LANE CHANGING MODEL WITH EARLY COMMUNICATION OF INTENTIONS

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Abstract: This paper describes the modeling and simulation of traffic flow with lane changing based on inter-vehicle communications. We regard vehicles as autonomous agents, and construct a simple traffic model in which some agents change lanes. We propose a new method for an agent to change lanes in which it tells the neighboring agents its intention beforehand, shares information with them, and determines the lane change time in cooperation with the other agents. The result of simulating this model showed that the early communication of intentions is effective in avoiding traffic jams and supporting smooth transportation.

1 INTRODUCTION

Research into alleviating traffic jams and smoothing traffic flow is receiving increased attention due to the advances in Global Positioning System (GPS) devices and car navigation systems.

One reason for traffic jams and collisions is a lack of understanding between vehicles, meaning that one vehicle does not know what other vehicles intend to do. In this research, we focus on lane changing in which mutual understanding and cooperation is essential.

Lane changing occurs frequently on roads with multiple lanes, crossings, or highway entrances and exits, and changing lanes smoothly becomes more difficult if the road is congested. Signal flashers are one method of indicating lane-changing intention explicitly, but they are not always easily noticed on a congested road. This results in aggressive lane changing or vehicles making mutual concessions to lose a good timing.

In the field of intelligent transportation systems (ITS), research on intelligent driving with inter-vehicle communication using traffic simulation tools has been a topic of some interest (Kato et al., 2002; Ammoun et al., 2007; Kanaris et al., 2001). The aim of such research is safe driving without traffic accidents, and the mechanism for cooperation and interaction between vehicles is generally not considered.

In the field of artificial intelligence (AI), several traffic models that consider vehicles as agents have been proposed, but few of them examine lane changing with communication. Ehlert and Rothkranz modeled a vehicle using an agent that determines its behavior reactively based on the environment, but no communication occurs between agents (Ehlert and Rothkrantz, 2001). Dresner and Stone developed a model in which vehicles as well as intersections are modeled as agents that communicate with each other (Dresner and Stone, 2005).

Nagel and Schreckenberg proposed the cell automaton model, which simulates traffic flow (Nagel and Schrechenberg, 1992). Since then, many studies have used cell automatons to model traffic flows that include lane changing (Su et al., 2005; Jin et al., 1999; Knospe et al., 1999). The main goal of this series of works was to create a traffic model that simulates a realistic traffic flow, not to model the cooperation and interaction between agents.

Changing lanes is usually performed as follows: finding a gap of sufficient size between vehicles in the target lane, activating the appropriate signal flasher, and changing lanes. Gipps analyzed the procedure of lane changing and proposed a basic model (Gipps, 1986). According to Gipps, lane changes occur for several reasons:

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- the physical possibility of safely changing lanes without an unacceptable risk of collision
- the location of permanent obstructions
- the presence of special-purpose lanes such as transit lanes
- the driver's intended turning direction
- the presence of heavy vehicles
- the possibility of gaining a speed advantage

Hidas showed that Gipps's model is not applicable on congested roads, and proposed a new one. He noted that lane changing is either a cooperative or a forced maneuver on congested roads (Hidas, 2002). He assumed inter-vehicle communication, and showed that the results of a simulation based on his model coincided with observed traffic data (Hidas, 2005).

Inter-vehicle communication related to lane changing (i.e., the indication of the intent to change lanes), however, occurs immediately before the vehicle starts the lane-change action in the models proposed so far. Therefore, lane changing is unsafe and requires time when the target lane is congested. Moreover, only the cooperation of the vehicles in the target lane after the communication is considered, not the behavior of the subject vehicle before the communication. In fact, the subject vehicle may change speed to find an appropriate space to move into before actually changing lanes. In addition, when two vehicles in almost the same position in neighboring lanes wish to change lanes at the same time, deadlock will occur, and this issue is not considered so much.

Consider a specific example. A vehicle in the left lane wishes to move to the right lane, while another vehicle right next to it in the right lane wishes to move to the left lane at exactly the same time as shown in Fig. 1. This is considered to be a type of deadlock. Both vehicles might take exactly the same action, that is, seek enough space in the adjacent lane only to discover that this does not exist, then decrease speed and wait for another chance. As a result, neither vehicle may find a suitable opportunity for a long time.

Consider another situation. One vehicle intends to change lanes, and sufficient space exists in the target lane, but the vehicle ahead decelerates (Fig. 2), possibly in preparation for a lane change of its own. However, the subject vehicle does not know the reason for the deceleration and cannot judge whether it should change lanes immediately or continue at reduced speed for reasons of safety.

Consider yet one more situation. The subject vehicle intends to change lanes. As it is just about to do so, the preceding vehicle in the adjacent lane accelerates as shown in Fig. 3, and the vehicle behind it also

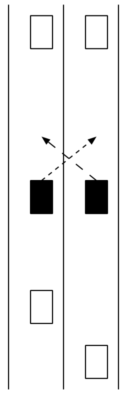

Figure 1: Deadlock case.

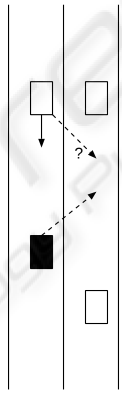

Figure 2: Indeterminate case.

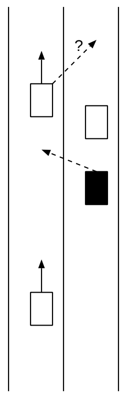

Figure 3: Blocked case.

accelerates without knowing why the vehicle ahead has sped up. This reduces the gap, and the subject vehicle loses its chance to change lanes.

All these problems occur because the vehicles do not know the reason for the actions of the others.

In this paper, we propose a model in which the intentions of vehicles are shared, not just before changing lanes, but even earlier so that both the subject vehicle and the vehicles in the target lane have sufficient time to prepare. Thus, lane change can take place smoothly at the appropriate time. The vehicles all understand the intentions of others because they share information and cooperate with each other to alleviate traffic jams and collisions.

This paper is organized as follows. In section 2, we present the basic lane-changing model without inter-vehicle communications, and in section 3, we propose the model with early communication. In section 4, we describe and evaluate the experimental results. In section 5, we compare our method with related work. Finally, in section 6, we present our conclusions.

2 BASIC MODEL

2.1 Road

A road is defined as a sector between signals that consists of two straight lanes. Each sector is divided into three zones as shown in Fig. 4: *entrance*, *middle* and *exit*. The entrance is the first zone from the start line, the exit is the final zone before the end line, and the middle is the zone in-between. Lane changing occurs only in the middle and exit zones, so that the model can reflect the effect of lane changing on the cars behind. (If lane changing were permitted to occur in the entrance zone, the start time of vehicles would be delayed, and congestion would not occur.)

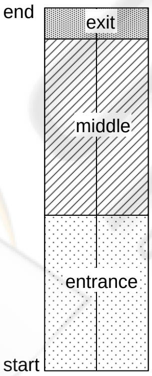

Figure 4: Road model.

2.2 Vehicle

Each vehicle is modeled as an autonomous agent that has its own intention and determines its behavior by communicating with other vehicles. The action of changing lanes affects the behavior of the other agents.

Each agent has two goals: to accomplish its own intention and to contribute to achieving the goals of the others. These goals, however, sometimes oppose each other. Even if no such opposition exists, a behavior may be good for one agent but not for the others.

The vehicles immediately ahead and behind the subject vehicle in the current lane are called the *current preceder* and the *current follower*, respectively. The vehicle just ahead and just behind the subject vehicle in the other lane are called the *new preceder* and the *new follower*, respectively, as shown in Fig. 5.

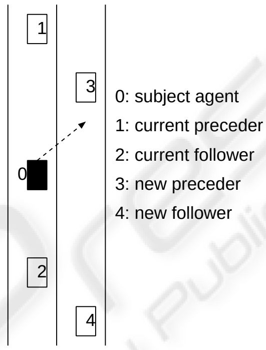

Figure 5: Agents involved in a lane change.

Each agent starts when a sufficient distance is made between it and the immediately preceding agent. It has its own goal lane, and if the goal lane is different from the initial lane, it intends to change lanes. The velocity of each agent is one of *stop*, *slow*, *normal*, and *fast*. This is determined depending on the distance from the immediate preceding agent and the distance that will avoid a collision while changing lanes.

Each agent should satisfy the following conditions.

- Sufficient distance should exist between it and the current preceder. When the current preceder stops, the subject agent decelerates gradually to stop just behind the current preceder.
- When an agent that intends to change lanes enters the middle zone and checks the environment, if sufficient distance to the new preceder and the new follower exists, it then activates its signal flasher; otherwise, it decelerates and waits for another chance to change lanes safely.
- When an agent notices the blinking signal flasher of an agent in the adjacent lane, it decelerates (Fig. 6(a)) or accelerates (Fig. 6(b)) depending on the distance between it and the current preceder and current follower. In either case, it cooperates so that the agent with the blinking signal flasher can change lanes smoothly.

- If an agent cannot find an opportunity to change lanes safely while it is in the middle zone, then the change of lanes takes place in the exit zone at the highest priority. If several agents intend to change lanes, then their lane changes are accomplished on a first come, first served basis.
- When two agents are at almost the same level in neighboring lanes, then both of them decelerate and wait for a better time to exit the state of deadlock. If such a state continues in a designated time interval, then one of them is given the priority for changing lanes.

Note that the signal flasher is not activated until safe lane changing is guaranteed.

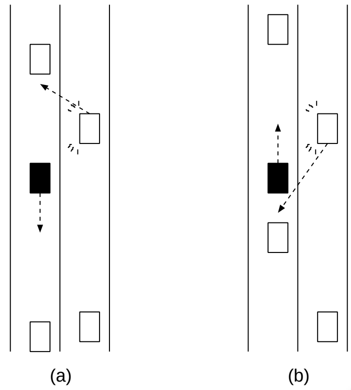

Figure 6: Behavior of the agent upon noticing a blinking signal flasher.

3 MODEL WITH EARLY COMMUNICATION OF INTENTIONS

Lane changing in the basic model has two main drawbacks. One is that an agent may miss a chance to change lanes due to the behavior of other agents. The other is the possibility of deadlock between two agents in the same position in different lanes. To eliminate these problems caused by a lack of mutual understanding, we propose a model in which agents communicate with each other to convey their intentions in advance.

We call the agent in the target lane nearest the subject agent the *partner*. The partner is either a new preceder or a new follower of the subject agent. The request message for lane changing is sent in the entrance zone. The partner replies with a message of acceptance or rejection. When the request is accepted, the agent in the target lane tries to facilitate lane changing by the subject agent. Otherwise, the subject agent itself manages to control its speed to get a chance of safe lane changing. Thus both agents cooperate. Moreover, when the partner receiving the lane change request decides to accelerate, it sends a message to its current follower to warn of a newcomer. We call this message *a newcomer notification*. It is this message that gives the reason for the acceleration. If this message were not sent, then the follower would also accelerate without knowing why the preceder was accelerating, which would leave no space for a newcomer.

The subject agent sends the lane-change request message only once. Agents do not engage in a complicated negotiation. In this model, communication of intention is performed in the entrance zone, lane changing is usually conducted in the middle zone, and final lane changing occurs in the exit zone.

We describe the protocols for changing lanes below.

The Agent that Intends to Change Lanes

1. If it does not receive a newcomer notification from its current preceder, it maintains speed and sends its request message to the partner.
2. If it receives a newcomer notification from its current preceder and if it does not receive a lane-change request from the adjacent lane, it decelerates without sending a request.
3. If it receives a newcomer notification from its current preceder and also receives a lane-change request from the adjacent lane, it decelerates and sends a request message to the partner.

The Agent Receiving the Lane-change Request

1. If it has no intention of changing lanes
   (a) If it receives a newcomer notification from its current preceder, it decelerates.
   (b) If sufficient distance exists behind the current preceder, it accelerates, sends an acceptance message to the subject agent, and also sends a newcomer notification message to its current follower.
   (c) If sufficient distance exists behind the current follower, it decelerates and sends an acceptance message to the subject agent.
   (d) Otherwise, it maintains its speed and sends a rejection message to the subject agent.
2. If it intends to change lanes
   (a) If it receives a newcomer notification from its current preceder, it maintains its speed without sending a request.
   (b) Otherwise, it decelerates without sending a request.

The Agent Receiving the Acceptance

1. It maintains the current speed and changes lanes according to the basic model when it enters the middle zone.

The Agent Receiving the Rejection

1. If sufficient distance exists behind the current preceder, it accelerates.
2. If sufficient distance exists ahead of the current follower, it decelerates.
3. Otherwise, it maintains its speed.

4 EXPERIMENT

4.1 Simulation

We implemented the model using Java and performed simulations under different conditions to demonstrate the effectiveness of early communication of intentions. Figure 7 shows a screenshot of our system.

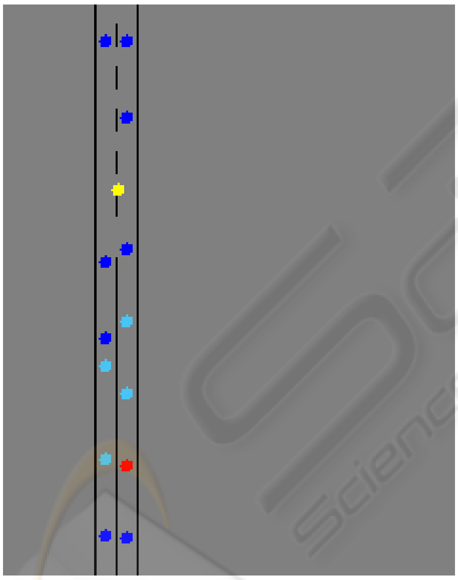

Figure 7: System screenshot.

We assume that all agents are equivalent; i.e., they are of the same size, the same performance, and exhibit behavior based on the same maneuvers. The parameters used in the simulation are shown in Table 1.

4.2 Experimental Results

We performed simulations for three data patterns. Data patterns 1 and 2 are the cases in which the agents in both lanes intend to move to adjacent lanes, where

Table 1: Parameters. (px = pixels).

length of the road	700 px
length of the entrance zone	350 px
length of the exit zone	40 px
size of the agent	10 px
smallest safe gap between agents	20 px
total number of agents	50
the times of simulation	100

the rates of the agents that change lane are 30% (data pattern 1) and 50% (data pattern 2), respectively. Data pattern 3 is the case in which only the 50% of agents in the left lane intend to move to the right lane.

We investigated how smoothly lane changing occurs depending on the existence of early communication.

Tables 2– 4 show the results. In these tables, as shown in Fig. 8, (a) is the case with no communication, (b) is the case in which the communication is performed 234–350 pixels (px) after the start line, and (c) is the case in which the communication is performed 117–234 (px) after the start line. *DL* is the number of deadlocks, and *Final* is the number of agents that change lanes in the exit zone. All the agents are ready to start when the time is zero, and each agent starts when a sufficient space is made between it and the immediately preceding agent. *Start* is the mean number of starting time (step) of all the agents and *start_SD* is its standard deviation. *Travel* is the mean number of time (steps) required for each agent to travel from the start line to the end line, and *travel_SD* denotes its standard deviation.

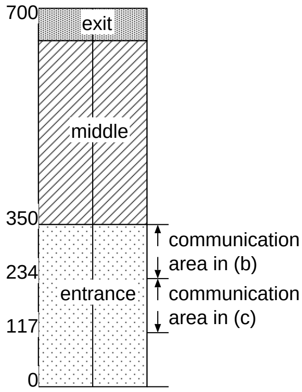

Figure 8: Areas in which communication is performed.

4.3 Evaluation

Two Goal Lanes (Data Patterns 1 and 2). We compare the result with communication (b)(c) and that without communication (a). Both the number

Table 2: Pattern1.

	DL	final	start	start_SD	travel	travel_SD
(a)	0.16	4.09	200.71	127.59	331.41	29.53
(b)	0.00	0.85	202.02	129.83	318.25	24.95
(c)	0.00	1.11	202.22	130.15	317.96	24.59

Table 3: Pattern 2.

	DL	final	start	start_SD	travel	travel_SD
(a)	0.74	8.93	212.71	141.54	405.75	65.23
(b)	0.01	1.33	217.15	149.11	365.28	45.14
(c)	0.02	1.26	213.78	146.19	362.26	47.50

of deadlocks and that of the agents finally changing lanes are smaller in the former case. Both starting delay and traveling time are smaller, and their standard deviations are also smaller in the former case. It follows that early communication is effective in achieving smooth lane changes. It is much effective in the case the rates of the agents that change lane is high.

What about the timing of communication? Comparing the results (b) and (c), there is no big difference. If communication is performed just before entering the middle zone, there may not be enough time to prepare for a smooth lane change. On the other hand, if communication is performed earlier, the situation may change after the preparation is accomplished. It is necessary to determine the timing of communication depending on the traffic situation.

One Goal Lane (Data Pattern 3). The delay of the start was large since one lane was too congested to create a sufficient gap behind the preceder. In this case, the agents starting earlier succeeded in changing lanes smoothly, while those starting later could not find a safe gap immediately and arrived at the end line rather late. That is why the standard deviations of the starting time and travelling time are larger in (b)(c). In this case, early communication is not so effective, comparing with the case of two goal lanes.

5 DISCUSSION

Numerous studies have been done on traffic control for autonomous driving, including lane changing. While most of these models assume inter-vehicle communications, these occur just before the action and do not convey the intention in advance. Moreover, the case of deadlock is not correctly modeled.

Hidas proposed a lane-changing model for congested roads (Hidas, 2002) and divided the pattern of lane changing into three, free, cooperative, and forced, insisting that the last two patterns occur on congested roads. When an agent intends to change lanes but doing so is not feasible, it then sends a *courtesy* message. In cooperative maneuvering, the subject agent waits until agents in the target lane make a space for it before changing lanes, while in the *forced* maneuver, the subject agent changes lanes even if not enough space exists; after the change, the agents following the subject agent decelerate to create a safe distance. Hidas showed the result of his evaluation when incidents occur and changing lanes is essential. The model with communication is more advantageous than the one without, both in terms of travel time and traffic flow. Later he analyzed video recordings of real traffic flow and showed that the proposed simulation model correctly represented the observed traffic pattern (Hidas, 2005).

The difference between the Hidas model and ours is in the behavior of the subject agent when lane changing is not feasible. In the Hidas model, the subject agent has a plan that is shared with the agents in the target lanes. The subject agent waits for the chance without taking any positive action. In our model, the subject agent itself changes speed. It follows that our model is more cooperative since both the subject agent and the responders cooperate to achieve the same goal. In addition, we use early communication of intentions while the Hidas model does not.

6 CONCLUSIONS

We proposed a model with early communication of intention to change lanes that creates more cooperative behavior among the agents involved. We created a simulator based on this model and showed that the model has the following characteristics:

- collision-free
- almost deadlock-free

Table 4: Pattern 3.

	DL	final	start	start_SD	travel	travel_SD
(a)	0.00	22.06	201.93	132.63	540.95	156.00
(b)	0.00	18.72	214.10	145.07	505.95	152.54
(c)	0.00	19.42	205.00	135.38	516.29	168.58

- produces a short travel time for each agent

In this paper, we put the assumption that all agents are cooperative and follow the protocol. It is because our target is an autonomous driving environment, which is considered to be an advanced form of the automated highway systems. However, it is interesting to simulate the case in which some agents do not follow the protocol as a more realistic situation.

Moreover, we plan to extend the model to cover the following cases:

- more than two lanes
- multiple sectors
- sudden arrival of a vehicle from a structure beside the road

From the theoretical point of view, we are considering a more refined model of lane changing based on the inner state of agents. The inner state of agents can be suitably modeled using the Belief-Desire-Intention (BDI) model (Wooldridge, 2000). The environment perceived by an agent and messages sent by the neighboring agents are regarded as beliefs of an agent, the request conveyed earlier is regarded as a desire, and the request just before taking the action is considered an intention. In this way, we hope to create a more refined model and simulate the agent behaviors from another perspective.

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