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Human Driver Model and Driver Decision Making for Intersection Driving

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Abstract— **In this paper, a general architecture of human driver model at intersections is proposed. One of the key modules in the architecture, driver decision making module, is discussed in details under various traffic scenarios. Process flow diagrams that are built in the decision making module for various decision making processes at both unsignalized and signalized intersections are also presented. This human driver model can be used not only for simulating human driver response, but also for autonomous vehicle's decision making in the intersection area. A left-turning scenario at an unsignalized intersection was simulated by applying the proposed driver decision process flow diagram. Driver's behavior was mimicked and safe vehicle operations were demonstrated.**

I. Introduction

The studies of human factors have attracted the attention of researchers in the development of intelligent transportation systems (ITS), because there is an increasing need in the real world for human-centered design and control, such as vehicles design, traffic flows management, driver assistance systems development and even highway and urban road geometry design. Furthermore, it is desired to integrate a comprehensive, quantitative human driver model with automation into micro level simulation tools for traffic simulation and performance evaluation at traffic level, because, humans not only bring a number of truly admirably skills for driving targets that most artificial intelligent technology can not accurately simulate, they also help to improve driving safety and driving learning. Consequently, human driver behavior need to be carefully studied [1], [2]. In this paper, we construct a human driver model and examine the driver behaviors at both signalized and unsignalized intersections.

The remainder of this paper is organized as follows. After a brief literature review, description of the general driver model at intersections is given in Section II. Section III presents detailed decision making process flow diagrams on how driver makes decisions at intersections under different scenarios, which compose key parts of the proposed architecture. In section IV, results of a left-turning scenario simulation using the driver decision process flow diagram are presented. Finally, Section V concludes the paper.

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II. Human Driver Model at Intersection

A. Brief Literature Review on Human Driver Model

Since 1960s, human driver model has attracted the attention of researchers in transportation studies. Descriptive model, which provides straightforward ideas of human driver under different kinds of scenarios, was initially developed [3], [4]. However, it does not provide enough information for the reproduction and prediction of human behavior. Moreover, those descriptive language of human driver's behavioral data, like most behavioral data for many real world tasks, are multimodal, continuous, noisy and even confusing.

Risk-based human driver models [5], [6], [7] combine driver's motivation, experience etc. with risk perception, acceptation etc. together and focus on driver's psychological thinking process. This type of models is also used for driver assistance systems' design and development.

The cognitive human driver model has attracted researchers' attention for several years. The essential quality of the cognitive human driver model focuses on human drivers' psychological activities during the driving. The difference between behavioral model and cognitive is: behavioral model is a kind of descriptive model that people know what drivers will do but do not know why. Cognitive model on the other hand can help to develop understanding of driver behaviors. COSMODRIVE (Cognitive Simulation Model of the Driver) model was developed at French Institute for Transportation Research [8].

PATH researchers extended and organized the COSMODRIVE framework for the purpose of driver modeling in their SmartAHS. The model allowed simultaneous simulations of vehicles controlled by drivers and semi-automated systems for comparisons. Driver's knowledge database and the cognitive process underlying the driving activity contributes to the cognitive approaches [2], [9], [10].

B. Human Driver Model at Intersection

In our studies, we first present a general architecture of the human driver model as shown in Fig. 1.This model is based on the structure of COSMODRIVE [8], [2], [9], [10], a well-known framework developed for the application of a driver cognitive model, as mentioned in Section II-A. The model consists of seven modules, which can be divided into two groups from external and internal view of the driver. Environment module is the external group, while all other modules are in the internal group.

- **Environment Module:** The environment module represents the outside world of the vehicle. It takes

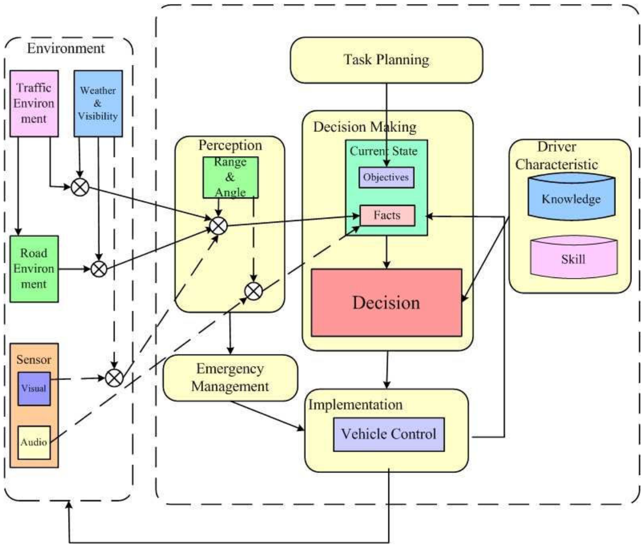

Fig. 1. General Architecture of Human Driver Model

traffic environment (traffic flow, traffic composition, etc.), road environment(speed limit, lane numbers, etc.), and weather/visibility (sunny/rainy/windy, good/poor, etc.)into accounts. Additional sensors, such as camera/LIDAR may also provide the driver with necessary visual data of the environment. Once a driver-assistance system is available, the system assistant message will also be served as a complement to the environment (e.g. beep collision warnings).

- **Perception Module:** The perception module represents the visual and audio sense. The data generated by the perception module includes estimation of velocity, direction, distance between vehicles, etc. in range and angle. In a microscopic traffic simulator, when considering the changes of visibility for the drivers, we can simply adjust the parameters of "Range" and "Angle" according to the situation in the perception module. In real world, "Range" and "Angle" are based on the driving environment, for example, blizzard weather leads to short range and small angle.
- **Task Planning Module:** The task panning module provides the decision making module with information on which direction the vehicle is going, such as N→S, S→E.
- **Driver Characteristics Module:** The essential function of driver characteristics module is to predict human driver's psychological activities based on his/her knowledge, which contains both driving knowledge based and traffic rule based information, and his/her driving skill, which indicates his/her ability of driving (novice/expert). It changes as the subject driver changes.
- **Decision Making Module:** The decision making module is the most important part of the driver model. It acts as a higher level controller for the vehicle. The tasking planning module provides strategy, while the decision making module develops tactics. The decision is made based on the perceptive information, its itinerary from task planning module, the driver's own characteristics along with vehicle's current state. Details of decision making module will be discussed in Section III using process flow diagram.
- **Implementation Module:** The implementation module is responsible for the two dimensional control of the vehicle based on the information it receives from the decision making module.
- **Emergency Management Module:** The emergency management module deals with unexpected/irregular emergency, such as other vehicle's traffic violation, obstacle avoidance.

III. Driver Decision Making

In this section we will expand the driver decision making module and develop a series of process flow diagrams to represent the driver decisions.

A. Intersection Area

The intersection area is redefined as shown in Fig. 2. The vehicle enters the intersection when d is less than L_1, in other words, the intersection area is $2L_1 \times 2L_1$. d is the distance from the mass point of the vehicle to the center o of the intersection. L_1 is determined by the environment (traffic flow on the lane, speed limit, etc.). L_1 has to be long enough to enable the vehicle to change to the correct lane before it is L_2 away from the center. One choice of L_1 is presented as in Fig. 3.

L_2 is the distance indicating from where the vehicle should decelerate to its turning speed and prepare for turning. L_2 is also determined by the environment (speed limit, road condition, etc.) and the vehicle deceleration limit. L_2 needs to be large enough to ensure not only the desired turning speed but also a safe stop without entering the conflict area (the red dashed rectangle in case of emergency in Fig. 2). A larger L_2 is not efficient as the slow-down procedure will affect all the following vehicles, while a smaller L_2 may not meet the safety requirement. One choice of L_2 is presented as in Fig. 3. An analytical expression can be developed as

$$L_1 = F(f,v) = L_2 + \alpha(f) \cdot T_L \cdot v \quad (1)$$

$$L_2 = F(v,a,a_{max}) \quad (2)$$

$$= \frac{v^2-(\beta v)^2}{2a} + \frac{(\beta v)^2}{2a_{max}} + S + S_m \quad (3)$$

where $\alpha(f)$ is a coefficient function indicating the severity of the traffic flow (low, medium, heavy traffic) based on the traffic flow rate and the LOS (level of service) of the intersection. T_L is the time required for completing a lane change. v can be either the speed limit or current average velocity. β is the road condition coefficient for determining the desired turning speed, a is the regular deceleration rate, and a_{max} is the deceleration limit and S_m is the safety margin with respect to the average waiting before turning. Note that L_1 is a constant for all the vehicles that entering the intersection within a short period if the environment does not change much, but L_2 may be varied from vehicle to vehicle.

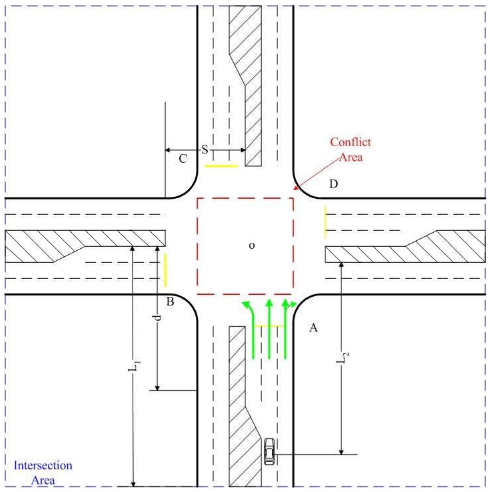

Fig. 2. Intersection Area

B. Pre-conditions

No matter which direction the vehicle will turn to (left, right or keep straight), there must exist no other vehicle in the conflict area. Furthermore, the car-following condition should always be simultaneously satisfied, i.e. the minimum safety distance between the vehicle and the last vehicle on the target lane has to be retained. We define condition 1 (C1) to be:

C1: Conflict area is cleared and minimum safety distance is kept.

C. Priority

Priority is introduced to establish efficiency and solve deadlock problems that may occur at the intersection. Priority is assigned to vehicles based on their position, anticipated movement, time, etc.

- **Unsignalized case (Stop Sign):**Priority levels are designated (highest to lowest): Go Straight (without stop sign), Right Turn (without stop sign), Left Turn (without stop sign), Go Straight (with stop sign), Right Turn (with stop sign), Left Turn (with stop sign)
- **Signalized case:**Priority levels are designated (highest to lowest): Go Straight, Right Turn, Left Turn

If the vehicles are of the equal priority according to the above criterion, the earlier arrival has higher priority; if vehicles happen to arrive at the same time, then the rightmost vehicle deserves the highest priority; if four vehicles with the same priority from four directions arriving at the same time and one is another's rightmost vehicle, some window mechanics have to be introduced, random amount of time is added to each vehicle and the one with smallest time has the highest priority.

D. Driver Decision Making at Intersections

Here we discuss driver decision making based on different scenarios and driving goals (left turning/go straight/right turning). At this stage, we will not consider the skill-based (Expert/Novice) driver characteristics but conservative, obeying traffic rule drivers. For simplicity, we define Go 1: Go Straight; Go 2: Make the Right Turn; Go 3: Make the Left Turn; Stop 1: Decelerate to its desired velocity and prepare for turning; Stop 2: Decelerate to stop; Stop 3: Emergency stop.

1) Unsignalized Intersection:

- **Right Turn:** The process flow diagram of vehicle that performs a right turning at an unsignalized intersection is presented in Fig. 3. Considering a vehicle entering the intersection from point A as shown in Fig. 2, it has to make sure that no coming vehicles from B enter its target lane during the right turning procedure. Therefore, we define condition 2 (C2) to be:
  C2: No go-straight-vehicle from B in D_2 m. The calculation of D_2 highly depends on the speed limit,traffic flow rate,current velocity, the main idea of computing this kind of limits is that vehicles will not arrive in the target lane within a short period.
  We also assume that there are stop signs in at least one direction. Obstacle emergency service will be checked during the entire traveling. Traffic sign violation will be also checked when the distance between the vehicle and the center of the intersection is L_2 less.
- **Go Straight:** Fig. 4 shows the process flow diagram of the vehicle that goes straight at the intersection. In this case, both left turning vehicles from B and right turning vehicles from D bring the potential danger to the traveling vehicle. Thus, we define condition 3 (C3) as:
  C3: No right-turning vehicle for the target lane in D_3 m.
  C4: No left-turning vehicle for the target lane in D_4 m. The calculation for D_3 and D_4 are similarly as D_2.
- **Left Turn:**Fig. 5 shows the process flow diagram of the vehicle that performs a left turning at the intersection. Left turning is more complicated, as not only the vehicles from B and D, but also the vehicles from C have to be considered. Thus, we define condition 5 (C5) as
  C5: No go-straight vehicle from C for the target lane in D_5 m.
  We also define condition6 (C6) as
  C6: No right-turning vehicle from C for the target lane in D_6 m.

2) Signalized Intersection:

- **Right Turn:**The process flow diagram of vehicle that performs a right turning at signalized intersection is shown in Fig. 6.
- **Go Straight:** Fig. 7 shows the process flow diagram of the vehicle that goes straight at the signalized intersection. Besides traffic violation and obstacle emergency,

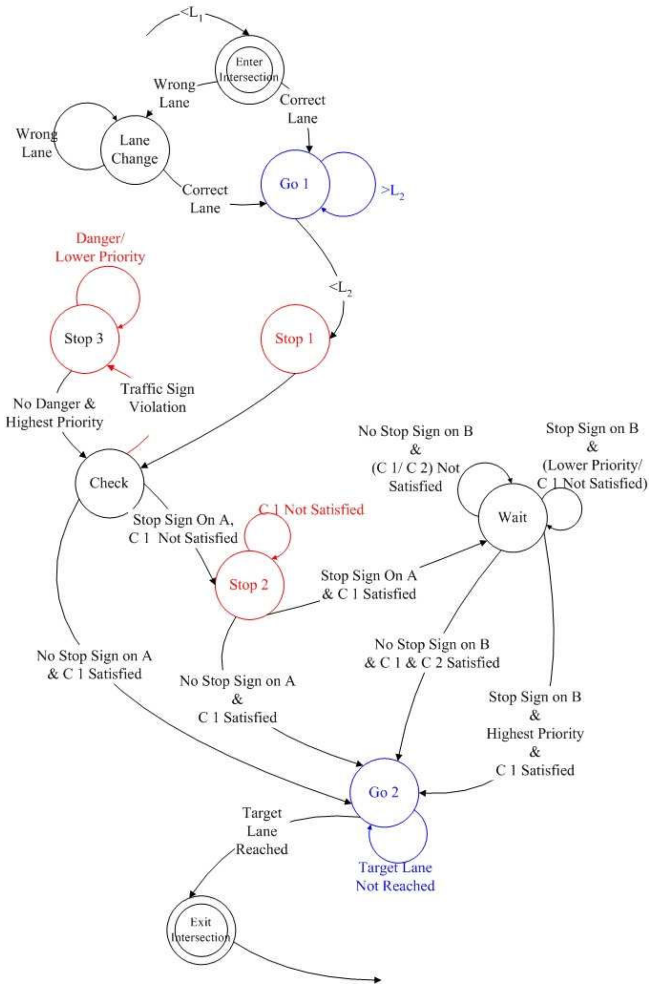

Fig. 3. Process Flow Diagram of Right Turn at Unsignalized Intersection

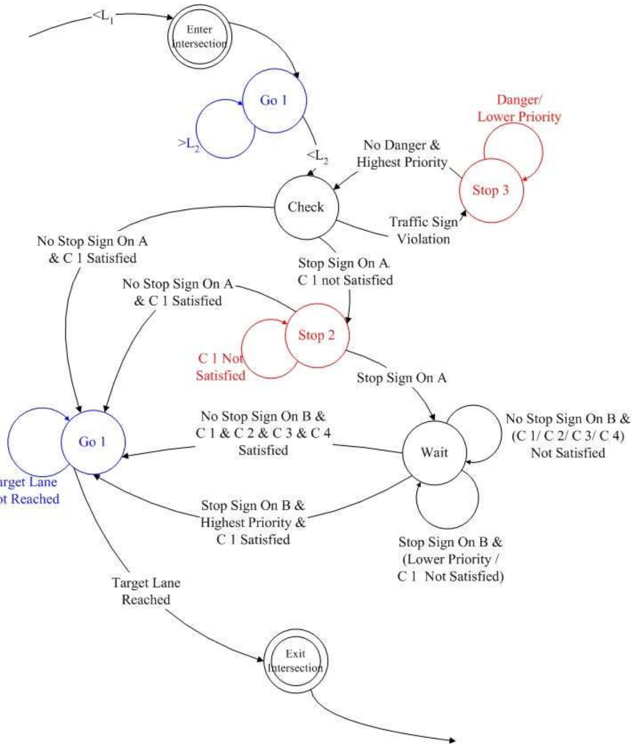

Fig. 4. Process Flow Diagram of Go Straight at Unsignalized Intersection

TABLE I
SIMULATION PARAMETERS

Speed Limit	35 miles/hour
Traffic Flow	3600 vehicles/hour
Deceleration Limit	$-0.31g$
Acceleration Limit	$0.2g$
Vehicle length	$9.14m$
Vehicle width	$2.59m$

yellow phase makes the situation more complicated. During the yellow phase, a vehicle may neither be able to complete the passing the intersection nor make a safe stop (vehicle is in the dilemma zone [11]). In Fig. 7, conservative driver is considered which the above case may never happen as the driver will try to stop at very beginning if C1 is not satisfied during the yellow phase. However in case that the vehicle is in the dilemma zone, go-straight vehicle will try to accelerate and pass the intersection, as it should maintain a high speed.

- **Left Turn:** Fig. 8 shows the process flow diagram of the vehicle that performs a left turning at the intersection. Considering a left-turning vehicle that is in the dilemma zone, as its speed is already reduced, we assume that it will try to make an emergency stop.

IV. Simulation Results

The driver decision making process flow diagrams that were discussed in Section III are applied for simulating a left turn scenario at an unsignalized intersection using a microscopic simulator. The simulated intersection area is the same as Fig. 2

In this study, visibility is assumed to be good, the driver is able to estimate the speed and position of other vehicles in 50 m range with an angle of $-\frac{\pi}{2}$ to $\frac{\pi}{2}$ radians. The lane change model developed in [12] is used as the lateral lane change model. A simple single time-constant, delayed driver response model as mentioned in [13] is assumed as the driver time delay model. The subject vehicle moves from south to west.

Fig. 9 shows the position trajectory of the left-turning vehicle starting from its entering into intersection to its arrival of the target lane. Fig. 10 shows the velocity and acceleration on the x and y axis of the subject vehicle. The first drop from 0 in the velocity along the x-axis indicates the lane change of the subject vehicle. From time point of 13 sec to 24 sec, both the velocity along the x-axis and the y-axis are zero, which indicates the subject vehicle is waiting for clearance of the conflict area. Only after the proposed condition C1, C5, and C6 are satisfied, the subject vehicle speeds up from zero and makes the left-turning. The velocity along the y-axis first increases and then decreases, as the vehicle makes a turn until the vehicle successfully

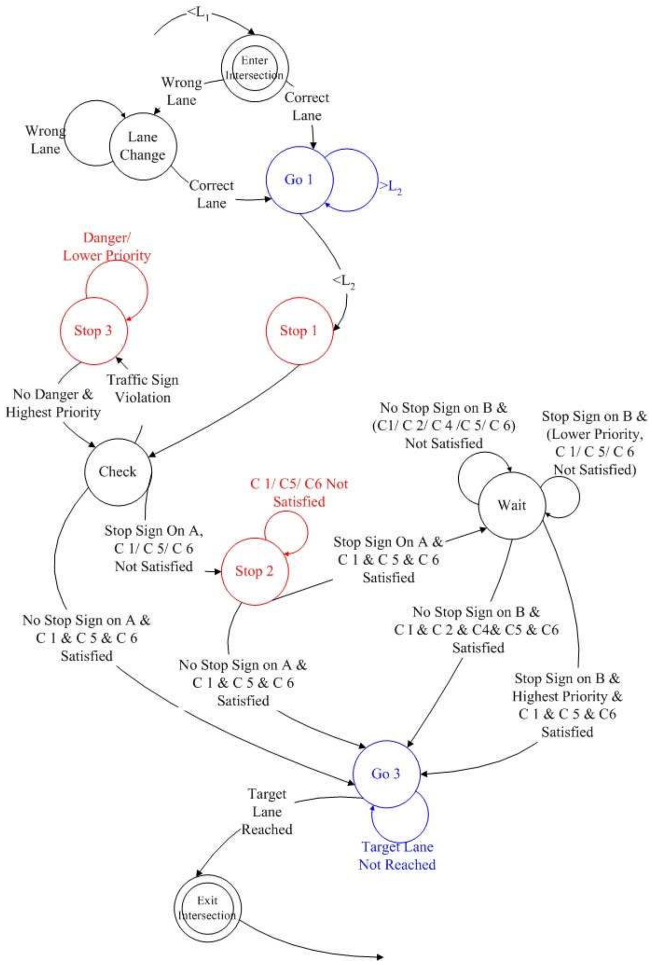

Fig. 5. Process Flow Diagram of Left Turn at Unsignalized Intersection

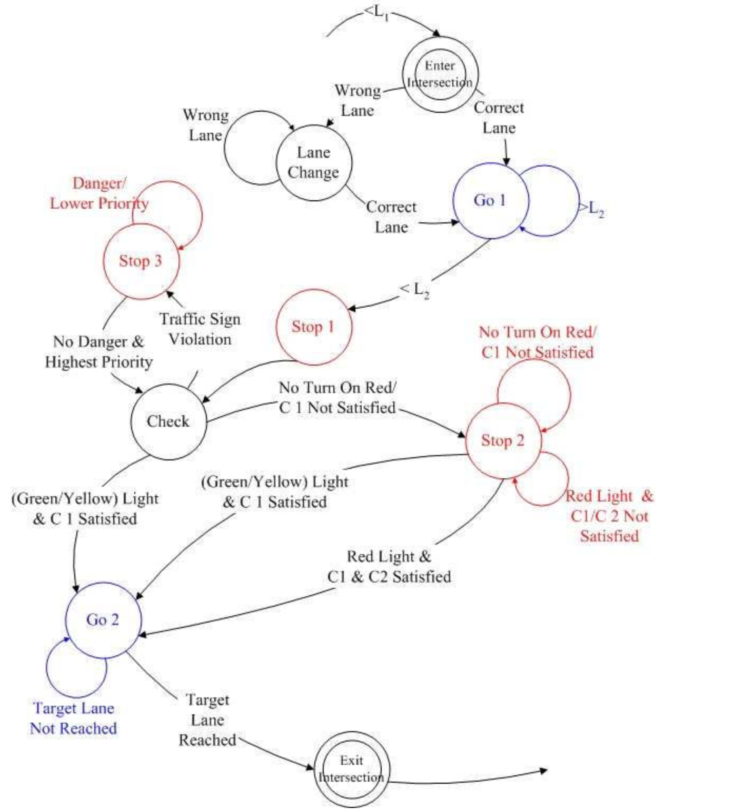

Fig. 6. Process Flow Diagram of Right Turn at Signalized Intersection

arrives the target lane, the velocity along the y-axis becomes zero with acceleration of zero. Simultaneously, the velocity along x-axis increases. Note that trajectories of both velocity and acceleration in Fig. 10 is smooth. Also note that the acceleration is far below the physical limits which indicates that comfortability is also obtained. The simulation also shows that safety is ensured if the decision making strategy is applied by autonomous vehicle.

V. CONCLUSIONS

A general architecture of driver model at intersections is presented. Details on driver decision making in various scenarios are discussed with process flow diagram presented. The developed model, especially the driver decision making procedure, is implemented into a microscopic simulator for simulating a typical left-turning scenario at an unsignalized intersection. Simulation results show safe vehicle operations and mimicked human driver behavior with reasonable velocity and acceleration within certain bounds and constraints. The proposed architecture of driver model may be used in autonomous vehicle for decision making, or in microscopic simulator for human driver response modeling. It should be mentioned that this study is based on rather simple

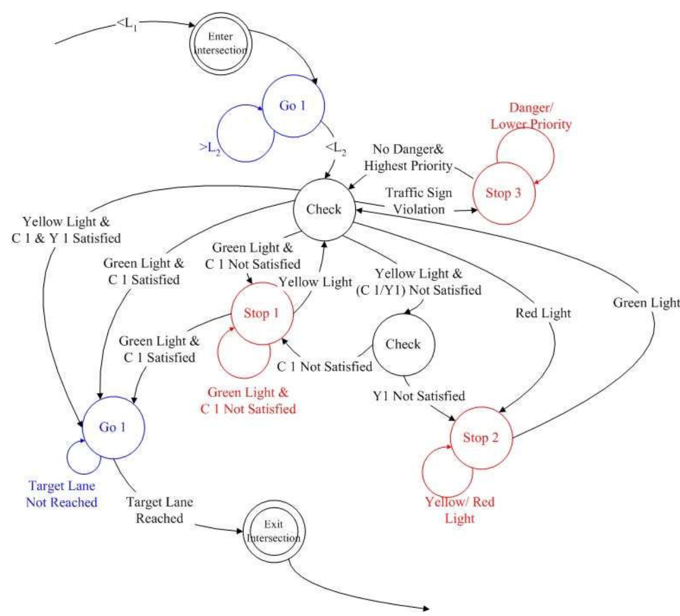

Fig. 7. Process Flow Diagram of Go Straight at Signalized Intersection

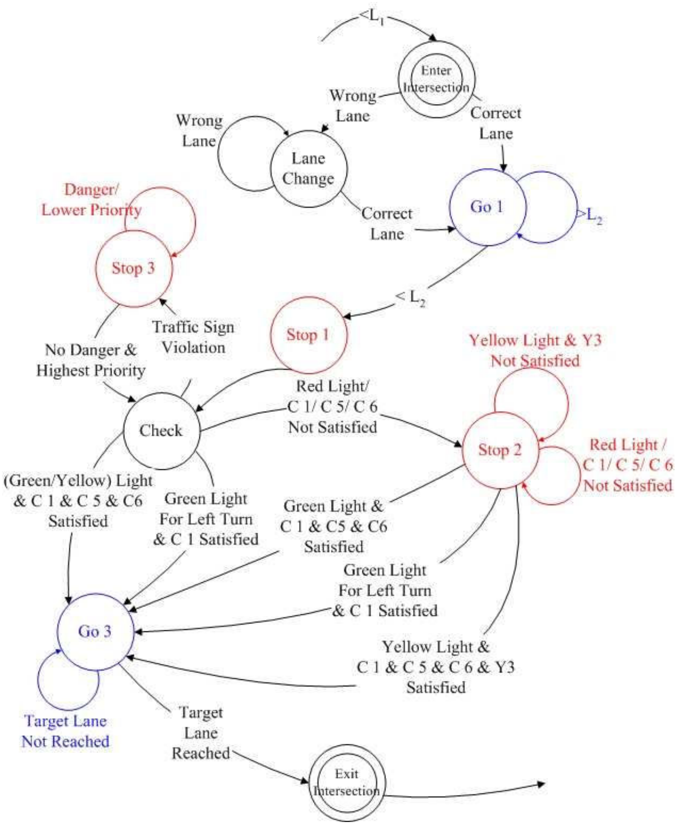

Fig. 8. Process Flow Diagram of Left Turn at Signalized Intersection

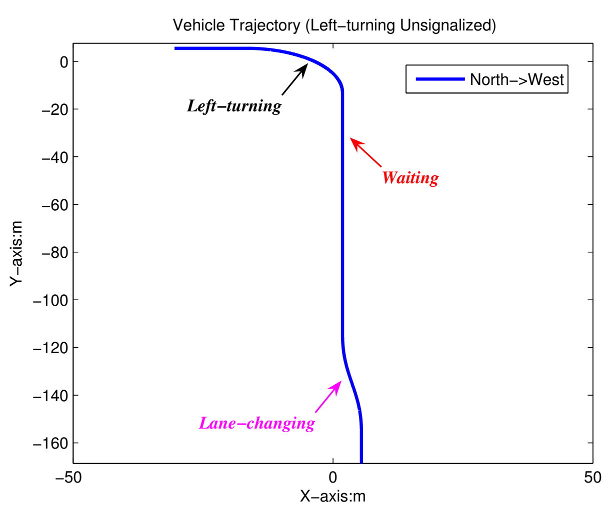

Fig. 9. Position Trajectory of A Left-turning Vehicle at An Unsignalized Intersection

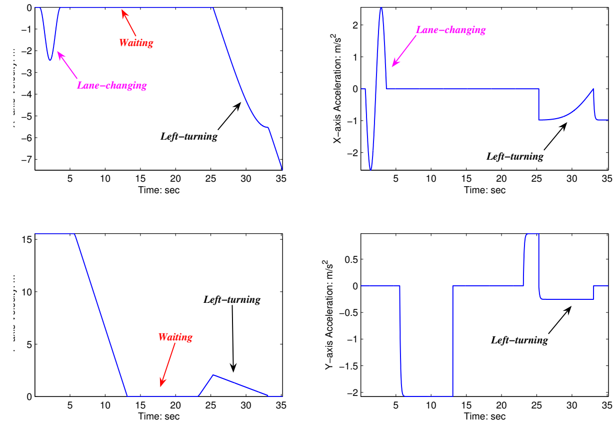

Fig. 10. Velocity and Acceleration of A Left-turning Vehicle at An Unsignalized Intersection

assumptions for driver characteristics module, more study with complicated assumptions will be conducted in the future since it is crucial to the driver model.

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