Intelligent Operation Support Method based on Time Change Fuzzy Sets

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Abstract— *In the present paper, an effective support method for equipment operation under a dynamic environment is proposed. The proposed method presents operation instructions that the driver should be preparing to follow in the future. Using this method, the current and future states of the surrounding environment can be considered. The time change fuzzy set, which considers the state and time, to be universe of discourse. The time change fuzzy set is used for a computer as a buildup method with expert knowledge concerning the time change in the state. Experiments to support a lane change operation were conducted using a driving simulator. The obtained results indicated that the proposed method safely supports a lane change operation, and the time lag between the instruction being given by the system and operation being performed by the driver is decreased.*

Keywords— Dynamic environment, fuzzy inference, operation support, safety, time change fuzzy sets.

1 Introduction

When a human operates equipment in a dynamic environment, in which the surrounding conditions change with time, the operator should correctly understand complex changes in the surrounding environment. In addition, the operator must judge whether an operation is appropriate within a limited time. Therefore, an equipment operation support system is necessary in order to reduce the load on the operator and to achieve safe operation.

The equipment operation support system causes a time lag between the instruction by system and the operation by the driver. This is a significant problem in a dynamic environment, into which surrounding circumstances change with time.

Fuzzy sets can quantitatively manage human subjective assessments, such as ”He is *young*,” and thought processes, such as ”IF x is *small*, THEN y is *very large*” [1, 2]. Mamdani applied fuzzy control, which is an intelligent control, experimentally to a steam engine for the first time [3]. Yasunobu achieved the selection of the control order based on a multipurpose evaluation of an expert driver using the predictive fuzzy control and applied to the automatic train operation (ATO) system [4, 5, 6]. These fuzzy sets and control methods are applied to numerous intelligent cooperative control systems based on ”fuzzy instruction” [7, 9] and a ”fuzzy target”[8]. However, in fuzzy sets, it is difficult to build in expert knowledge concerning the time change. High-performance computers that have recently been developed have enabled equipment operation support, including expert knowledge, in real time.

In the present study, we construct an effective support method for use in a dynamic environment. When operating equipment in a dynamic environment, experts perform appropriate operations by considering not only the present state but also potential future states. In the present paper, time change fuzzy sets, which considers the state and time, to be universe of discourse. Time change fuzzy sets are used to provide expert knowledge to the computer regarding the time change of the states. Time change fuzzy sets can provide a sense of time change, such as ”Speed is continuous high” and ”Temperature change to cold from hot” to a computer.

The proposed method is applied to support a lane change operation using a driving simulator.

2 Support method in a dynamic environment

In this section, an effective support method for a dynamic environment is considered. The process of the proposed system is shown in Fig. 1.

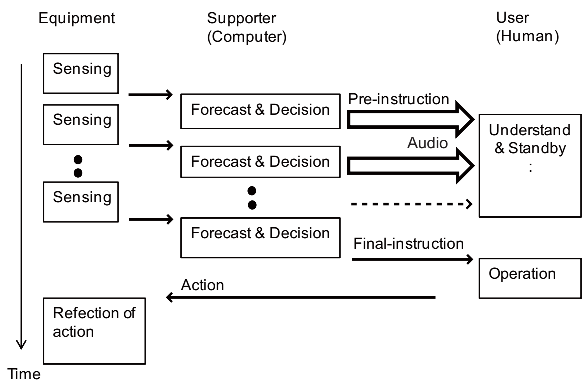

Figure 1: Process of the proposed operation support method.

The support (system) consists of 1) sensing equipment and surrounding states, 2) forecasting of future states, 3) instruction decision, and 4) presentation of instruction in advance and sending of a pre-instruction via audio. The driver (human) is 5) perceives the pre-instruction, and 6) interprets the intention of the system and waits for the final/pre-instruction. The support (system) continues 7) sensing the surrounding state and sends a final short signal. The driver (human) 8) starts an operation.

In the proposed method, the driver can confirm the operation instructions in advance. In addition, the time of 4) presentation of instruction in advance, 5) perception of instruction, 6) interpreting the intention of the system, can be sufficiently secured. The time lag can be related only to 8) operation.

The proposed method 2) forecasts future states and 3) decides pre-instruction or final-instruction, and the manner of action 2) and 3) is important.

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3 Fuzzy inference that considers future time

A computer can be made to emulate man's interpretive ability by building expert knowledge into a system using the fuzzy theory and fuzzy inference.

In a dynamic environment, an expert operates equipment by considering not only present states but also forecasting future states. It is necessary to define fuzzy sets concerning the change of states in order to build expert knowledge about the change of states and to perform inference by considering future states.

3.1 Time change fuzzy sets

In the present paper, we define a fuzzy set that changes with time. A fuzzy set to which a time axis has been added is referred to herein as a time change fuzzy set.

The total set of the state is assumed as R. The time change fuzzy set $\widetilde{X}_f n$ in state $x(t)$ of the object is defined by the following expression (1):

$$\widetilde{X}_{fn(x,p)} = \int_{R\times P} \mu_{\widetilde{X}_{fn(x,p)}}/(x,p), \quad x \in R, p \in (0,P). \tag{1}$$

Here, $\mu_{\widetilde{X}_{fn(x,p)}}$ is the membership value in universe of discourse the state x and the following time p, and P is the maximum following time.

An example of a time change fuzzy set is shown in Fig. 2. This fuzzy set describes a "change in distance from far to near". The axes of this figure indicate distance, x, the following time, p, and the membership degree of the fuzzy set μ.

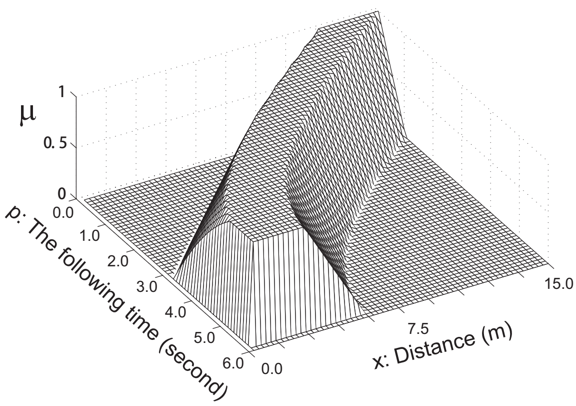

Figure 2: Example of a time change fuzzy set: change in distance from far to near.

Figure 3 shows the time change fuzzy set at $p = 0$ sec, $p = 3$ sec, and $p = 6$ sec.

Time change fuzzy sets indicate how a fuzzy set changes with time. Time change fuzzy sets can be used to build expert knowledge concerning the time change of states into a computer.

3.2 Fuzzy inference rules

Time change fuzzy sets are used to if-part and to then-part of fuzzy inference. To simplify explanation, three fuzzy rules for lane change support are described below.

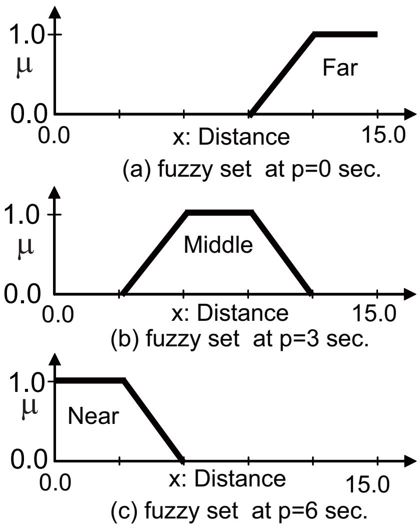

Figure 3: Time-sliced fuzzy sets of the time change fuzzy set: change in distance from far to near.

Rule 1: If forward vehicle (x) is *continuous far* and following vehicle (y) is *continuous far*, then lane change (z) is *continuous safe.*

Rule 2: If forward vehicle (x) is *continuous far* and following vehicle (y) is *change from far to near*, then lane change (z) is *change from safe to danger.*

Rule 3: If forward vehicle (x) is *change from near to far* and following vehicle (y) is *change from far to near*, then lane change (z) is *continuous middle.*

The terms x, y, and z in the above rules are defined by time change fuzzy sets, as shown in (1) . The above rules are then described as follows:

$$\text{r1: } \widetilde{X}_{1(x,p)} \quad and \quad \widetilde{Y}_{1(y,p)} \quad \Rightarrow \quad \widetilde{Z}_{1(z,p)},$$

$$\text{r2: } \widetilde{X}_{2(x,p)} \quad and \quad \widetilde{Y}_{2(y,p)} \quad \Rightarrow \quad \widetilde{Z}_{2(z,p)},$$

$$\text{r3: } \widetilde{X}_{3(x,p)} \quad and \quad \widetilde{Y}_{3(y,p)} \quad \Rightarrow \quad \widetilde{Z}_{3(z,p)}.$$

3.3 Fuzzy inference process

Figure 4 shows an example of the fuzzy inference process. The if-part is given by time change fuzzy sets $\widetilde{X}_{(x,p)}$ and $\widetilde{Y}_{(x,p)}$, and the then-part is given by time change fuzzy set $\widetilde{Z}_{(x,p)}$. These fuzzy sets are in the form of time functions, as shown in Fig. 4. The input functions $\widehat{x}_{(p)}$ and $\widehat{y}_{(p)}$ are calculated by forecasting the future states from the present states.

The degree of membership of the input value to the time change fuzzy sets $\widetilde{X}'_{i(p)}$ and $\widetilde{Y}'_{i(p)}$ as shown in (2) and (3), respectively, is calculated by minimum operation, whereby time change fuzzy sets are removed by the input value. For example, when the time change fuzzy set $\widetilde{X}_{i(x,p)}$ is removed by the input value of $\widehat{x}_{(p)}$, the section area becomes $\widetilde{X}'_{i(p)}$.

$$\widetilde{X}'_{i(p)} = \widetilde{X}_{i(x,p)} \wedge \widehat{x}_{(p)} = \widetilde{X}_{i(\widehat{x}_{(p)},p)} \quad i = 1,3, \tag{2}$$

$$\widetilde{Y}'_{i(p)} = \widetilde{Y}_{i(y,p)} \wedge \widehat{y}_{(p)} = \widetilde{Y}_{i(\widehat{y}_{(p)},p)} \quad i = 1,3. \tag{3}$$

Each rule ri is evaluated to $\widetilde{Z}'_{i(z,p)}$, as shown in (4).

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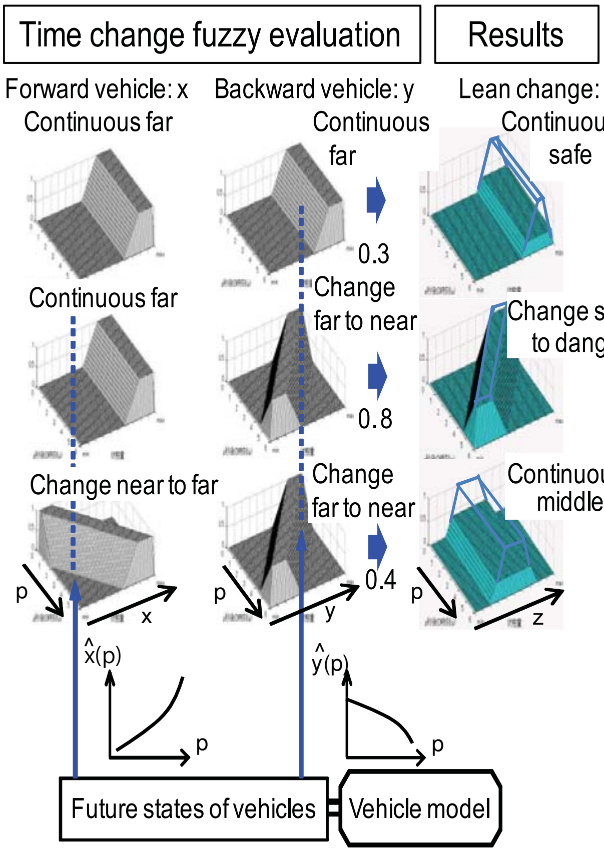


Figure 4: Fuzzy inference using time change fuzzy sets.

$$\widetilde{Z}'_{i(z,p)} = \widetilde{Z}_{i(z,p)} \wedge \widetilde{X}'_{i(p)} \wedge \widetilde{Y}'_{i(p)} \quad i = 1, 3. \tag{4}$$

3.4 *Result of fuzzy inference*

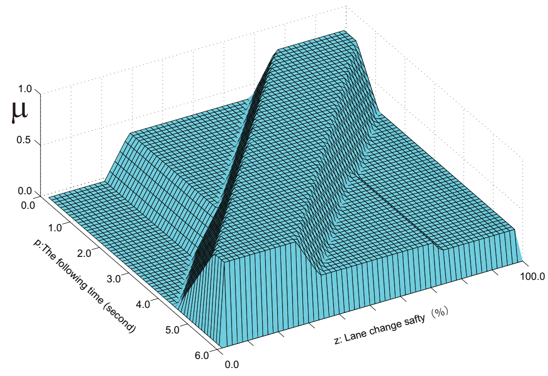
When the evaluation values of rules $\widetilde{Z}'_1$, $\widetilde{Z}'_2$, and $\widetilde{Z}'_3$ are 0.3, 0.8, and 0.4, respectively, as shown in Fig. 4, the result of fuzzy inference, i.e., $\widetilde{Z}_{ans(z,p)}$, as given by (5), is as shown in Fig. 5(a).

$$\widetilde{Z}_{ans(z,p)} = \widetilde{Z}'_{1(z,p)} \cup \widetilde{Z}'_{2(z,p)} \cup \widetilde{Z}'_{3(z,p)}. \tag{5}$$

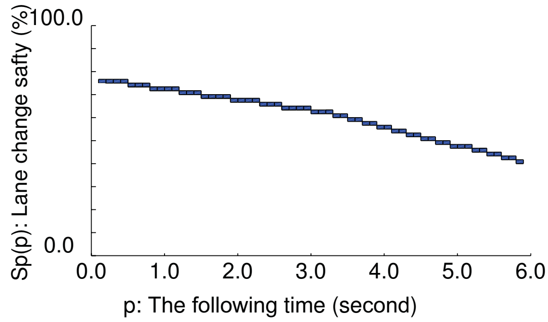
In the present study, $Sp_{(p)}$ is the lane change safety at time p obtained using the center of gravity method (defuzzification), as given by (6). Figure 5(b) shows the lane change safety at time p.

$$Sp_{(p)} = \frac{\int z \cdot \mu_{\widetilde{Z}ans(z,p)} dz}{\int \mu_{\widetilde{Z}ans(z,p)} dz} \tag{6}$$

Thus, the future output states are inferred from the future states of input, which are forecast from the present states. The system determines the operation that the driver should perform in the future based on the results of inference. The operation instruction is presented to the driver in advance, and the support method described in Section 2 is achieved. The shape of this fuzzy set looks like a type-2 fuzzy set[10]. The type-2 fuzzy set extends the membership grade to fuzzy value. Other side, this time change fuzzy set based on universe of discourse time and dynamic state, and simple membership grade from 0.0 to 1.0.



(a) Fuzzy set of lane change safety: $\widetilde{Z}_{ans}$



(b) Lane change safety at p: $Sp_{(p)}$

Figure 5: Result of fuzzy inference.

4 Application supporting a vehicle lane change

4.1 *Outline of the support system*

The support method proposed in Section 2 and fuzzy inference that considers the time change proposed in Section 3 are applied to support the lane change of a vehicle.

An expert driver can forecast the future states of other vehicles and judge intuitively whether a lane change can be performed safely.

In the present study, the knowledge of the expert driver is referred to as driving knowledge. A support system is constructed that forecasts future traffic states from present traffic states, judges whether a lane change can be performed safely and presents instructions to the driver.

It is preferable to maintain the velocity of the vehicle constant during a lane change so that the driver can operate the vehicle safely. Therefore, constant velocity is a requirement for safe lane changing. In addition, it is necessary to keep safety from the presentation of system's instruction to the operation of driver. This requirement is judged based on whether a sufficient distance between the driver's vehicle and the other vehicles will be maintained during a lane change.

The lane change support process is as follows. (a) Assume that the velocity of one's own vehicle is constant, (b) Forecast changes in the relative positions of the other vehicles, and (c) Present the instruction to change lanes if it appears that safety will be maintained.

4.2 *Forecast future states*

Other vehicles are assumed to maintain their velocities. The relative positions of the other vehicles are calculated as follows based on assumption (a) above.

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Predictive states after p seconds are as follows:

$$\widehat{x}_{(p)} = \widetilde{x}_{(t)} + v_x p \quad (7)$$
$$\widehat{y}_{(p)} = \widetilde{y}_{(t)} + v_y p, \quad (8)$$

where $\widetilde{x}_{(t)}$ and $\widetilde{y}_{(t)}$ denote the relative position of forward and backward vehicle at the present time, t, and v_x and v_y denote the relative velocity of these vehicles respectively.

4.3 Judge lane change appropriateness

In order to judge whether a lane change is possible based on the prediction of future states, expert knowledge concerning the future state of traffic is necessary. In the present study, the appropriateness of the lane change is referred to as the lane change appropriateness and is expressed as a number from 0 to 10. These numbers correspond to the following meanings: 0; dangerous(unsafe), 5; will be safe soon, and 10; safe.

Fuzzy inference is performed by using the predictive values of the relative positions of other vehicles as the input calculated in Section 4.2, and the lane change appropriateness is given as the output. The instruction to change lanes is presented to the driver based on the lane change appropriateness.

4.4 Presentation of audio instructions

In the proposed system, the driver is presented with audio instructions. The instruction is decided according to the lane change appropriateness and the change. In the present study, the instruction is output as follows.

Audio instruction:

· Present: Safety is high. Future: Safety is high.
⟶ Instruction: ”You can safely change lanes.”

· Present: Safety is high. Future: Safety is low.
⟶ Instruction: ”It's getting dangerous.”

· Present: Safety is low. Future: Safety is high.
⟶ Instruction: ”You will be able to change lanes soon.”
After a few seconds.
⟶ Instruction: ”Change lanes now.” = Go signal

· Present: Safety is low. Future: Safety is low.
⟶ Instruction: ”You can't change lanes.”

5 Driving simulator experiments

Experiments using the lane change support system are performed using proposed support method. The case in which the vehicle in the left-hand lane on a two-lane roadway enters the right-hand lane is assumed. The only vehicle in the left-hand lane is the driver's own vehicle, and two or more other vehicles are driving in the right-hand lane. Fig. 6 shows a photograph of the driving simulator. The test drivers are three men in their twenties.

The following two situations are assumed in the experiments.

Situation 1) Approach from the rear: A vehicle approaches from the rear (Fig. 7(a)).

Figure 6: Driving simulator.

Situation 2) Nearby vehicle moves away: A nearby vehicle moves away gradually (Fig. 8(a)).

First, an experiment is performed using the support method in which only the present state is considered. Then, the experiment is performed using the proposed method (Section 2) in which the future states are considered. In the proposed method, time change fuzzy sets (Section 3) are used. Audio instructions are presented as described in Section 4.4.

5.1 Situation 1: Approach from the rear

5.1.1 Results obtained by considering only the present state

The results of an experiment conducted with one test driver in Situation 1 without considering future states is shown in Fig. 7(b). In this method, in which only the present state is considered, the experimental system can only judge whether the present state is ”safe” or ”unsafe”, and the safety of future states cannot be predicted. Fig. 7(b) indicates that when the driver started to operate the steering wheel, the system reported that the state changed from safe to unsafe. In this example, the time lag between the instruction of the system and the operation by the driver caused a problem.

5.1.2 Result obtained by considering the future states

The results of an experiment conducted with one test driver in Situation 1 considering future states is shown in Fig. 7(c). As the results indicate, the experimental system did not indicate that the state became safe, and driver did not operate the steering wheel. In Situation 1, the experimental system can predict the safety of future states. In addition, the experimental system judges that indicating that the state will become safe is not appropriate considering the time of driver's perception, understanding, and operation.

5.2 Situation 2: Nearby vehicle moves away

5.2.1 Results obtained by considering only the present state

The results of an experiment conducted with one test driver in Situation 2 are shown in Fig. 8(b). This figure shows the time lag between the time at which the “safe” message is provided by the system and the time at which the driver begins to operate the steering wheel. The average of time lag of the three testers is $1.70 sec$.

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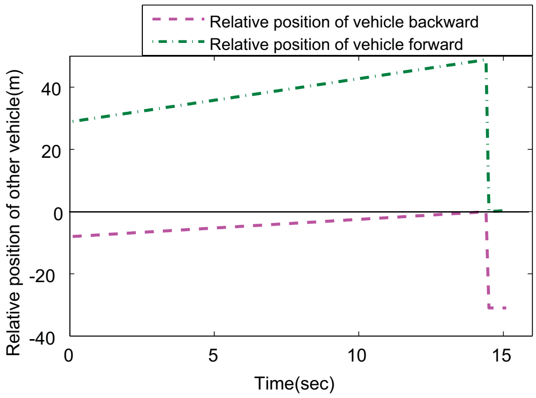
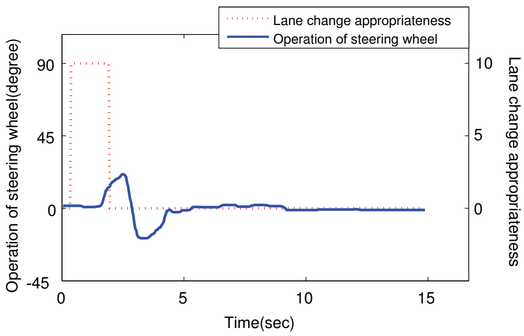
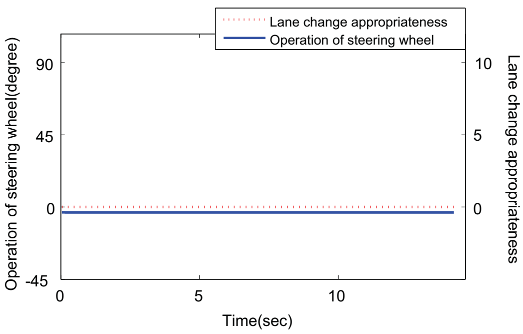


(a) Situation 1:Approach from the rear

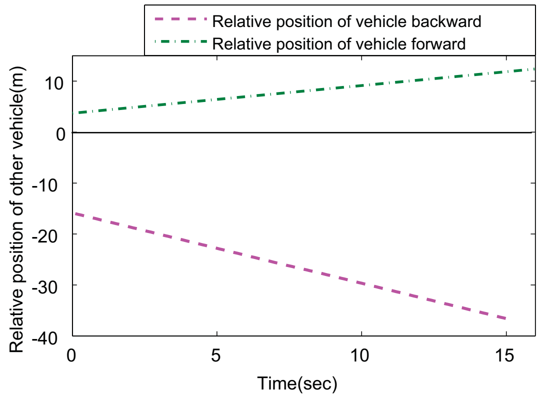


(b) Results obtained by considering only the present state: Situation 1

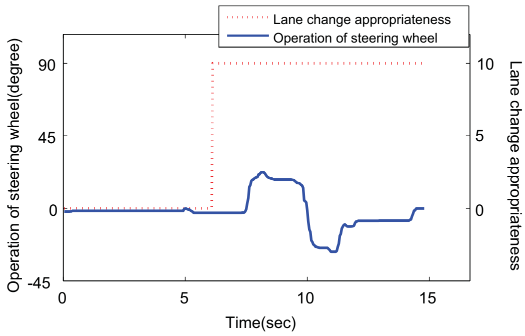


(c) Results obtained by considering future states: Situation 1

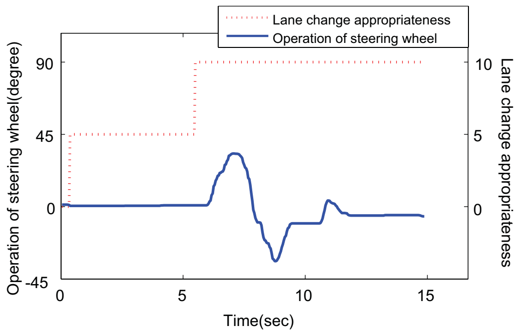
Figure 7: Experiments results obtained for Situation 1.



(a) Situation 2:Nearby vehicle moves away



(b) Results obtained by considering only the present state: Situation 2



(c) Results obtained by considering future states: Situation 2

Figure 8: Experiments results obtained for Situation 2.

5.2.2 *Results obtained by considering future states*

The results of an experiment conducted with one test driver considering future states in Situation 2 are shown in Fig.8(c). The difference from Fig. 8(b) is that the message "It will be safe to change lanes soon" is presented to the driver, because this method considers not only the present state but also predicts future states. The "safe" message is then presented at the time when system judges that it will be safe to change lanes for a while. The final signal is then presented to the driver.

In this way, the driver is presented with the knowledge that he will be able change lanes soon, and can prepare to change lanes. In addition, the time required to provide the audio instruction can be shortened by using a signal to indicate that it is safe to change lanes.

As shown in Fig. 8(c), the time lag between the time at which the " safe " message is provided by the system and the time at which the driver begins to operate the steering wheel became shorter. The average time lag of three testers is $0.63sec$.

5.3 *Discussion*

The results of the experiments reveal the following.

- In Situation 1, the proposed support system can predict danger in future states, whereas the system that considers only the present state cannot predict danger in future states.
- In Situation 2, in the proposed support system, the time lag between the time at which the system provides an instruction and the time at which the driver performs an operation is shorter than that in the system that considers only the present state.

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Therefore, the effectiveness of the proposed system as a support system for use in a dynamic environment is demonstrated.

6 Conclusions

An effective support method for use in a dynamic environment is proposed in the present paper. The proposed method forecasts future states that are calculated from present states, and the driver is provided in advance with instructions to perform various operations. In order to achieve the proposed method, time change fuzzy sets are proposed as a method of building expert knowledge concerning the time change of the states into a computer.

The proposed method was applied to a lane change support system and experiments were performed. The obtained results indicate that it is possible to achieve a safety support system that can predict danger in future states and can reduce the time lag between the system providing an instruction and the driver performing an operation. In addition, the results indicate the effectiveness of the proposed support method.

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