Road Traffic Law Compliance Decision-making on Highway Automated Driving

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***Abstract*—One key for the safety automated driving is to promise the decision-making compliance the road traffic law which merely considered in the current autonomous technology. Because the current definitions of road traffic laws are natural language which cannot be directly understood and used by autonomous vehicles. To enable autonomous vehicles to properly understand traffic laws, while taking compliance into account when making decisions, this paper proposes a trigger-based layered compliance decision-making framework, we mainly added a compliance decision-making layer into the existing decision-making framework, which mainly includes online violation monitor and compliance decision-making. First, we monitor whether the autonomous vehicle is in compliance state during driving, and provide new compliance reference trajectory, corresponding constraints according to the type of violation when the vehicle is about to violate, so as to ensure that the autonomous vehicle is always in compliance. Finally, we verify the proposed compliance decision-making method on the DJI AD4CHE highway dataset under four typical highway scenarios: speed limit, distance limit, overtaking and lane changing, and the results show that our compliance decision-making method can greatly reduce the occurrence of highway violations.**

***Index Terms*—Autonomous vehicles, Road traffic law , Decision-making, Model Predictive Control**

I. INTRODUCTION

WITH the development of the automotive industry, the consequent road traffic safety problems are becoming more serious, and according to The Statistical Annual Report of Road traffic accidents of the People's Republic of China, in 2017-2020, approximately 235100 road accidents in China occurred annually and 62900 deaths occurred annually, of which approximately 86.6% of road traffic accidents were the result of drivers' violating road traffic laws. The University of Michigan Traffic Research Institute, USA, considers that the development of automated driving technology can effectively avoid 85% of traffic accidents[1]. And the European Union also proposed a green transportation vision to achieve zero deaths by 2050[2]. Therefore, we have reason to believe that the development of autonomous vehicles will help reduce the incidence of accidents and improve It should be noted that with the development of autonomous vehicles (AVs), in the foreseeable future, AVs and human driven vehicles will inevitably travel together on the road for a period, which puts a greater test on the safety of decision-making system for AVs. Unreasonable decision-making behavior will lead to chaos in the traffic flow, even cause tremendous accidents. At the same time, we have noticed that the current stage of automatic driving accidents mostly occurs on highways. Compared with urban roads, the working condition of highways is relatively simple, so most drivers choose to start the automatic driving function on highways. However, due to the generally high speed on highways, once an accident occurs, it will greatly endanger the life and property safety of passengers.

To ensure the safety of AVs in the mixed traffic flow with human driven vehicles, the most important thing is to require AVs to follow the traffic laws that human drivers follow. Road traffic laws are not only an important guarantee of safety and the cornerstone of unmanned landing, but also an important basis for subsequent accident liability division[3]. Therefore, achieving compliance judgment and compliance decision-making in complex scenarios of AVs is a key problem to be solved in the field of automated driving. However, due to the fuzziness of the definition of traffic laws and the slow progress of the solution of the decision-making system, how to make the AVs comply with the traffic laws of human drivers still remains challenge.

Most of the existing decision-making systems for AVs only take the collision free driving of vehicles as a safety condition, or simply add some parameter setting considering traffic laws to the decision-making system. There are few researches that really focus on the traffic laws and consider in to the decision-making system. At present, there are two main schemes for the decision-

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Color versions of one or more of the figures in this article are available online at http://ieeexplore.ieee.org making considering traffic laws, one is the learning-based compliance decision-making, mainly using reinforcement learning and deep learning methods; Another one is rule-based compliance decision-making, mainly using the method of finite state machine or reachable set.

A common way to consider traffic laws in deep reinforcement learning approaches is to train policies by designing traffic laws as constraint or reward functions. By making traffic laws as constraints, the policy that can consider simple traffic laws can be trained by solving constrained Markov decision problems, such as methods based on Lagrange multipliers[4][5], constrained strategy optimization methods[6][7], etc. Besides, it is also a common method to consider the punishment for violation of traffic laws in the reward function[8][9]. In addition to the above two methods, some people consider combining reinforcement learning with rule-based methods to make compliance decisions, such as Liu et al[10]. proposed a reinforcement learning-based method with a rule-based backup policy to handle the law adaptive decision-making problem. However, the above learning-based methods can only deal with simple traffic laws , such as keep a safe distance, which cannot deal with complex traffic laws ,and learning based decision-making methods are mostly end-to-end[24]. Due to the black box nature of deep reinforcement learning, whether it can meet the requirements of high reliability in the auto drive system still needs further research.

Because the learning-based method is difficult to train and can only deal with simple traffic laws, the current rule-based method is the mainstream method for compliance decision-making, which mainly include reachability set-based decision-making and finite state machine-based decision-making. The reachability set-based decision can ensure legal safety by taking the compliant driving area as the reachability set and searching feasible trajectory in it. For example, Christian et al[11]-[13] . defined the concept of legal safety by coupling regulations with safety, and adopted reachable set for prediction[14] and decision-making, thus achieving crash-free driving on complex roads. However, the current approach to reachable sets has coupled law and security, which cannot guarantee complete compliance. The method based on finite state machine can define the compliance actions in the current scene in advance, to ensure the complete compliance driving, such as Chen et al[17]. proposed a method of generating candidate driving behavior set based on traffic laws, generating corresponding driving behavior state machine, and making corresponding compliance decisions, Others also consider the use of vehicle-road coordination solutions to solve compliance decision-making problems, such as considering a policy-based framework to define and allocating temporary traffic laws[18]. However, the above methods need to formulate decision rules for specific scenarios, and the limitations of the rules limit the adaptability of the system when dealing with a variety of complex scenarios[25], and the traffic laws involved are mostly non-interactive rules that only involve Ego vehicle and road.

The most intuitive way to solve the compliance decision problem considering regulations is to digitize regulations into logical language, Cristian et al[15] quantified passenger transportation demand, safety preference and traffic laws using LTL language, and proposed a function to measure violation, insecurity, and transportation delay to deal with the conflict between road rules and passenger transportation demand and safety preference. Jana al[16].Converted traffic laws into FLTL, and defined the degree of vehicle trajectory insecurity according to the number of steps leading to the violation of each safety rule and the weight of priority, and then minimized the degree of trajectory insecurity. But the top two methods can only handle static, non-interactive traffic laws such as obstacle avoidance, driving in a given direction, and sometimes the compliance of road traffic laws will be sacrificed for traffic efficiency. Most of the proposed rule-based compliance decision-making methods only consider simple static laws such as driving in the lane direction, not on the sidewalk, etc. It is difficult to deal with complex scenarios involving interaction with human drivers in mixed traffic flow, especially vague traffic regulations are rarely considered . and many methods cannot guarantee complete compliance, sometimes at the expense of compliance for efficiency.

This paper considers the traffic law compliance decision-making problem for AVs against dynamic traffic laws in a highway hybrid traffic stream (mainly considering four common traffic laws: speed limiting, distance limiting, overtaking, and lane changing), dividing the decision-making tasks into a high-level decision-making layer and a maneuvering execution layer. We mainly on the maneuvering execution layer, referring to the method of digitization of traffic laws mentioned in the previous work[19], to construct a trigger-based layered decision-making framework, adopt the MPC based approach, achieve the compliance safety decision-making of AVs, The goal of making the vehicle compliant when it is in violation and preventing it from violating when it is in compliance is realized. The main contributions of this paper are as follows:

- Based on the digitization method of traffic laws, a trigger-based layered decision-making framework is constructed, which can generate corresponding compliance references and constraints according to the violation types of the vehicle's predicted state, thus preventing the vehicle from violating the traffic laws during driving;
- Propose a method to generate the corresponding traffic law compliance constraints(yellow dotted line, Fig.1) and references(red solid line, Fig.1) , according to the violation types of AVs, and the priority of different compliance constraints and references is determined;
- The proposed method is verified on the data set of DJI AD4CHE[23] highway in China, which proves the effectiveness of the proposed compliance decision-making method.

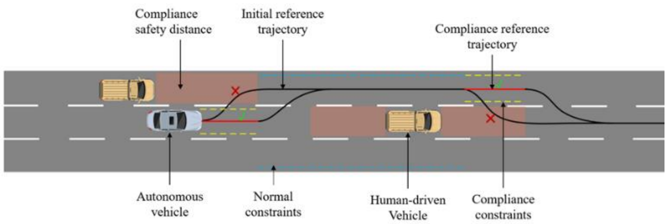


Fig.1 Compliance decision-making. Initial reference trajectory (solid black line) is a trajectory planned by a maneuvering execution planner, which only consider collision avoidance, while the maneuvering execution planner gives normal constraints (blue dotted line). When the vehicle state is about to violate traffic laws , our compliance decision-making method generates a new trajectory (solid red line) which causes the vehicle to abandon the original violation and at the same time produces compliance constraints(yellow dotted line)to prevent the vehicle from violating.

This paper is organized as follows. The section II introduces the trigger-based layered decision-making framework. The section III introduces the generation method of compliance constraints and references, the setting of priority, and the vehicle state prediction method. The section IV introduces the simulation verification, which is carried out on the DJI AD4CHE[23] dataset in China to prove the effectiveness of the proposed compliance decision-making method. And in the section V, the conclusion and the prospect of future work are presented.

II. Trigger-based Layered Decision-making Framework

In this work, a trigger-based layered decision-making framework is proposed. In order to improve the generalization and reusability of our compliance decision-making algorithm, the implementation of compliance in the compliance decision-making system in this paper is not integrated in the classical decision-making algorithm itself, but an independent part after the motion planning layer. Meanwhile, some of the traffic laws on the highway correspond to behaviors that don't happen all the time, such as overtaking and lane changing, if we monitor all the laws on the highway all the time, it will create an excessive use of resources. To this end, we propose a Trigger-based layered decision-making framework, which mainly consists of two parts, the online violation monitoring module and the compliance decision-making module, in which the compliance decision-making module contains a three-layer architecture : layer a, compliance reference & constraints layer; Layer b, Priority based combination selection layer; Layer c, compliance reference trajectory generation layer. As shown in Figure2：

We divide the classical decision-making into a high-level decision-making layer and a maneuvering execution layer. The upper decision-making level is the behavioral level in Figure 2, which generates decision intent, such as overtaking or changing lanes, which acts as a trigger signal for the online violation monitor. In the maneuvering execution layer, the detailed motion is planned and executed. Here, the maneuvering execution layer is the motion planning layer in Figure 2, which produce a detailed reference trajectory, which we call the initial reference trajectory.

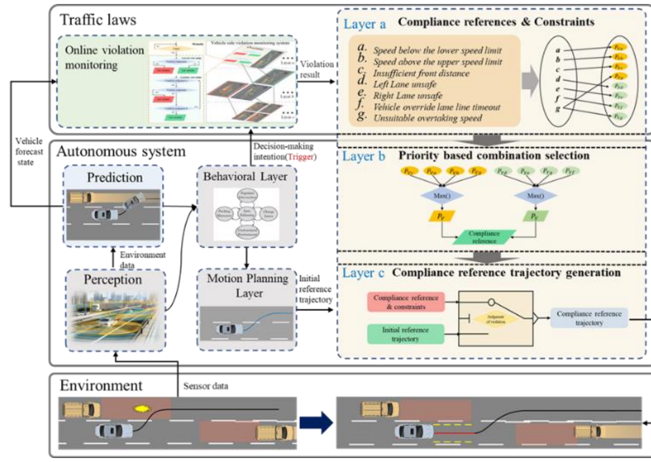


Fig. 2. Trigger-based layered decision-making framework.

The online violation monitor is mainly used to identify the violations of the vehicle when the vehicle is about to violate the road traffic laws, and give the types of violations of the vehicle. When the behavior layer generates the corresponding decision intention, the intention is used as a trigger signal to trigger the online violation monitor to start monitoring the driving state. Note that what is monitored here is not the vehicle's current state, but the predicted state of the vehicle. When the predicted state of the vehicle violates the traffic laws, the online violation monitor will output the violation type of the vehicle to the downstream compliance decision-making module. The main function of the compliance decision-making module is to provide the compliance reference trajectory and constraints according to the types of violations that the vehicle will happen, so as to prevent vehicle violations. Layer a contains the basic types of highway violations that we have defined in advance and the corresponding compliance references and constraints. According to the results of online violation monitoring, layer a will output the compliance reference and constraints corresponding to the violation results; Because vehicles may have multiple violations at the same time, each violation will have compliance reference and constraints, and some may cause conflicts. Therefore, in layer b, we define the priority for each basic violation type, and layer b will select the output results of layer a according to the priority, determine the optimal compliance reference and constraints, and combine them to output; layer c is mainly used to select the final reference trajectory, determine whether to output the initial reference trajectory or the compliance reference trajectory output by layer b according to the online violation monitoring results, and output it to the control layer for execution.

Through this framework, when the ego vehicle is about to violate the traffic laws while driving on the highway, the online violation monitor will timely identify the violations that will occur, and the compliance decision-making module will generate the appropriate compliance reference trajectory based on the violations through the three-layer architecture, so that the ego vehicle will temporarily give up the initial violations and implement the compliance behavior, so as to ensure that the ego vehicle will never violate the traffic laws during driving.

III. METHODS

A. Compliance constraints and reference generation

According to the *special provisions on highways* in the *Implementation Regulations of the Road Traffic Safety Law of the People's Republic of China*, the road traffic laws on highways mainly include the following provisions:

1) Each lane of a highway should indicate the speed of the lane. The maximum speed of the lane must not exceed 120 and the minimum speed should not be less than 60. If the speed indicated by the road speed limit sign is inconsistent with the provisions of the above lane, the vehicle shall drive at the speed indicated by the road speed limit sign.
2) When the speed of a motor vehicle running on highway exceeds 100 km/h, it shall keep more than 100 meters from the vehicle in front of the same lane; when the speed is below 100 km/h, the distance between it and the vehicle in front of the same lane may be shortened appropriately, but the minimum distance shall not be less than 50 meters.
3) When driving from the ramp to the highway, the vehicle should slow down and turn on the left turn light. Drive off the highway, slow down and turn on the right turn light.
4) Motor vehicles shall not ride over the lane boundary or drive on the shoulder when driving on the highway.
5) If there are more than two lanes in the same direction of the road, the motor vehicle changing the lane shall not affect the normal operation of the motor vehicle driving in the relevant lane.
6) When a motor vehicle is overtaking, it should turn on the left turn light ahead of time, exceed the left side of the front vehicle after confirming that there is a sufficient safe distance, turn on the right turn light and return to the original lane after pulling away the necessary safe distance from the overtaken vehicle.

In this paper, we only focus on the main highway, not on the compliance of the highway ramp, so we focus on the study of 1,2,4,5,6, which are summarized as four traffic laws: speed limit, distance limit, lane change and overtaking.

Due to the uncertainty of the behavior of other vehicles in mixed traffic flow, there may be many types of violations nested with each other. At the same time, many types of violations in traffic laws can be further decomposed, for example, the process of overtaking can be divided into three stages: left-lane change, lane maintenance and right-lane change. The process of overtaking includes the process of changing lanes. Therefore, the violation of overtaking is likely to include the violation of changing lanes. Furthermore, the process of changing lanes can be divided into lane maintenance and lane change stage, and the violation of speed and distance limits will be included in the lane maintenance stage. It is not only a heavy workload but also a poor reusability if only references and constraints to each violation such as overtaking and lane changing are included. Therefore, by disassembling the digital judgment logic of the four traffic laws on speed limit, distance limit, lane change and overtaking of highways, we summarize all the basic violation types contained in them. When online monitoring is in progress, according to the violation types output by the online monitor, we can get the compliance reference and constraints for the current traffic laws.

The basic types of violations on the highway we summarized are shown in TABLE I

TABLE I Highway basic violation type

Basic violation type	Logical expression
a. Speed below the lower speed limit	$v_{ego} < v_{speed\_\min}$
b. Speed above the upper speed limit	$v_{ego} > v_{speed\_\max}$
c. Insufficient front distance	$(vx(Ego) > 100km/h \wedge distance(Ego, Tgt_f) < 100m) \vee (vx(Ego) \leqslant 100km/h \wedge distance(Ego, Tgt_f) < 50m)$
d. Left Lane unsafe	$\exists Tgt_{r,fl} \wedge \begin{pmatrix} TTCX(Ego, Tgt_{r,fl}) \leqslant TTCX \\ \vee\, distance(Ego, Tg_{r,fl}) \leqslant d_{cl\min} \end{pmatrix}$
e. Right Lane unsafe	$\exists Tgt_{r,fr} \wedge \begin{pmatrix} TTCX(Ego, Tgt_{r,fr}) \leqslant TTCX \\ \vee\, distance(Ego, Tg_{r,fr}) \leqslant d_{cl\min} \end{pmatrix}$
f. Vehicle override lane line timeout	$(t - t_{in}) > t_{max\_cl}$
g. Unsuitable overtaking speed	$v_{ego} < v_{Tgt} + \Delta v_{ot}$

As shown in Table 1, according to the main traffic laws on the highway, namely speed limit, distance limit, lane changing and overtaking, we have decomposed a total of seven basic violation types. Where, v_{ego} represent the speed of ego vehicle, $v_{speed_min}$and v_{speed_max} represent the lower limit and upper limit of the speed allowed by the current lane. $distance(Ego, Tgt_f)$ represent the distance between the ego vehicle and the vehicle in front of the same lane , $TTCX$ is the time to longitudinal collision, In this paper, it is set to 2.3s[19]; $d_{clmin}$is the minimum actual distance of a vehicle from relevant vehicles, which is set to 14m[19]; t_{in} indicates the time when start to drive on the lane line; t_{max_cl} epresents the maximum allowable time for driving on the lane line, which is set to 6s[19], v_{Tgt} represent the speed of the target vehicle being overtaken andΔvot represents the compliant overtaking speed difference.

Considering the lateral and longitudinal control requirements of the ego vehicle, we hope that the lateral and longitudinal control of the ego vehicle can be decoupled. In this paper, the longitudinal control is realized by the given reference speed, and the lateral control is realized by the given transverse reference position. Therefore, our compliance reference and constraint are mainly given for the speed V and the lateral position Y of the Ego vehicle.

（1） ***a:*** As shown in Figure 3, for basic violation type a, the vehicle has three states: when the vehicle is in violation state, which means that the vehicle speed is below the lower limit required by the traffic laws; When the vehicle is in decision violation stat, which means that the vehicle speed has been compliant, but the initial reference speed given by the motion planner is still illegal; When the vehicle is in compliance state , which means both the speed and the reference speed have been compliant.

When the vehicle is in violation state, we need to give appropriate compliance reference speed to make ego vehicle comply as soon as possible, at this time, the initial reference speed is truncated, and the new compliance reference speed will be directly sent to the downstream control layer, which we call v_{cref}. In order to make the ego vehicle speed comply with the traffic law, while keeping the driving intention as much as possible, the compliance reference speed v_{cref} is set as the lower limit of the compliance speed:

$$V_{cref}(ego) = V_{speed\_\min} \tag{1}$$

When the ego vehicle is in decision violation state, although the vehicle speed is compliant, the initial reference speed may cause the vehicle to jump repeatedly between compliance and violation. We need to give a compliance reference speed to replace the initial reference speed, which named v_{iref}, it is also set to the minimum compliance speed. At the same time, in order to prevent the speed from violating the regulations again, the corresponding compliance speed constraint should be imposed, which is set as the current lane compliance speed range:

$$V_{iref}(ego) = V_{speed\_\min} \tag{2}$$

$$V(ego) \in [V_{speed\_\min}, V_{speed\_\max}] \tag{3}$$

When the ego vehicle is in compliance state , at this time, because the vehicle speed and the initial reference vehicle speed are both compliant, the latter will be sent directly to the control layer for execution, but in order to prevent vehicle speed violations, the compliance vehicle speed constraint still exists.

$$V_{ref}(ego) = Initial\ reference\ speed \tag{4}$$

$$V(ego) \in [V_{speed\_\min}, V_{speed\_\max}] \tag{5}$$

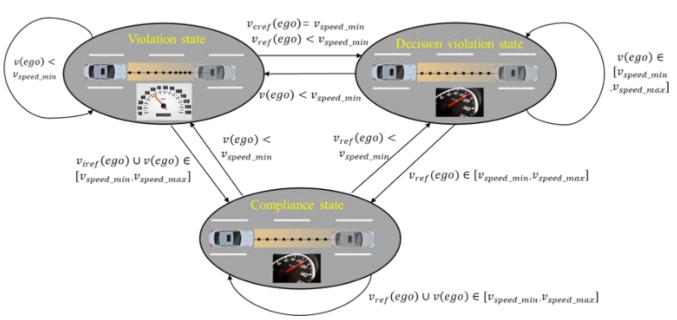


Fig. 3. State transfer diagram of ***a***

(2) ***b***: As shown in Figure 4, for basic violation type b, the vehicle also has three states, namely, violation state, where the vehicle speed is higher than the upper limit of compliance speed, decision violation state and compliance state. When the vehicle is in violation state, the reference speed sent to the control layer is the compliance reference speed v_{cref}, which is set as the upper limit of compliance speed

$$V_{cref}(ego) = V_{speed\_\max} \tag{6}$$

When the ego vehicle is in decision violation state, the reference speed is v_{iref} , which is set as the maximal compliance speed. Similarly, speed constraints need to be applied to prevent further violations, which same as (5):

$$V_{iref}(ego) = V_{speed\_\max} \tag{7}$$

When the ego vehicle is in compliance state , the reference speed is initial reference speed . The speed constraint is the same as (5).

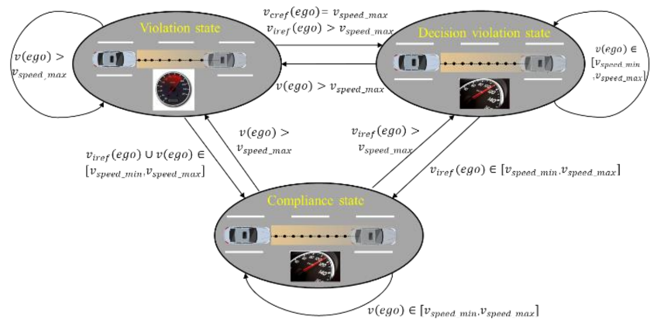


Fig.4. State transfer diagram of ***b***

(3) ***c***: As shown in Figure 6, for basic violation type *c*, the vehicle has two main states: violation state, at which time the distance between the vehicle and the vehicle in front is violation; In compliance state, the distance between the vehicle and the vehicle in front meets the traffic laws. When the vehicle is in violation state, first, the vehicle should decelerate as far as possible to reach the compliance distance with the vehicle in front. In this paper, it is simply assumed that the deceleration rate of the vehicle is constant, and the speed of the vehicle in front remains unchanged during this period.

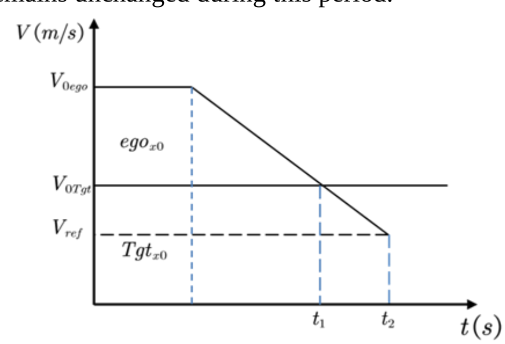


Fig. 5. v-t diagram

As shown in Figure 5, the reference speed is set as follows:

$$V_{ref}(ego) = -\frac{t_1(V_{0ego} - V_{0Tgt})}{t_2} - \frac{2(D - Tgt_{x0} + ego_{x0})}{t_2} + v_{0Tgt} \tag{8}$$

Where, t_1 and t_2 respectively refer to the time taken to decelerate from the Ego vehicle to the same speed as the front vehicle and the time taken to reach the compliance distance between the Ego vehicle and the front vehicle. V_{0ego} and V_{0Tgt} refer to the speed of the Ego vehicle and the speed of the front vehicle when the compliance decision is triggered. D refers to the compliance distance (when the speed of the vehicle on the highway is greater than 100km/h, D is 100m, and when the speed of the vehicle is lower than 100km/h, D is 50m). ego_{x0} and Tgt_{x0} refer to the initial position of the Ego vehicle and the front vehicle when the compliance decision is triggered.

At the same time, if Ego vehicle intends to change lanes or overtake when the current distance violation occurs, the behavior should be suspended temporarily. Therefore, the Ego vehicle reference trajectory should also be set as the center line of the current lane(Fig.6, Solid red line). In order to prevent further Lane changes, constraints should be imposed to keep the current Lane in order to avoid Ego vehicle violations(Fig.6, Yellow dotted line):

$$Y_{ref}=(y_{line}(Initiallane)+y_{line}(Initiallane+1)/2 \quad (9)$$

$$Y\in\left(\begin{array}{c} y_{line}(lane(ego))+\dfrac{w_{ego}}{2}, \\ y_{line}(lane(ego)+1)-\dfrac{w_{ego}}{2}\end{array}\right) \quad (10)$$

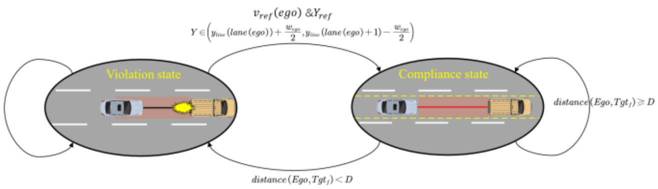


Fig.6. State transfer diagram of ***c***

Where, Y_{ref} refers to the lateral coordinate of the reference trajectory, *Initiallane* refers to the initial lane where the ego vehicle is located when the compliance decision-making is triggered by the upper-level decision, *lane(ego)* refers to the current lane where the ego vehicle is driving, $y_{line}(Initiallane)$ and $y_{line}(lane(ego))$ refer to the lateral coordinate of the initial lane and the lane line corresponding to the current lane respectively, and w_{ego} refers to the vehicle width.

When the vehicle is in compliance state, the reference trajectory sent to the control layer is the initial reference trajectory:

$$Y_{ref}=Initial\ reference\ trajectory \quad (11)$$

(4) ***d***: As shown in Figure 7, for basic violation type *d*, the vehicle has two states: violation state, which means that the vehicle has the decision intention to change lanes to the left and changes lanes when the left lane is unsafe, such as when the distance from the left vehicle is insufficient; Compliance status means that the vehicle has the intention to change lanes to the left and changes lanes when the left lane is safe.

$$Y_{ref}=(y_{line}(Initiallane)+y_{line}(Initiallane+1)/2 \quad (12)$$

$$Y\in\left(\begin{array}{c} y_{line}(lane(ego))+\dfrac{w_{ego}}{2}, \\ y_{line}(lane(ego)+1)-\dfrac{w_{ego}}{2}\end{array}\right) \quad (13)$$

When the vehicle is in compliance state, the reference trajectory sent to the control layer is the initial reference trajectory, Same as (11).

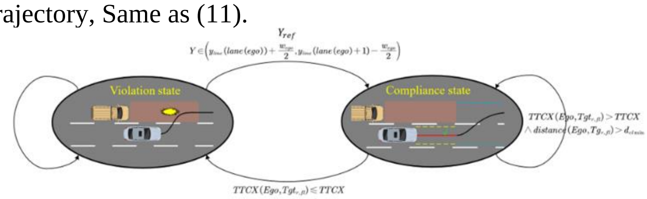


Fig.7. State transfer diagram of ***d***

(5) ***e***: As shown in Figure 8, for the basic violation type *e*, the vehicle has two states. The violation state means that the vehicle has the intention to change lanes to the right and changes lanes when the right lane is unsafe; Compliance state means that the vehicle has the intention to change lanes to the right and changes lanes when the right lane is safe.

When the vehicle is in the violation state , we need to give a new compliance reference trajectory to make the vehicle temporarily give up the lane change and drive along the current lane. It is worth mentioning that there are two corresponding situations: the ego vehicle intention to change the lane right or the ego vehicle intention to return to the original lane after overtaking. The compliance reference trajectory of the two situations is different and cannot be represented by the initial lane, so it is represented by the current lane. At the same time, it is also necessary to impose the corresponding compliance position constraint to prevent vehicles from changing lanes in case of violation, which same as (10).

$$Y_{ref}=(y_{line}(lane(ego))+y_{line}(lane(ego)+1))/2 \quad (14)$$

When the vehicle is in compliance state, the reference trajectory is set as the initial reference trajectory, Same as (11).

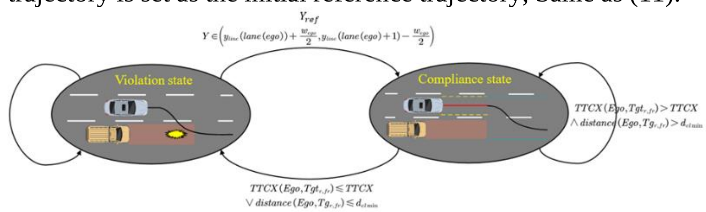


Fig.8. State transfer diagram of ***e***

(6) ***f***: As shown in Figure 9, for the basic violation type *f*, the violation state means that the time of the vehicle running down the lane line exceeds the threshold allowed by the traffic law, which is 6s in this paper. The compliance state means that the time of the vehicle running down the line does not exceed the threshold. When the vehicle is in the violation state, because our monitoring is based on prediction, there is no real violation of the vehicle at the beginning of the violation state. At this time, we need to give the compliance reference trajectory to make the vehicle drive into the lane as soon as possible, which is set as the current lane centerline, same as (14):

When the vehicle is in compliance state, the reference trajectory is set as the initial reference trajectory, Same as for (11).

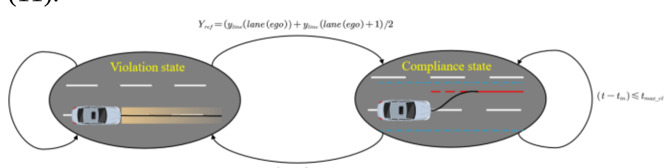


Fig.9. State transfer diagram of ***f***

(6) ***g***: As shown in Figure 10, the vehicle has two states. The violation state means that the vehicle has the intention of overtaking and is driving in the overtaking lane, and returns to the original lane when the overtaking speed is insufficient; Compliance status means that the vehicle has the intention of overtaking and is driving in the overtaking lane, and returns to the original lane when the overtaking speed is sufficient.

When the vehicle is in a state of violation, the vehicle should temporarily abandon returning to the original lane and drive along the overtaking lane, while increasing the vehicle speed to achieve a compliant overtaking speed. The compliance reference track is set as the center line of the overtaking lane, and the compliance reference speed is the sum of the difference of the compliant overtaking speed and the speed of the overtaken vehicle. At the same time, corresponding position constraints should be imposed to prevent the vehicle from returning to the original Lane in violation.

$$V_{ref} = V_{tgt} + \Delta v_{ot} \tag{15}$$

$$Y_{ref} = \begin{pmatrix} y_{line}(Initiallane+1)+ \\ y_{line}(Initiallane+2) \end{pmatrix} / 2 \tag{16}$$

$$Y \in \begin{pmatrix} y_{line}(Initiallane+1)+\dfrac{w_{ego}}{2}, \\ y_{line}(Initiallane+2)-\dfrac{w_{ego}}{2} \end{pmatrix} \tag{17}$$

When the vehicle is in compliance, the reference speed and trajectory are the initial reference speed and the initial reference trajectory.

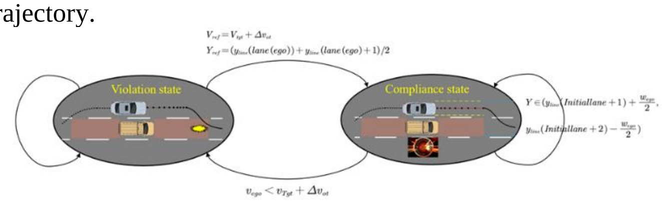


Fig.10. State transfer diagram of ***g***

B. Priority of compliance references and constraints

Due to the existence of multiple types of violations on highways, multiple violations may occur at the same time in many cases, such as speed limit violations and distance limit violations. In Section III.A, we have determined the corresponding compliance reference and constraints for each basic violation type. If multiple violations occur at the same time, they may lead to conflicts between compliance references, which need to be avoided. To this end, considering both safety and real highway situations, we have set appropriate priorities for different types of violations, considering the longitudinal and lateral control requirements of the vehicle. The priority is mainly divided into two parts: Compliance Reference Speed Priority and Compliance Reference lateral Trajectory Priority:

1) The priority of Compliance Reference Speed:

The priority of Compliance Reference Speed Among the seven types of violations, four violations **a**, **b**, **c,** and **g** give a new reference speed for compliance. Considering that the three violations **a**, **b,** and **c** can seriously affect driving safety, while the corresponding violation **g** can guarantee safety by giving up overtaking, so **g** has the lowest priority. Definition: P_{Vg}=1.

Violations **a**, **b** and **c** corresponds to speed limiting and distance limiting, where **a** and **b** are mutually exclusive violations of the same kind. Ignoring the surrounding traffic violations, as **b** occurs, the vehicle speed is lower than the compliance speed lower limit, at this point, ego vehicle can't violate the distance limit, at this time only **a** and **c** is likely to happen at the same time, both of the speed limit and the distance limit of compliance reference speed will make the ego vehicle to slow down, In addition, the reference speed given by the distance limit is often far less than the lower limit of the compliance speed, so the speed will be compliant quickly in the deceleration process. However, the compliance speed constraint imposed after the compliance of the vehicle speed can ensure that the vehicle speed is always compliant. Therefore, the priority of setting **c** is higher than that of **a**, **b**, definition： $P_{Va} = P_{Vb} = 2, P_{Vc} = 3$

2) The priority of Compliance Reference lateral position:

Among the seven types of violations, the four violations of d, e, f and g will give a new reference trajectory for compliance. Among them, d and e are mutually exclusive and similar violations. Although the four types of violations have different representations of compliance trajectory, in fact, the corresponding trajectory are all the center lines of the same lane. For example, if e, f, g is triggered at the same time when overtaking, the ego vehicle is in the overtaking lane. *Egolane=Initiallane+1* , Then all three compliance reference trajectories are

$Y_{ref} = (y_{line}(Initiallane+1) + y_{line}(Initiallane+2))/2$.

Therefore, there is no clear requirement for the priority setting of the compliance reference trajectory. In this paper, **d** and **e** have the highest priority, **g** has the second priority and **f** have the lowest priority, that is: $P_{Yd} = P_{Ye} = 3$, $P_{Yg} = 2, P_{YF} = 1$

C. Control design for compliance decision-making

(1) Vehicle Dynamic Modeling

Due to the complexity of vehicle dynamics in reality , in order to reasonably balance the accuracy and calculation cost of the model, a 3-DOF bicycle model with certain assumptions[21][22] is adopted in this paper. The vehicle dynamic model is shown in Figure 11.

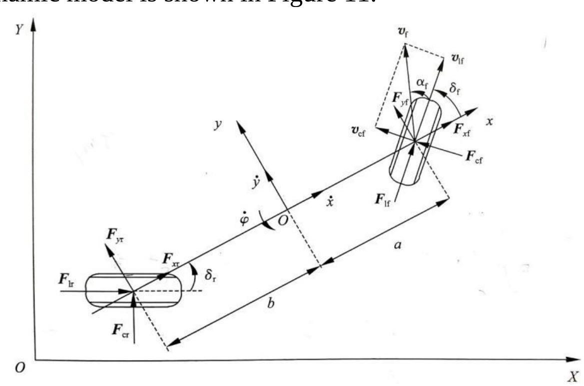


Fig.11. Vehicle Dynamic Model

Fig. 11 depicts the vehicle model with the longitudinal, lateral and yaw dynamics governed by:

$$m(\dot{v}_x - v_y\dot{\varphi}) = F_{xT} \tag{18}$$

$$m(\dot{v}_y - v_x\dot{\varphi}) = F_{yf} + F_{yr} \tag{19}$$

$$I_Z\ddot{\varphi} = F_{yf}l_f - F_{yr}l_r \tag{20}$$

The vehicle's motion with respect to global coordinates:

$$\begin{aligned} \dot{X} &= v_x\cos(\varphi) - v_y\sin(\varphi) \\ \dot{Y} &= v_x\sin(\varphi) + v_y\cos(\varphi) \end{aligned} \tag{21}$$

where, *X* and *Y* are the vehicle longitudinal/lateral positions with respecting to the global coordinate; φ denotes vehicle heading angle;v_x, v_y represent vehicle longitudinal and lateral velocities ; m is the vehicle mass; I_Z is the vehicle moment of inertia;l_r , l_f represent the distances from the vehicle CG to the rear/front axles respectively; F_{xT} is the total tires longitudinal force; F_{yf} and F_{yr} are the total lateral forces of the front/rear tires respectively.

Making a small Angle assumption on the tire sideslip Angle, the tire lateral force can be expressed as a linear function of the tire sideslip Angle:

$$F_{yf} = -C_{\alpha f}\alpha_f = C_{\alpha f}\left(\delta_f - \frac{v_y + l_f\dot{\varphi}}{v_x}\right) \tag{22}$$

$$F_{yr} = -C_{\alpha r}\alpha_r = C_{\alpha r}\left(-\frac{v_y - l_r\dot{\varphi}}{v_x}\right) \tag{23}$$

where, α_f and α_r denote the front and rear tires' sideslip angles, δ_f is the front steering angle , $C_{\alpha f}$ and $C_{\alpha r}$ denote the cornering stiffness of the front and rear tires.

(2) MPC Algorithm Design

In this section, the Model Predictive control (MPC) algorithm is used as the re-planning control algorithm. MPC can receive the compliance reference and constraints planned by the upstream compliance reference constraint generation layer and plan an optimal trajectory.

Combined with the (15)-(20) in the previous section, the vehicle state space expression in the global coordinate system can be obtained as：

$$\begin{aligned}\dot{x} &= Ax + Bu \\ y &= Cx\end{aligned} \tag{24}$$

Where:

$$x = [v_x, v_y, \dot{\varphi}, \varphi, X, Y]^T, u = [F_{xT}, \delta_f]^T, y = [Y, v_x]^T$$

$$A = \begin{bmatrix} 0 & 0 & v_y & 0 & 0 & 0 \\ 0 & -\dfrac{C_{\alpha f}+C_{\alpha r}}{mv_x} & \dfrac{C_{\alpha f}l_f + C_{\alpha r}l_r}{mv_x} - v_x & 0 & 0 & 0 \\ 0 & \dfrac{C_{\alpha r}l_r - C_{\alpha f}l_f}{I_Z v_x} & -\dfrac{C_{\alpha r}{l_r}^2 + C_{\alpha f}{l_f}^2}{I_Z v_x} & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ \sin(\varphi) & -\cos(\varphi) & 0 & 0 & 0 & 0 \\ \cos(\varphi) & \sin(\varphi) & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$B = \begin{bmatrix} \dfrac{1}{m} & 0 & 0 & 0 & 0 & 0 \\ 0 & \dfrac{C_{\alpha f}}{m} & \dfrac{l_f C_{\alpha f}}{m} & 0 & 0 & 0 \end{bmatrix}^T, C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

What MPC needs to trajectory is the desired lateral position and longitudinal vehicle speed, which in this paper are the compliance reference lateral position Y_{ref} and compliance reference vehicle speed V_{ref}.

$$y_{des} = [Y_{des}, v_{xdes}]^T = [Y_{ref}, V_{ref}]^T \tag{25}$$

One of the advantages of MPC is that it can handle multiple constraints. In this paper, besides the common actuator capacity constraints, MPC constraints also include traffic law constraints, namely compliance lateral position constraints and compliance speed constraints.

First, the actuator capacities are considered as:

$$\begin{aligned} |\delta_f| &\le \delta_{f,\max} \\ F_{xT} &\le \frac{T_{\max}}{R_{eff}} \\ |\Delta\delta_f| &\le \Delta\delta_{f,\max} \end{aligned} \tag{26}$$

where $\delta_{f,\max}$ is the maximum steering angle, here $\delta_{f,\max}$ is 0.3 radians , R_{eff} is the radius of the wheels, $R_{eff} = 0.335m$, $T_{\max}$ is the maximum propelling torque, $T_{\max} = 3000N$, $\Delta\delta_f$ is the change of steering angle in one step, and $\Delta\delta_{f,\max}$ is its capacity, $\Delta\delta_{f,\max} = 0.8°$.

Then, the traffic law compliance constraints are considered, which mainly include lateral position constraints and vehicle speed constraints, refer to the instructions in 3.1, when the vehicle speed in compliance, we will impose the compliance speed constraint to prevent the violation of the vehicle speed:

$$V_{speed\_min} \le v_x \le V_{speed\_max} \tag{27}$$

At the same time, when a violation is about to occur, the compliance lateral position constraint should be imposed to restrain the ego vehicle in the current lane to avoid the violation. When ego vehicle in compliance state, the default constraint is the lane boundary:

$$Y_{\min} \le Y \le Y_{\max} \tag{28}$$

Where, $Y_{\max}$ and $Y_{\min}$ are the upper and lower limits of compliance constraints given by the compliance reference constraint generation layer .

Finally, the cost function consists of the tracking of the reference path and control input ,The cost function is as follows, where the tracking of the reference path, control input is weighted by the matrix Q and R respectively.

$$\min J = \sum_{k=1}^{N_p} \| y^{t+k,t} - y_{des}^{t+k,t} \|_Q^2 + \sum_{k=1}^{N_c} \| u_c^{t+k-1,t} \|_R^2 \tag{29}$$

$s.t(k = 1, ..., N_p)$

$$x^{t+k,t} = Ax^{t+k-1,t} + Bu_c^{t+k-1,t} \tag{29a}$$

$$y^{t+k,t} = Cx^{t+k,t} + Du_c^{t+k,t} \tag{29b}$$

$$y_s^{t+k,t} = C_s x^{t+k,t} + D_s u_c^{t+k,t} \tag{29c}$$

$$y_s^{t+k,t} \leqslant y_{s\_\max}^{t+k,t} \tag{29d}$$

$$u_{c\_\min} < u_c^{t+k-1,t} < u_{c\_\max} \tag{29e}$$

$$\Delta u_{c\_\min} < u_c^{t+k,t} - u_c^{t+k-1,t} < \Delta u_{c\_\max} \tag{29f}$$

where, N_p is the prediction horizon; N_c is the control horizon; $t+k, t$ represents the predicted value at k steps ahead of t; The constraints variables y_s are linearized as a function of the inputs as well as states ,where C_s and D_s denote the output and feedforward matrices, $C_s = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$,The variables that are constrained here are the speed v_x and the lateral position Y ,which are presented in (24.d), where y_s is the hard constraint variables.

D. Vehicle state prediction

Considering the time delay of ego vehicle monitoring data and environmental data, if monitoring the current state of the ego vehicle, it may lead to violations before compliance. For this reason, we consider state monitoring based on prediction. On-line monitor monitors not the current state of ego vehicle, but the predicted state of ego vehicle.

The prediction here considers a simple dynamic-based vehicle state prediction. Vehicle state variables needed for on-line monitoring are mainly lateral position Y_{pre} and longitudinal position X_{pre}, lateral speed $v_{y\,pre}$ and longitudinal speed $v_{x\,pre}$, and heading angle φ_{pre}. These five state variables are predicted as follows:

$$\begin{cases} X_{pre} = X + nT\left(v_x\cos(\varphi) - v_y\sin(\varphi)\right) \\ Y_{pre} = Y + nT\left(v_x\sin(\varphi) + v_y\cos(\varphi)\right) \\ v_{x\,pre} = v_x + nT\left(v_y\dot{\varphi} + \dfrac{F_x}{m}\right) \\ v_{y\,pre} = v_y + nT\begin{pmatrix} -v_x\dot{\varphi} + \dfrac{(l_rC_r - l_fC_f)}{mv_x}\dot{\varphi} - \\ \dfrac{(C_r + C_f)}{mv_x}v_y + C_f\sigma_f \end{pmatrix} \\ \varphi_{pre} = \varphi + nT\dot{\varphi} \end{cases} \tag{30}$$

Where T is the sampling step and N is the predicted step here N is equal to 10.

E. Logical process of traffic law compliance decision-making

This section uses left lane change as an example to describe the compliance decision-making process.

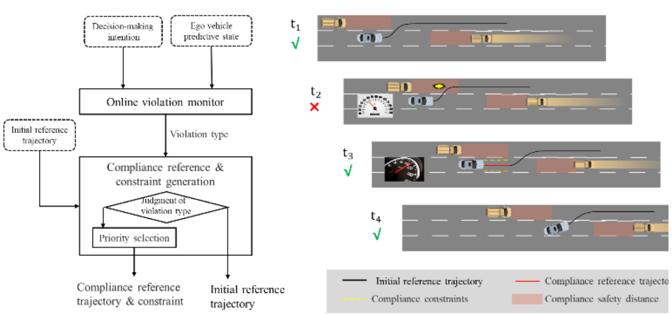


Fig.12. Logic process of compliance decision-making

As shown in Figure 12, the left side shows the logical process of our compliance decision, and the right side shows the schematic diagram at different times. At time t_1, the ego vehicle has an intention to change lanes on the left, which triggered our compliance decision-making module to start online violation monitoring of the left lane change behavior of the vehicle, monitoring the predicted state of the vehicle. The current moment is compliant, and the vehicle follows the initial reference trajectory. At t_2, the vehicle behind the left lane accelerates suddenly, and the distance between the ego vehicle and the vehicle behind the left lane is insufficient, that is, the left lane is unsafe. If the ego vehicle continues to change lanes at this time, it will have violations, and the ego vehicle's speed is lower than the minimum speed limit. The online violation monitor gives the corresponding basic violation types as a and d. The violation type will be transmitted to the downstream compliance decision module together with the initial reference trajectory. The module judges that the current vehicle will violate the rules, and generates the corresponding compliance reference and constraint according to the corresponding combination of violation types. The compliance constraints and references are then sent to the downstream priority selection module. According to the predefined priority, the module selects the best compliance reference and constraint, combines them into the compliance reference trajectory, and finally sends them to the downstream control layer. At t_3, the self-driving vehicle will drive according to the compliance reference trajectory, that is, temporarily give up lane change and accelerate. At t_4, the ego vehicle meets the lane change requirements and starts to change lanes according to the initial reference trajectory.

IV. EXPERIMENTAL VALIDATION

The above trigger-based layered compliance decision-making framework is implemented by Simulink model, and the involved online violation monitoring and Traffic law compliance reference & constraint generation methods are implemented by Simulink coding. In this section, the effectiveness of the proposed traffic law compliance decision-making method is verified by the Chinese highway vehicle trajectory data set.

A. The vehicle trajectory dataset

The AD4CHE dataset[23] is used to validate the proposed traffic law compliance decision method. Like the Germany's HighD dataset, the AD4CHE dataset is also an overhead viewing angle dataset, which is acquired around China highways and annotated by DJI with drones. Most of the data in AD4CHE are arranged like that in HighD. The difference between HighD and AD4CHE is that the road in AD4CHE is not straight but with different curve roads and some inward and outward remittances. Thus, a lane map is also provided in AD4CHE for quickly calculating which lane the object vehicle belongs to.

In addition, it must be mentioned that the AD4CH data set is a data set for congested road sections, so the vehicles in this data set drive at a relatively slow speed and the distance between them is very tight, which leads to a high violation rate of vehicles. Since the distance between vehicles in the AD4CHE data set is too compact, it is difficult to achieve the compliance distance without collision, so for the consideration of verification, we improve the speed and relative distance of vehicles in the AD4CHE data set to twice the original.

All vehicles in the data set have an ID, which is allocated according to the order in which the vehicles appear; The selected vehicles are called ego vehicle, and other vehicles in the scene are regarded as surrounding vehicles. As shown in Figure 10, first, we get the input information we need from the data set. It is worth noting that in order to improve the calculation speed, we do not care about all the surrounding vehicles in the data set, but select the six vehicles closest to the ego vehicle according to the location relationship between the surrounding vehicles and the ego vehicle and the lane they are in[19]. These six vehicles are called target vehicles. After that, the online violation monitoring module will monitor the predicted state of ego vehicle and target vehicles in real time, and output the results of violation monitoring. If the results are fully compliant, the compliance decision module will output the initial reference trajectory to MPC to control the ego vehicle to move according to the initial decision intention; If the result is in violation, the initial reference trajectory will be truncated, and the compliance decision-making module will generate the corresponding compliance reference and constraints according to the type of violations, and then determine the final compliance reference and constraints according to the priority, and output them to the MPC module for execution, so as to prevent ego vehicle from committing violations.

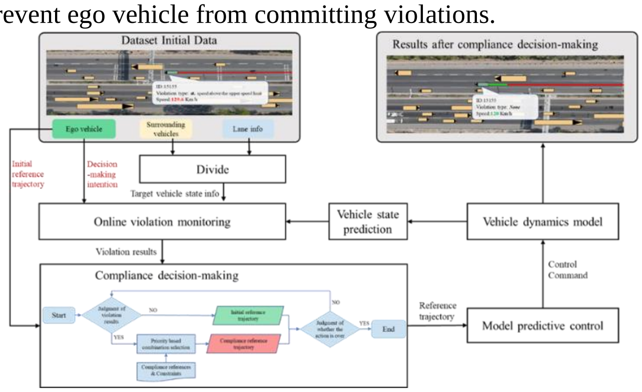


Fig.13. Compliance decision-making model with accessing the AD4CHE dataset

The information we can directly obtain from the dataset mainly includes: ego vehicle information, surrounding vehicle state information and lane information. Since the behavior layer and motion planning layer are not designed in this paper, we also need to indirectly obtain the initial reference trajectory and decision-making intention information of ego vehicle through the AD4CHE data set, which is not available in the data set, so we choose to use the existing data in the data set to approximate.

(1) Decision making intention: For typical highway traffic laws (speed limit, distance limit, overtaking, lane changing), speed limit and distance limit are always monitored, while the violation monitoring of lane changing and overtaking are triggered by decision-making intention. For lane changing decision, we regard the lane changing stage when the lateral speed of the autonomous vehicle is greater than 0.25m/s as the stage when the lane changing decision-making intention is generated. When the lateral speed of the autonomous vehicle is greater than 0.25m/s, it is considered that the lane changing intention is generated, which triggers our traffic law compliance decision-making model to carry out real-time monitoring and decision-making of lane changing regulations, namely:

$$\begin{aligned}&\mathrm{v}_y(Ego) > 0.25m/s \Rightarrow \\ &Decision\_change\_leftlane = True\end{aligned} \tag{31}$$

$$\begin{aligned}&\mathrm{v}_y(Ego) < -0.25m/s \Rightarrow \\ &Decision\_change\_rightlane = True\end{aligned} \tag{32}$$

Similarly, when there is another vehicle in the same lane in front of the ego vehicle, and the speed of the front vehicle is lower than that of the ego vehicle, the TTC with the ego vehicle is less than 20s, and the lateral speed of the ego vehicle is greater than 0.25m/s, the vehicle is considered to have the decision-making intention of overtaking:

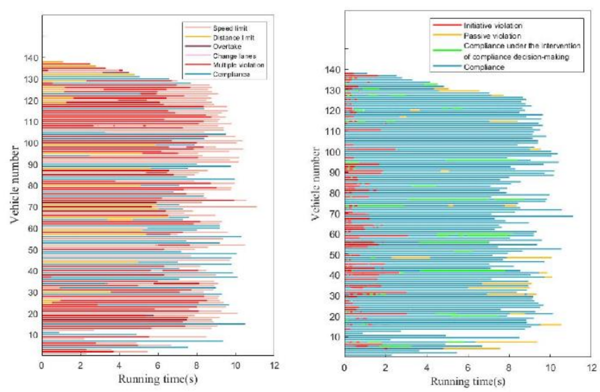
$$\begin{pmatrix}\exists Tgt \in front(Tgt, Ego) \wedge v_x(Tgt) < v_x(Ego) \wedge \\ TTCX(Ego, Tgt) < 20s \wedge |v_y(Ego)| > 0.25m/s\end{pmatrix} \tag{33}$$
$$\Rightarrow Decision\_overtake = True$$

(2) Initial reference trajectory: We use the ego vehicle trajectory in the AD4CHE dataset as the initial reference trajectory given by the motion planning layer.

B. Statistical analysis of results

In this section, we connect each vehicle in the AD4CHE dataset to the compliance decision-making model to verify the effectiveness of our compliance method, and finally obtain the statistical results by traversing all vehicles in the dataset, note that the right side of the AD4CHE dataset is heavily congested, while the left side is better. Therefore, we only verify compliance decision-making for vehicles on the left side of the AD4CHE dataset. The verification results are shown in Figure 14.\

Figure 14 (a) is a statistical result obtained by monitoring the true tracks of all vehicles in the data set. The lateral axis is the time the vehicle exists in the data set, and each line of the longitudinal axis represents the compliance status of a vehicle. Due to the congestion, most of the vehicles in the data set are in violation.



(a) Original vehicle violation state (b) Vehicle violation state under the compliance decision-making

Fig.14. Statistical results of vehicle violation state

Figure 14 (b) is a statistical result of the vehicle compliance status after incorporating the data set into our compliance decision model. It can be clearly seen that the violation status basically concentrates on the moment the vehicle first appears. This is because the vehicle has violated the traffic laws at the beginning, mainly the speed limitation violation and the distance limitation violation. However, with the involvement of our compliance decision model, the vehicle quickly changes from the violation status to the compliance status. There are also green lines in the diagram, called compliance status with involvement of compliance decision making, which means that if the vehicle follows the initial reference trajectory, a violation will occur, but the vehicle will remain compliant with involvement of our compliance decision model. It is worth mentioning that this condition only occurs when the vehicle changes lanes and passes because the decision-making intent of the vehicle arises only when the vehicle passes and changes lanes.

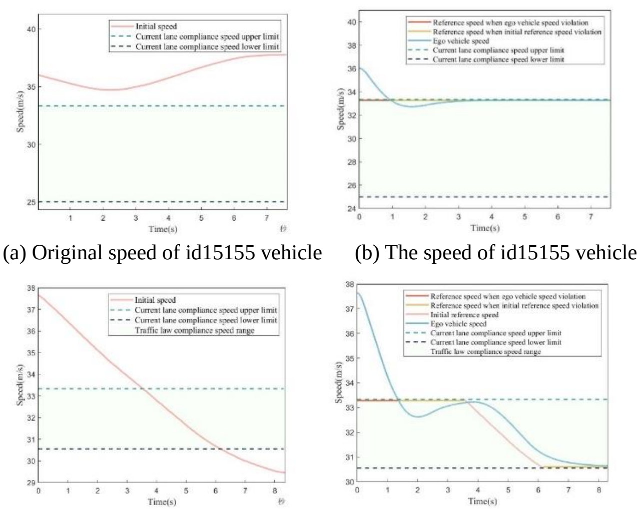
By comparing the two statistical charts shown in Figure 14, it is obvious that our proposed compliance decision-making method can effectively reduce the occurrence of violations while driving and ensure the compliance of the vehicle.

C. Traffic law compliance verification of individual vehicles

In order to reflect the effect of our compliance decision-making method, this section selects some illegal vehicles more intuitively as ego vehicle, and takes the six vehicles closest to the ego vehicle as target vehicles to independently verify the four main traffic laws of the highway, namely speed limit, distance limit, lane change and overtaking.

(1) Traffic law compliance verification of speed limit:

For traffic law of speed limiting, our traffic law compliance decision-making algorithm mainly gives compliance reference speed and compliance speed constraints. Take the id15155 and id15170 in the AD4CHE data set as an example, as shown in Figure 15:



(a) Original speed of id15155 vehicle (b) The speed of id15155 vehicle

(c) Original speed of id15170 vehicle (d) The speed of id15170 vehicle

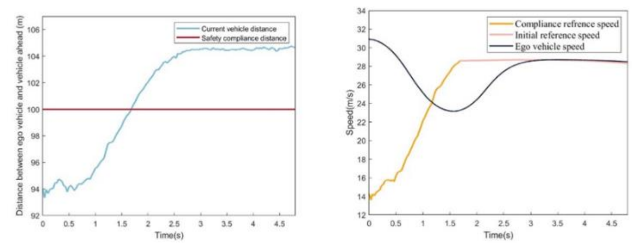
Fig.15. vehicle speed limit verification

Figure 15(a) and (b) show the speed change of id15155. It can be clearly seen that its original speed in the data set is always in violation. After accessing our compliance decision-making model, since both the initial speed and the reference speed are in violation, our compliance reference speed currently is $v_{\_cref}$, and the vehicle is in compliance within one second. After that, the vehicle speed is compliant, but the initial reference speed is still illegal, so at this time, the reference speed of vehicle becomes $v_{\_iref}$, and vehicle can maintain the highest speed limiting driving permitted by traffic laws. The id15170 car is different from the 15155 vehicle. From Figure 15 (c), ego vehicle speed first exceeds the upper speed limit, then complies with the traffic law, and finally falls below the lower speed limit. After the compliance decision-making model is added, the vehicle can quickly reach compliance and maintain high-speed driving. At 3.7 seconds, the vehicle speed and the initial reference speed are both compliant. The reference speed becomes the initial reference speed given by the motion planner. In this paper, it is the original speed in the data set. The vehicle starts to slow down. At the 6th second, the initial reference speed again violates the rules, and the reference speed becomes our compliance reference speed $v_{\_iref}$, the ego vehicle drives at the lower speed limit allowed by traffic laws.

The results show that our compliance decision-making method can enable the vehicle to comply as soon as possible when the speed is violated, while retaining the initial driving intention of the vehicle as far as possible.

(2) Traffic law compliance verification of distance limit:

For the traffic law of distance limit, when the distance between the ego vehicle and the vehicle in front is insufficient, we mainly give the compliance reference speed to keep the ego vehicle decelerating at a safe distance from the vehicle in front, as shown in Figure 16 :



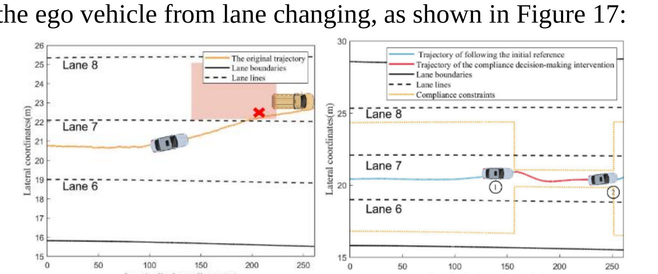
(a)Distance between ego vehicle and front vehicle (b) Ego vehicle speed

Fig.16. Distance limit verification

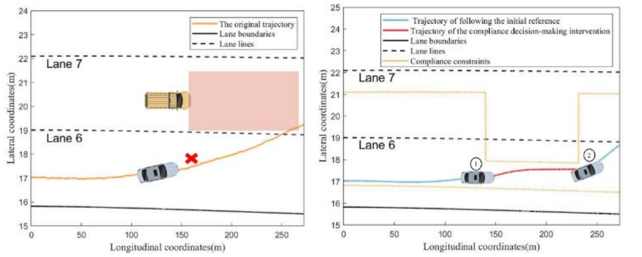
As shown in Figure 16(a), the selected vehicle is id15129, which is less than 100m away from the vehicle in front at the beginning. The compliance decision module gives a new compliance reference vehicle speed according to the current distance, speed and compliance distance between the front vehicle and the ego vehicle, and the ego vehicle decelerates under the effect of the compliance reference speed to maintain the compliance distance. In order to prevent the ego vehicle from repeating between the violation and the compliance, we set the compliance distance D to 105m. After the distance is compliant and stable, the reference speed becomes the initial reference speed. The result shows that our compliance decision-making method can make the vehicle comply as soon as possible when the distance is violated.

(3) Traffic law compliance verification of change lane

For the traffic law of lane changing, we mainly give the reference trajectory. When the ego vehicle generates the lane changing decision-making intention, if the current situation does not conform to the traffic law of lane changing , such as the left lane of the ego vehicle is unsafe, the compliance decision-making model will give a new compliance reference trajectory to make the ego vehicle temporarily give up lane changing, and at the same time impose constraints to prevent the ego vehicle from lane changing, as shown in Figure 17:



(a) ID 15150 vehicle original trajectory (b) Trajectory of id15150 vehicle



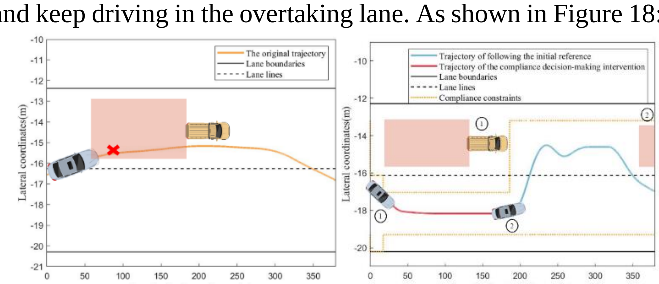
(c) ID 15228 vehicle original trajectory (d) Trajectory of id15228 vehicle

Fig.17. Lane changing verification

As shown in Figure 17, the selected vehicles are id 15150 and id 15228. Figure 17 (a) and 17 (c) are the original trajectories of id 15150 and id 15228 in the data set. Both of them have lane change violations. The reason for the violation is that the left lane is unsafe. After accessing the compliance decision model, it can be seen from Figure 17 (b) and (d) that at time 1, the ego vehicle generated the intention of lane change on the left, but at this time, the safe distance between the ego vehicle and the vehicles on the left lane is insufficient, If the ego vehicle continues to change lanes, a violation will occur. According to the predicted violation results given by the online violation monitor, the new reference trajectory given by the compliance decision model makes the ego vehicle temporarily give up the lane change and drive along the current lane, while the compliance constraint is tightened to the self-lane to prevent the vehicle from lane change. At moment 2, the left lane is safe, and the ego vehicle starts to change lanes following the decision intention.

(4) Traffic law compliance verification of overtaking

For traffic law of overtaking, there are five basic violation types in overtaking: c, d, e, f and g. We divide the overtaking process into two stages: before overtaking and during overtaking, among which c, d and f belong to the violation before overtaking, and e and g belong to the violation during overtaking. For the violation before overtaking stage, according to the compliance reference and constraints, the ego vehicle will temporarily give up overtaking and keep driving in the initial lane. For the violation in the during overtaking stage, the ego vehicle will temporarily give up return to the initial lane, and keep driving in the overtaking lane. As shown in Figure 18:



(a) ID 15331 vehicle original trajectory (b) Trajectory of id15331 vehicle

Fig.18. Overtaking verification

As shown in Figure 18 (a), the selected vehicle is a violation before overtaking, and the safety distance between the ego vehicle and the left front vehicle is insufficient at the beginning of overtaking. The violation type is *d*. If the vehicle continues to change lanes and overtake, the violation will occur. After access to the compliance decision model, as shown in Figure 18 (b), at time 1, the ego vehicle generates overtaking intention, and the online violation monitor gives the violation result according to the ego vehicle prediction state, according to which the compliance decision module generates the compliance reference trajectory to make the ego vehicle temporarily give up overtaking and keep driving on the initial lane, while tightening the compliance constraint to prevent ego vehicle from changing lanes to overtake; At time 2, the distance between the ego vehicle and the vehicle in front of the left is enough, the lane on the left is safe, and the ego vehicle starts to overtake.

The above experimental results prove that our compliance decision-making method can make the vehicle comply as soon as possible when it violates the traffic laws, and keep the driving intention as far as possible while making the vehicle comply with the traffic laws; Meanwhile, when the vehicle is about to violate the traffic laws, our method can also accurately identify the violation information of the vehicle, generate the corresponding compliance reference trajectory and constraints to keep the vehicle running in compliance.

V. CONCLUSION

In this work, a highway traffic law compliance decision-making method was proposed, different from the existing methods of simply coupling traffic laws with safety or only considering static non interactive traffic laws, the method proposed by us can ensure that the ego vehicle always conforms to traffic laws while ensuring safety. this paper proposes a trigger-based layered compliance decision-making framework, in which the decision intention generated by the behavior layer is used as a trigger signal to accurately identify the behavior of the vehicle. The online violation monitor is used to monitor the violation type of the predicted state of the vehicle before the vehicle violation and give the corresponding violation results. In the compliance decision-making module, we have designed a three-layer architecture, namely, the Compliance references & Constraints layer, the Priority based combination selection layer and the Compliance reference trajectory generation layer, which will generate the compliance reference trajectory and constraints according to the identified violation results to ensure the vehicle is always compliant during driving. Finally, we have simulated and verified the four main laws and regulations of speed limit, distance limit, lane change and overtaking on the AD4CHE highway data set, and the results show that the proposed method can effectively identify the violation information before the vehicle violates the rules and ensure that the vehicle always complies with the traffic laws.

However, the current work still has shortcomings, and there are still many ways to improve. Future work could include: (1) considering more reasonable methods of compliance reference and constraint generation to make the generated trajectory smoother; (2) Considering the soft and hard constraints of traffic laws to cope with the scenario where full compliance and security conflict; (3) Introduce evaluation indicators to quantify the current violation risk;(4) Consider more complex scenarios to improve the adaptability of the compliance decision-making method; (5)Consider the real vehicle experiment to verify the timeliness of our method.

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