles.
• We use the gray clustering model to evaluate the safety conditions of realistic freeways in U.S. since it can remedy the imperfection in the traffic model, and it could be more convincing by applying practical data.
• Our traffic flow model can clearly distinguish the different effects under different rules (with the right-most rule and without the right-most rule).
• The optimization of traffic management that we put forward can effectively promote the traffic flow; meanwhile, it is closer to the reality.

7.2 Weaknesses:

• Our traffic flow model do not considers some realistic situations such as drink driving, changes of weather and the distinction of day and night.
• The freeway which we simulate is excessively idealistic embodying in the straight roadway, no ramp and no barrier such as toll-gate, traffic light and construction section.
• There are some deficiencies of the driver assumption. Actually, in real life, no one can keep rational all time, and there might be some crashes happened when the traffic flow become crowded. Thus in our traffic flow model, we don't simulate the crash.
• Although the gray clustering model can evaluate the safety conditions of freeways, it might be too subjective when we separate those gray grades, and our safety conditions results are lacking the support of a large amount of data,
• The situations in our traffic flow model are complicated, and it caused great difficulty in computer programming.

8 Conclusion

We separate the problem of examine the tradeoffs of four factors into two parts, one is traffic flow, the other is traffic safety. Except the known requirements like traffic flow and traffic safety, the role of under- or over-posted speed limits, we come up with the type of vehicles. Then we introduce cellular automata to help build up multi-lane traffic flow model so that we can do simulations without rule, in the rule, and sensitivity analysis. By compare relevant simulation results we get the rule is truly effective.

However, traffic flow model must set up in absolute safety. We complete our model by using grey clustering evaluation to graduate Illinois, New Jersey, Minnesota, North Carolina and South Dakota into four degrees. Combined with traffic flow and safety, we confirm the rule is effective. When talked about left-hand traffic, we take advantage of models in right-hand traffic with a simple change of orientation.

Though intelligent transportation system is now still in research, we give a general introduction about the design of vehicle, road network and the cooperative control of multi-agent system to make ITS more understandable. By simulate ideal condition we get an expectation result and find it's better than the traffic flow model.

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