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Research on Cooperative Lane-changing Behavior Based on System Dynamics

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Research on Cooperative Lane-changing Behavior Based on System Dynamics

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Abstract. This research analyzed the contributing factor relating to the cooperative lane-changing behavior in the framework of system dynamics. From the perspective of traffic management, investigating data includes the current states of response toward lane-changing behavior and a series of factors related to it, in Shenzhen Traffic Police Bureau, China, in both qualified and quantified manner. In addition to that, data related to cars, drivers, environment, and weather in the same period of time were also collected. AMOS was used to analyze data, before simulating the cooperative lane-changing behavior system by VENSIM in order to explore the dynamic influence sequence of various factors on the cooperative lane-changing behavior with the change of time. The outcomes illustrate that different types and levels of traffic management tactics bring to different levels of cooperative lane-changing behavior. By using effective law enforcement and increasing the rate of personnel of learning enforcement properly and enforcement on time, etc. the cooperative lane-changing behavior can be enhanced to a different level noticeably. The evolution changing process appears periodically.

1. Introduction

At present, traffic accidents caused by lane-changing and traffic congestion become more and more prominent(Guo et al.,2000)(Mou et al.,2015)(Xu et al,.2010). Many types of research show that defective lane-changing behavior has a significant impact on driving safely and efficiently. Therefore, the study of cooperative lane-changing behavior is of great significance in increasing the safety and efficiency of traffic operation.

From the majority of research related to the lane-changing problem (LCP), the research methods of LCP focus on CA, subject, utility, fuzzy logic, game theory, etc. (Nagel et al., 1998). The basic research work of LCP is divided into the effect and safety of LCP (Qiao et al., 2015) (Olsen et al., 2002), physiology and mental state of LC drivers and the rules of LCP. However, there are a few researches analyzing LCP using system theory in order to research the influence of a variety of policies, subjective and objective factors. From the view of system dynamics, the researcher can consider the single factor in the system and think the interaction between the factors at the same time, combined with qualitative and quantitative analysis of the actual data, to understand the complex LCP (WANG, LU and PENG, 2008). As a powerful tool, system dynamics can be more logical to deconstruct the overall operation of the LCP system.

2. System boundary determination and causality construction

2.1. Analysis of influencing factors and determination of the boundary of cooperative lane-changing behavior

This part will focus on the factors affecting cooperative lane-changing behavior and then set the system boundary. The cooperative behavior of lane-changing is considered to be one system as a whole, and it includes five key subsystems, including driver subsystem, vehicle subsystem, road environment subsystem, environment subsystem, and policy subsystem. The factors in these five subsystems that are complex. The appearance of the cooperative behavior is not simply caused by a single reason, in contrast, a great deal of direct and indirect feedbacks and influences between factors in the whole system contribute that phenomena.

2.2. Construction of causal loop diagram

According to the basic principle of SD causal circuit diagram, the influence factors of cooperative lane-changing behavior are analyzed logically, and the causal-loop diagram of cooperative lane-changing behavior is constructed, as shown in Figure 1.

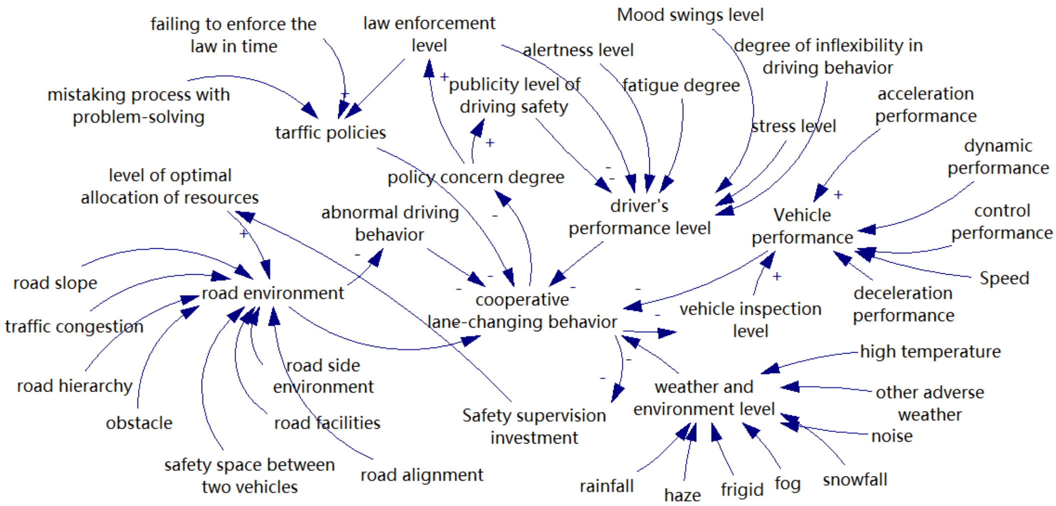

Figure 1. Causal-loop Diagram of Factors Influencing Cooperative Lane-changing Behavior

3. Construction of SD model for cooperative lane-changing behavior

3.1. Establishment of system dynamics stock-flow diagram for vehicle lane changing behavior

The causality diagram of cooperative lane-changing behavior is based on the logical relationship between system elements, and its function is mainly to describe the feedback logic among the elements. On the basis of the causal loop diagram, the stock flow diagram is extended to describe the deterministic quantity. The stock-and-flow diagram of cooperative lane-changing behavior is shown below in Figure 2. The main types of variables included are divided into three categories: system state variables, rate variables, and auxiliary variables. The detailed list of variables type is shown in Table1.

Table 1. Table of variables formation

Variable types	Variable Name and Representation
state variables (11)	driver's performance level D_L、 increasing rate of training funds on inspection I_{SML}、 weather and environment level R_L、 cooperative lane-changing behavior D_C、 vehicle inspection level C_{IPL}、 hours of study and training on inspection I_{SCT}、 road obstruct level R_{BL}、 vehicle performance D_L、 road repair level R_{RL}、 road environmental level D_{RL}

	etc.
Rate variables (17)	the increasing rate of publicity of driving safety S_{LSR}、 increasing rate of training funds on inspection I_{SMR} etc.
Auxiliary variables (54)	the response speed of driving safety publicity S_{LST}、 fatigue degree T_{LL}、 rainfall intensity R_{LL}、 road hierarchy index R_{LL} etc.

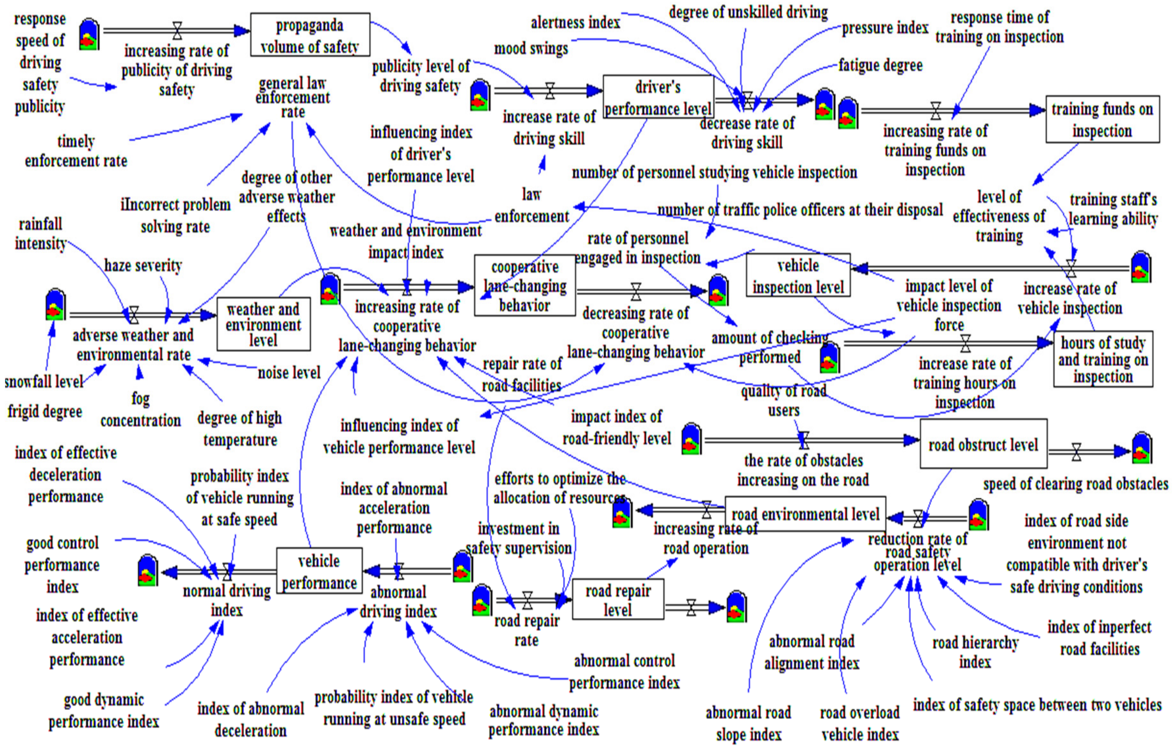

Fig.2 Stock-and-Flow Diagram of Cooperative Lane-Changing Behavior

3.2. Determining variable parameters and establishing various equations

Based on data survey, structural equation modeling (SEM) and literature review, this paper makes a full analysis and demonstration to find the relationship between key variables of the system, and to study the incentives of its internal role (Chasey, de la Garza and Drew, 2002)(Fallah-Fini et al.,2010).

Structural equation modeling (SEM) is a modeling method to determine the relationship and structure between variables when there are many types of variables in the problem. For some variables involved in the study of cooperative behavior, such as driver's performance level, vehicle performance, environment, and other factors, a series of latent variables cannot be measured directly, and need to be measured indirectly through relevant external indicators. Latent variables cannot be processed by traditional statistical methods. In this paper, the method of structural equation modeling is adopted to establish the survey data based on 3000 drivers who hold a car driving license, drive for at least three years and have stable driving skills. The survey includes drivers' physical and psychological qualities, vehicle status, self-assessment of diversion behavior, traffic safety awareness, illegal awareness, and other issues during the actual driving process in the last month. The survey was conducted in March 2018 for a period of 1 month and was investigated on the Internet. At the end of the survey, data screening and processing were carried out by SPSS, and SEM analysis was carried out by Amos software.

The key steps of SEM and analysis are mainly divided into establishing the basic framework of the model, establishing the relationship between the model and the data, selecting the parameters to be analyzed and calculated, and finally standardizing the results. The result data after standardization is shown in Figure 3.

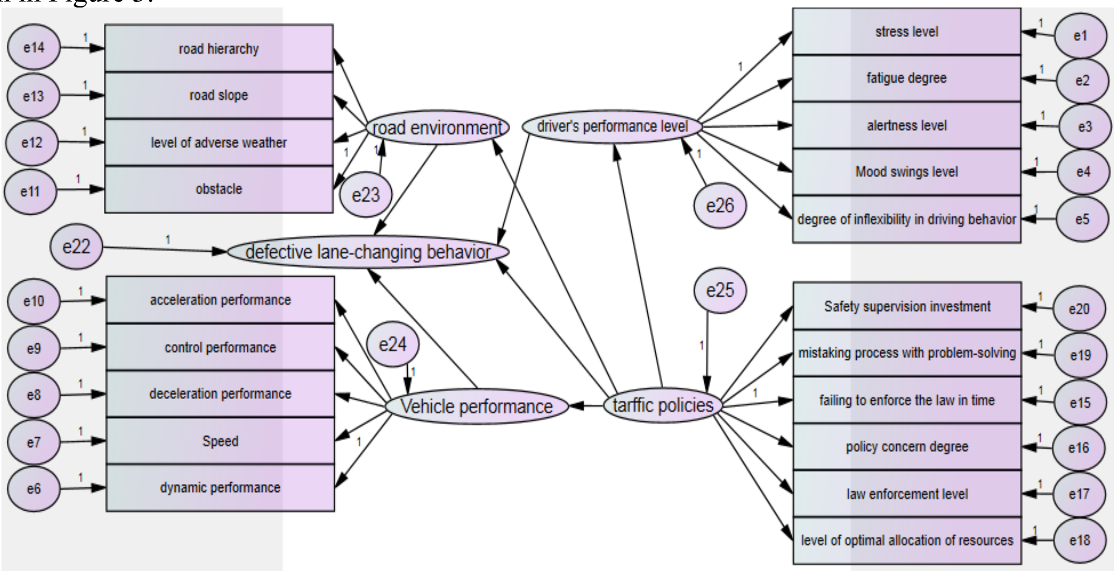

Figure 3. The standard path map of the factor evaluation model

$$D_{CPR} = R_{IC}*R_L + C_{IC}*C_L + D_{IC}*D_L + E_{IC}*E_L$$
$$(R_R + C_R + D_R + E_R = 1) \tag{1}$$

$$D_C(T) = \int_{T_0}^{T} (D_{CPR(X)} - D_{CMR(X)})dx + D_{C(T_0)} \tag{2}$$

Other equations of state are given in a manner similar to (1) and (2):

The relationship between propaganda volume of safety and publicity level of driving safety is given in the form of the table function. The equation is:

S_{LI} = $WITH\ LOOK\ UP$ (S_{LL} ([(0,0)-(1000,1)],(9.17431,0.01),(85.6269,0.05),(119,0.14),(238,0.28),(385,0.32),(504,0.44),(559,0.46),(666,0.47),(733,0.46),(795,0.43),(834,0.43))) (3)

Similar to formula (3), the equation of other auxiliary variables was given. In (1), D_{CPR} represents the increasing rate of cooperative lane-changing behavior, R_R, C_R, D_R, E_R represent the weather and environment, vehicle performance, driver's performance, and road environmental impact index, respectively.$R_{IC}, C_{IC}, D_{IC}, E_{IC}$ represent its' corresponding level variables. In (2), D_{CMR} represents the decreasing rate of cooperative lane-changing behavior, T_0, T represent the starting and ending time of level variables in simulation, and $D_{C(T_0)}$ represent the initial figure of level variables. In (3), S_{LI}, S_{LL} represent the volume and level of driving safety propaganda, and its function obeys the distribution of table function. The input conditions set by the simulation are determined by the results of the survey data processing, the structured analysis method and the actual data statistics and analysis of the traffic management department, including driver information, traffic management personnel, vehicle management information, road and environment management information, publicity and safety education and training information, etc. The data sources are from the road traffic safety and management data of the Shenzhen Traffic Police Bureau. In addition to that, some data points were set according to the needs of system dynamics simulation.

4. Simulation and result analysis of cooperative lane-changing behavior

4.1. Input data for simulation

According to the data of road traffic safety and management of Shenzhen Traffic Police Bureau and the data obtained from the survey data of driver's lane-changing behavior, initial results of level variables after standardization treatment are as follows, with no dimension: ($D_L, I_{SML}, R_L, D_C, C_{IPL}, I_{SCT}, R_{BL}, D_L, R_{RL}, D_{RL}$)=(0.78,0.67,0.89,0.50,0.69,0.51,0.34,0.85,0.58,0.79). With the help of AMOS software, the influence index of each factor on cooperative lane-changing behavior is ($R_{IC}, C_{IC}, D_{IC}, E_{IC}$)= (0.075, 0.385, 0.465, 0.075), with no dimension. Simulation unit is set to monthly; a simulation step is set to half a month.

4.2. Output and analysis of simulation results

4.2.1. Analysis of initial simulation results

The initial simulation analysis of factors affecting cooperative behavior is shown in Figure 4 below.

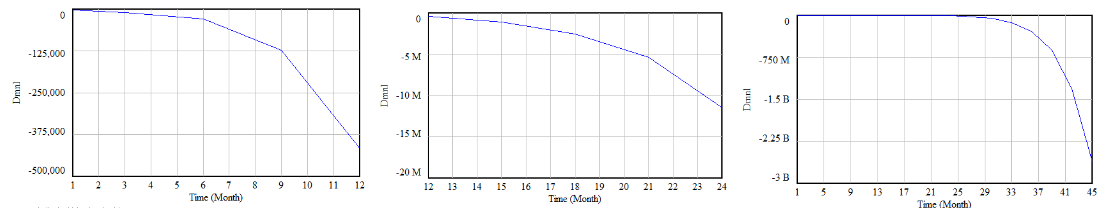

Figure 4. Phase diagram of initial simulation analysis of factors affecting non-cooperative lane-changing behavior

The results illustrate that the cooperative lane-changing behavior showed a downward trend and phased change, from a slow decline to an accelerated decline. Under the condition of simulation, the change of behavior character appears near T = 24 months, which is the turning point of the effect of driving safety concept training.

4.2.2. Simulation result comparison analysis

This paper makes a horizontal comparison of the changing values of cooperative behavior among driver's performance level, the speed of response to driving safety publicity, safety inspection, the ability of trainers to learn, the strength of law enforcement, number of inspectors studying vehicle inspection and the strength of optimizing the allocation of resources. The comparison method is set to decrease one percentage point for each factor in the same dimension, while other variables remain unchanged for simulation analysis.

From the analysis results of Fig. 5, it is concluded that under the same decrement of 0.1, the long-term effect of cooperative lane-changing behavior is obviously influenced by the number of vehicle inspectors. The reason is that this variable directly affects the scope and density of geographical supervision of vehicle cooperative behavior. In addition to that, in the deterrent range and intensity of traffic safety law enforcement and the number of vehicle inspectors who punish the non-cooperative lane-changing behavior, this factor has a more decreasing effect on the norms of cooperative behavior. The influence factors such as the decreasing of law enforcement intensity, training staff's learning ability and driver's quality have different degrees of decreasing effect on cooperative lane-changing behavior.

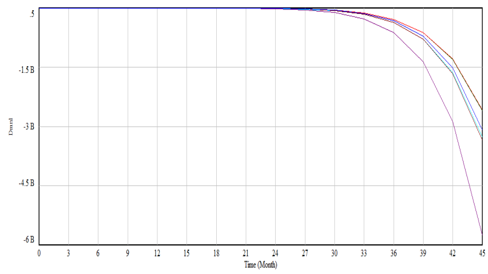

Figure 5. Summary of All Simulation Results

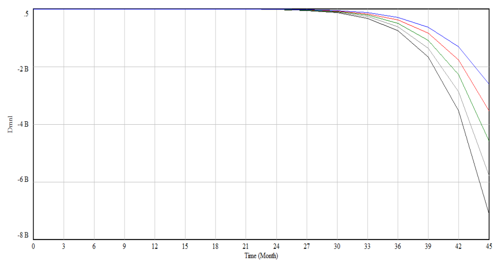

Figure 6. A longitudinal comparison Diagram between Decreasing Number of Personnel Studying Vehicle Inspection and Initial Value on Cooperative Lane-changing Behavior

Changing the figure of the independent factors in different degree. Figure 6 is a longitudinal comparison diagram between the changing value and initial value of the number of personnel studying vehicle inspection. The initial number of learners is 2550. The number of learning inspectors is decreased by 50 people per month, while the other factors remain unchanged, the simulation analysis is carried out. The simulation results show that the decrease in the number of personnel studying vehicle inspection has a long-term significant reduction in cooperative lane-changing behavior after 24 months.

Similarly, simulate a longitudinal comparison diagram of the decreasing of driver's quality and cooperative lane-changing behavior. Research can draw a conclusion similar to that in Figure 6. However, the impacts caused by the decreasing number of personnel studying vehicle inspection is 1.9 times higher than that caused by the quality of drivers in under the same condition. That is to say, the decreasing number of personnel studying vehicle inspection is worse than that of road users, and the effect is more obvious in the same time span.

Figure 7 is a longitudinal comparison of the effects of different learning abilities of personnel studying vehicle inspection on cooperative behavior. The learning ability decreases with the decrement of 0.1 spans per step, while other factors remain unchanged, the simulation analysis is carried out. Since 9 months, the decrease of this factor from 1 to 0.5 has a long-term significant reduction effect on cooperative lane-changing behavior; when the decrease of learning ability is 0.5, the reduction of cooperative lane-changing behavior will no longer continue to increase. At this time, the diagram shows a stable value, the reduction of cooperative lane-changing behavior reached its maximum value. Therefore, when the decrement is 0.5, it is the relative optimal point of behavior and investment on personnel training. This factor plays a significant role between the reducing of the cooperative behavior and personnel's learning ability in the short and long term.

Figure 7. A Longitudinal Comparison of the Effects of Different Learning Abilities of Trainers on Cooperative Lane-changing Behavior

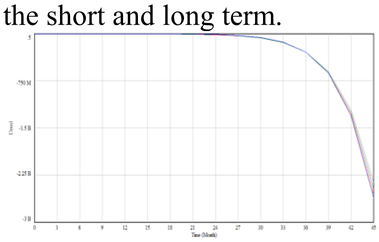

Figure 8. A Longitudinal Comparison between Different Value and Initial Value of Law Enforcement on Cooperative Lane-Changing Behavior

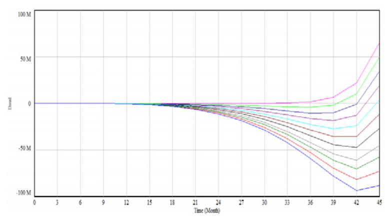

Figure 9. Longitudinal Comparison of the Influence of the rate of Enforcement timely on Cooperative Lane-changing Behavior

Figure 8. shows a longitudinal comparison between different decreasing value and the initial value of law enforcement intensity. Penalty intensity decreases with a decrement of 0.1 per step, while other factors remain unchanged, simulation analysis is carried out. The simulation results overlap basically, and the data show that the long-term changing effect of law enforcement on cooperative lane-changing behavior is not obvious.

Figure 9. is a longitudinal comparison of the effect of the rate of enforcement timely. The rate of law enforcement timely decreases by a decrement of 0.1 per step and the range of value is [0-1]. When other factors remain unchanged, simulation analysis is carried out. In the period of 1-18 months, the impact of the different rate of enforcement timely on cooperative lane-changing behavior is basically the same. From 18 months, the degree of influence of different value factors began to emerge gradually. There are three main trends.

In the first case, when the value of the variable is 0.8-1.0, the cooperative lane-changing behavior tends to increase significantly after it remains basically flat for a period of time. When T = 45 months, the simulation results are larger than the initial value of the cooperative lane-changing behavior figure, which has an increasing effect on cooperative lane-changing behavior.

The second case is that when the value is 0.6-0.7, the cooperative lane-changing behavior is flat in the initial stage, then decreases to a certain extent, and then increases significantly. The simulation results at T=45 months are larger than the initial value of the cooperative lane-changing behavior figure, and the influence on cooperative lane-changing behavior is not significant.

The third case is that when the value is 0.0-0.5, the cooperative lane-changing behavior is flat in the initial stage, then decreases significantly, and then increases gradually. The simulation results at T = 45 months are smaller than the original cooperative lane-changing behavior figure, which has a significant reduction effect on cooperative lane-changing behavior.

5. Conclusion

1) Cooperative lane-changing behavior system has nonlinear dynamic system characteristics. The initial scheme of the system has a negative effect on cooperative lane-changing behavior and shows a reduction effect.

2) Comparing the different influencing factors in the system horizontally, the influence of them on cooperative lane-changing behavior have different shape distribution characteristics from time span, space span, and influence degree span.

3) According to changing the value of each factor in the system, we find that there are obvious differences in the onset time of each factor. In the degree of impacts, the changing between stages is obvious.

4) The factors within the system have different effects on cooperative lane-changing behavior. Law enforcement intensity and other factors do not have a significant impact on this behavior. The rate of law enforcement timely has three stages for cooperative lane-changing behavior, which has an obvious and periodic impact on the scope of the span of this behavior. The decrements of the number of personnel studying vehicle inspection and the learning ability of them have a long-term reduction effect on cooperative lane-changing behavior; however, the effectiveness of decreasing the learning ability of learners has a maximum limit.

5) To improve the probability of cooperative lane-changing behavior, it is necessary to optimize the management plan according to the specific characteristics of each factor, investment effect and long-term and short-term safety driving management needs.

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