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Lane Change Decision Analysis Based on Drivers' Perception-Judgment and Game Theory

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Abstract. To clearly understand the mechanism of drivers' lane-changing decision, based on drivers' perception of external information, integrated cognitive judgment and game theory, the decision-making model was established, then the structure and operating mechanism of the model were detailedly analyzed. By introducing game theory-related knowledge, the non-cooperative mixed strategy game between the object vehicle and the following vehicle in the target lane was further discussed. Then, the benefits and Nash equilibrium solution of the participants in the game were deeply researched. Analysis shows that lane-changing decision is composed of information perception and three judgment-decision processes, the factors which would affect decision-making level include information source characteristics, the ability of drivers' perception and comprehensive cognitive judgment, driving behavior characteristics and so on. The Nash equilibrium solution of the lane change game is determined by driving safety level, journey time and importance degree of the revenues.

1. Introduction

During lane changing process, it may lead to traffic accidents because of drivers' unskilled operation or decision-making bias. Statistics show that improper lane changes accounting for about 8% of the total accidents, causing a large number of casualties and economic losses [1].

Lane-changing process can be divided into two stages, decision-making and execution [2]. In decision-making stage, drivers sense the driving environment and process the information flow inconsistent with his driving expectancy, resulting in lane change intention, until the driver starts the lane change operation. The execution stage, from starting time of the lane change to the overall vehicle body crossing the lane boundary, then adjusts its position in the target lane. At present, a lot of lane-changing research focuses on the execution stage [3]. In order to effectively analyze the lane-changing time and space requirements, plenty of lane-changing models are proposed, such models normally focus on mathematically describe the lane change execution process, and achieved some important academic achievements [4-8]. Driver's decision-making level plays an important role in the overall lane change process safety margin, unfortunately, nowadays hardly any insightful and sustainable research aims at lane change decision-making stage. This paper puts forward a lane changing decision-making model based on drivers' perception, decision-making and game theory, deeply analyze the formation mechanism of drivers' lane changing decision-making, and clearly clarify the game features between the object vehicle and other related vehicles.

2. Lane change decision-making model

2.1. Prerequisites of lane changes

Primarily, road conditions involved is multi-lane road, and don't consider the impact of opposite direction vehicle. We assume that related vehicles affect the object vehicles' lane-changing behavior include leading car in the current lane, the following car in the target lane and the leading car in the target lane. In addition, this paper mainly discusses the typical decision-making scenario of which the object vehicle intending to overtake the leading vehicle in the current lane, as shown in Fig.1.

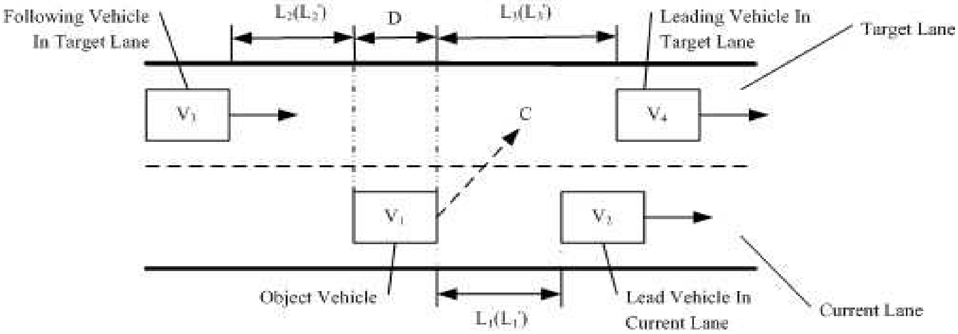

Fig.1. Sketch map of lane changes

We denote the object vehicle by V_1 , the leading vehicle in the current lane, the following car in the target lane and the leading car in the target lane respectively denoted by V_2 ,V_3 ,V_4 . L_1', L_2' and L_3' respectively represents the critical safe distance (the minimum safe distance to avoid collision, affected by vehicle performance, driving behavior characteristics, vehicles' instantaneous velocity) determined by the object vehicle and other related vehicles. Similarly, L_1, L_2, L_3 denote the actual distance between related collision vehicles, respectively. Point C is the critical collision point determined by V_1 and V_3.

2.2. Structure of the model

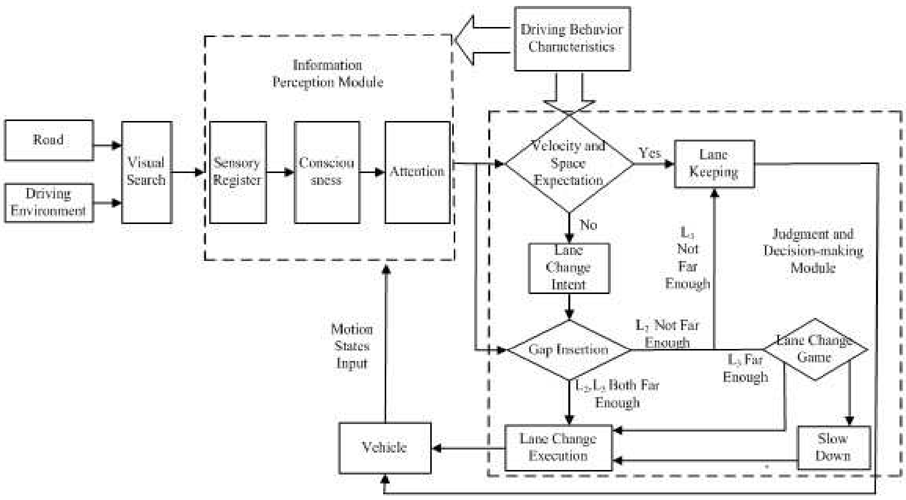

Fig.2. Structure of drivers' lane-changing decision model

During the driving process , on the basis of driving environment conditions, combining with driving experience, drivers extract the information possesses high stimulus intensity and highly in accordance with their driving interests. Drivers judge the apperceived information in real time, and take full account of other drivers' possible strategies, finally make the decision whether to change the lane or not. Based on fully understanding drivers' characteristics of perceptions and judgments, combining with fathoming the interactions between the related vehicles, a new decision model is put forward, as shown in Figure 2.

2.2.1. Information perception module

With the sensory register process, drivers preliminarily handling the outside stimulus information, which includes surrounding vehicles ,driving environments etc. After that, combining with driving experience, the perceived information is formed to deep consciousness counterparts. Afterwards, drivers select the appropriate consciousness information to focus on, accomplishing the function of information perception module. Generally, given higher stimulus intensity of the information, and get stronger correlation degree with driving intentions, the possibility of the consciousness information be focused on will increase [9].

The function of information perception module is affected by both stimulus information source characteristics and driving behaviors, they can achieve multichannel and dynamic matching during information handling process. Driving behaviors mainly include drivers' character traits, physiology and mental states, diving skills, stress reaction characteristics, professional quality and so on.

2.2.2. Judgment and decision-making module

Driving expectation refers to the psychological needs of velocity and space, it is determined by the drivers' driving behavior characteristics. The information deeply processed by information perception module interacts with the driving expectations, the first judgment and decision-making process in this module is accomplished. If the information is successfully matched with the driving expectation in the submodule, drivers will execute lane keeping maneuvers. Once driving exepectation could not be satisfied, drivers will generate lane change intent, which specifically behaves as frequently gazing at the rearview mirrors, higher transfer frequency and probabilities between some interest areas, accompany with distinct head rotations [10].

After generating lane change intent, combining with the processed information in the perception module, drivers execute the second judgment and decision-making process. When object vehicle driver judge that the actual distance between own vehicle and related cars in the target lane is longer than the individual critical safe distance, drivers will execute lane change decision. When drivers judge that the distance L_2 between V_3 and V_1 is shorter than L_2', classified discussions are as follows: assuming that the driver judges $L_3<L_3'$, lane keeping decision will be chosen. When the judgment results are $L_3>L_3'$, two-person game will be carried out between V_1 and V_3, namely the third judgment and decision-making process in the submodule. Given the driver has generated lane change intent, the object vehicle driver owns two pure strategy, mandatory lane change or slow down, the game features will subsequently be detailedly discussed. Up to this point, the object vehicle driver has accomplished one complete lane change decision-making process.

3. Game characteristics of lane change decision-making

3.1. Introduction of the two-vehicle game

In the actual lane changing process, the object vehicle's ultimate goal is to satisfy its own driving expectation, and get higher speed and space satisfaction degree. From the view of following vehicle (V_3) in the object lane, after the successful lane changes of V_1, the leading vehicle of V_3 becomes to V_1, which would lead to the decrease of V_3 driver's satisfaction degree. Discarding other factors (such as moral, intellect, etc.), from a psychological perspective, all drivers instinctively tend to maximize their benefits, soV_3 may accelerate to pass the critical conflict point, which would prevent lane change behavior of V_1, there are competition relation between the two.

Assuming that the actual distance between V_1 and V_4 is long enough, the influence of V_4 on lane change behavior of V_1 could be ignored. This phase of lane changes decision–making can be seen as scramble for the conflict point between V_1 and V_3, then evolves into two-player game aiming to improve individual velocity and space satisfaction degree.

3.2. Game characteristics analysis

In the lane changing game between V_1 and V_3, based on the two drivers' individual information flow processed by the information perception module, combining with the judgment of velocity and relative distance, fully considering the possible choice made by game opponent, then make their corresponding decision. Due to the lane change game characteristics, both game players could not predict opponent's selection strategy through cooperation, so it belongs to non-cooperative game, whose solution is namely the Nash equilibrium solution. The strategic combination of the Nash equilibrium is composed of the individual optimal strategy of both sides, but not necessarily the overall optimal policy, so both of the game players' driving expectation could not be satisfied at the same time. It should be noted that although it is non-cooperative game, from the safety pespective, it also could avoid an accident. Once an accident happens, it means the irreconcilable conflict between individual interest and collective reason, the worst game result arises for both the game players.

For V_1, there are two pure strategies to choose, mandatory lane change and slow down. Similarly, for V_3, collision avoidance and non-collision avoidance (keeping the uniform velocity or accelerating through the critical point) are corresponding pure strategies. Both of the game players can't explicitly give their own strategy but the probability distribution of strategy space, so it belongs to mixed strategy game. In this study, the revenues of drivers relating to lane changes contains driving safety level-*S* and journey time-*T*. Revenues matrix of the game players is shown in Table.1.

Tab.1. Revenues matrix of the game players

V_3 \ V_1	Mandatory lane change	Slow down
Collision avoidance	$\alpha S-\beta T, \beta T$	$-\beta T, -\beta T$
Non-collision avoidance	$\beta T-\alpha S, -\alpha S$	$\beta T, -\beta T$

In order to conveniently quantify the revenues of the game players, α and β are introduced describe the importance degree of different revenue parameters, where α represents the important degree of driving safety, β represents the important degree of journey time, and α plus β makes 1. The specific values of α and β are determined by safety awareness and mental states of the game players, they can be achieved by the questionnaires.

3.3. The Nash equilibrium

Suppose *P* is the probability that V_1 chooses the strategy of mandatory lane change, corresponding probability that V_1 chooses the strategy of slow down is 1-*P*. Similarly, *Q* represents the probability that V_3 chooses collision avoidance strategy, the probability that he chooses non-collision avoidance strategy is 1-*Q*, the expected revenues of V_1 can be expressed by equation (1), analogously, the expected revenue of V_3 is shown in equation (2).

$$E_1(P, Q) = PQ\beta T - P(1-Q)\alpha S - (1-P)Q\beta T - (1-P)(1-Q)\beta T \quad (1)$$

$$E_2(P,Q)=PQ(\alpha S-\beta T)+P(1-Q)(\beta T-\alpha S)-(1-P)Q\beta T+(1-P)(1-Q)\beta T \quad (2)$$

If *Q* is known, combining with formula 1, the expected revenues that V_1 chooses mandatory lane changes (P=1) or slow down (P=0) may be expressed by equation (3) and (4), respectively.

$$E_1(1, Q) = Q\beta T-\alpha S + Q\alpha S \; ; \; E_1(0, Q) = -\beta T \quad (3)$$

Let $E_1(1, Q) = E_1(0, Q)$, then $Q^* =(\alpha S-\beta T)/(\alpha S+\beta T)$

When $Q> Q^*$, the optimal strategy of V_1 is mandatory lane change; while $Q< Q^*$, the optimal strategy of V_1 is slow down; if $Q= Q^*$ occurs, V_1 can randomly select either of the two strategies.

Similarily, we can infer that $P^* =\beta T/\alpha S$, then the Nash equilibrium of the mixed strategy game is $P^* =\beta T/\alpha S$, $Q^* =(\alpha S-\beta T)/(\alpha S+\beta T)$. We can conclude that in the lane change games, the probability of V_1 choosing mandatory lane change strategy is $\beta T/\alpha S$, corresponding probability of V_3 selecting collision avoidance strategy is $(\alpha S-\beta T)/(\alpha S+\beta T)$. The strategy selections for the game players are determined by driving safety level, journey time and importance degree of revenue parameters(α, β).

Given α plus β makes 1, with the increase of α, decrease of β, it will result in the increase of Q^*, then ultimately lead to the decrease of probability for V_1 selecting the strategy of mandatory lane change. In the lane changing process, compare with V_1, V_3 owns higher level right-of-way. While traffic conflict occurs, if V_3 chooses non-collision avoidance strategy, it's rational for V_1 to decrease the probability of choosing the mandatory lane change strategy. Countermeasures can be done for the purpose of increasing the value of α, for instance, increasing the punishment intensity of illegal lane changes, improving drivers' safety consciousness by various of propaganda and education works, etc.

4. Conclusions

(1)Driver's lane-changing decision-making model is put forward on the basis of considering the driver's information perception ability and driving expectations. In general, lane-changing decision is composed of information perception and three judgment-decision processes, factors that influence driver's decision-making level include information sources characteristics, the ability of drivers' perception and comprehensive cognitive judgment, drivers' driving behaviors, etc. Compare with previous lane-changing decision models, this model takes fully into account the information perception function module before the generation of lane changing intent, and weighs the strategy coupling process of the game players.

(2)From of the view of Nash equilibrium, the probability of V_1 choosing the mandatory lane change strategy, as well as the probability of V_3 choosing collision avoidance strategy, is deeply analyzed, respectively. The Nash equilibrium solutions are determined by the driving safety level, journey time and the important degree of the revenue parameters. Given a strategy changes relative to equilibrium point for one game player, the opponent always has the corresponding optimal strategy. With the improvement of drivers' safety consciousness, the importance degree of driving safety will increase accordingly, and finally this would remarkably improve the safety level in the lane change process.

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