BASIC STUDY ON TAILORMADE BRAKING SUPPORT SYSTEM

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It is desirable for driving support systems to improve the safety of driver vehicle systems, and at the same time to have a performance that does not make individual drivers feel uncomfortable. Since human beings have various control characteristics, any system that supports driving under fixed conditions without taking such characteristics into consideration cannot be a driving support system in the true sense. The authors believe that only those systems that reflect the characteristics of individual drivers improve safety and pave the way for their widespread use, and proposal Tailormade Driving Support System (TDSS) in IATSS RESEARCH Vol. 28 No. 1. This TDSS is composed of three systems that support braking, steering and accelerating, and it gives assistance fitted to individual drivers with a driver model that uses a neural network.

This research reviewed the construction of models of a Tailormade Braking Support System (TBSS) for braking to stop vehicles and the evaluation of drivers. As a result, the following conclusions were drawn. (1) Braking factors were found to change in the period from the start of braking to stopping; (2) Changes in braking factors can be logically incorporated into the control elements of braking support system; (3) Readymade Driver Model is effective as a model to be incorporated into the base system of TBSS; (4) Tailormade Driver Model built on Neural Network is effective as a main model to construct TBSS; (5) As for TBSS, both subjective and objective ratings on the timing and magnitude of braking are favorable, and its safety and sense of security are improved.

Key Words: Tailormade, Driving Support System, Braking, Neural Network, Driver Model

1. INTRODUCTION

Driving support systems have great effects on improvement of pre-crash safety and reduction in driving loads[1-7]. However, even a system that is expected to yield effects cannot come into wide use, if drivers as users feel uncomfortable with, and puzzled about it. Human beings have a variety of personalities, and the same goes for driving. Any system that defines characteristics of human beings in the same manner without taking such variety into consideration cannot be a true driving support system. As for the construction of a system that reflects characteristics of individual drivers, the authors reported a framework of a Tailormade Driving Support System (TDSS) [8]. The effect of this system on drivers is to allow them to feel quite normal when they use the system. This system first uses a Readymade Driving Support System as a base system that has the general characteristics of drivers incorporated into it, and builds TDSS by brushing up a Readymade system, while reflecting the characteristics of daily driving by individual drivers. For information, TDSS is composed of three systems that support braking, steering and accelerating. TDSS does not necessarily cope with all scenes of traffic, but it automatically restrains even personal characteristics in situations that involve safety-impairing actions, emergency braking, etc., and the machine ensures safety. Therefore, this research covers braking under normal operating conditions.

This research focuses on braking, and evaluates a Tailormade Braking Support System (TBSS) that is built on a neural network (NN). This system first analyzed braking factors of drivers through experiments, developed a Readymade Driver Model from clustering of major control elements, and constructed TBSS that reflects the characteristics of individual drivers. In closing, the research verified the effect of TBSS on drivers through objective and subjective ratings.

2. BRAKING SUPPORT SYSTEM THAT USES BRAKING FACTORS OF DRIVERS

2.1 Braking factors of drivers in braking

For construction of a braking support system, determination of control elements has important implications. For example, control elements in case of the approach of a leading vehicle include headway distance, relative velocity, relative deceleration, etc. To date, these elements have been set by trial and error, and safe and worry-free control has been studied. Here, the input information used by drivers for braking is defined as braking factors, and the frequency of the input information

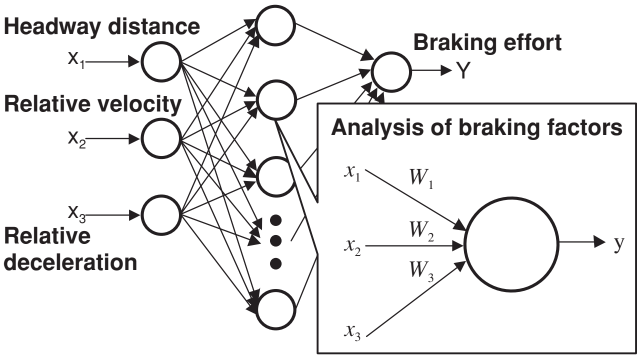

Fig. 1 Braking factors with NN

handled by drivers concerning headway distance, relative velocity and relative deceleration were prioritized. These priorities are reflected in control elements, aiming at safe control and resolution of uneasiness felt by drivers. For example, relative deceleration of higher priority is used as a braking factor in the first part of braking, relative velocity in the middle part, and the headway distance in the latter part. In this way, braking factors are changed with time in proportion to the priorities of braking factors.

Braking factors of drivers were analyzed by a factor analysis of NN[9, 10]. The factor analysis is a method to find the degree of the effect of each input on output by checking a magnitude of connection weight that is identified by NN's learning[11]. Fig. 1 shows the relationship between the input and output in a neuron model. Here, x_i is an input into a neuron, y is an output from a neuron, f is a sigmoid function, w_i is a connection weight, and b is the bias of the neuron. The calculation performed in the neuron model is shown in Expression (1). When the magnitude of each input is calculated by the ratio to all inputs, the level of influence F_i of ith input x_i on output can be expressed by Expression (2). The levels of influence of inputs including headway distance, relative velocity and relative deceleration on a braking effort as an output are calculated by applying the level of influence calculated by one neuron model to the neural network as a whole. Relative deceleration was used because the case where a leading vehicle decelerates and one's own vehicle approaches it was taken into consideration.

$$y = f\left\{\sum_{i=1}^{n}(w_i \cdot x_i + b_i / n)\right\} \quad (1)$$

$$F_i = \left|w_i \cdot x_i + b_i / n\right| \Big/ \sum_{i=1}^{n}\left|w_i \cdot x_i + b_i / n\right| \quad (2)$$

2.2 Method of experiment on braking

A driving simulator[12] that can ensure the safety of subjects and easily change experimental conditions was used for the experiment.

The experiment was conducted by setting the headway distance and deceleration of a leading vehicle as shown in Table 1. The driver drives at a speed of 27.8 m/s (100 km/h) on a highway reproduced on the screen of the driving simulator. During the drive, a leading vehicle is visible on the screen, and the driver drives behind the leading vehicle with a specified headway distance. The leading vehicle brakes after driving over a certain distance and simulator driver's vehicle approaches the leading vehicle. Then, the driver conducts his or her usual braking action. This experiment measures the headway distance, relative velocity, relative deceleration, and deceleration of the simulator driver's vehicle.

Table 1 Experimental parameters

Velocity (m/s)	27.8
Headway distance (m)	20, 40, 60, 80
Deceleration of the leading vehicle (m/s^2)	1, 2, 3, 4, 5

2.3 Analyses of braking factors

The precision of the driver model built on NN was verified by braking simulation of non-learnt data. Fig. 2 shows the simulation results. With these results, a factor analysis of this NN is conducted as NN brakes like the driver, and the priorities of braking factors are determined. Under the conditions of a 40 m headway distance and a 2 m/s^2 deceleration of the leading vehicle as shown in Fig. 2, a difference is seen in the latter part of braking. This seems to be attributable to variations in teacher signals as safety is ensured in the first part of braking and the degrees of freedom in the driver's braking are large in the latter part of braking. However, this latter part of braking does not give any sense of discomfort to the driver because it is in a state of low speed.

Fig. 3 shows the factor analysis of NN after learning, and the priorities of braking factors of the driver. Fig. 3 shows a tendency of braking factors that relative deceleration became larger in first part, relative velocity became larger in the middle part, and headway distance became larger in the latter part. So, the factor of relative deceleration tends to become large at the time of the start of braking, and then the factor of relative velocity tends to become large. The shorter the headway distance is, the larger the factor of headway distance becomes. The same tendency was found under other experimental

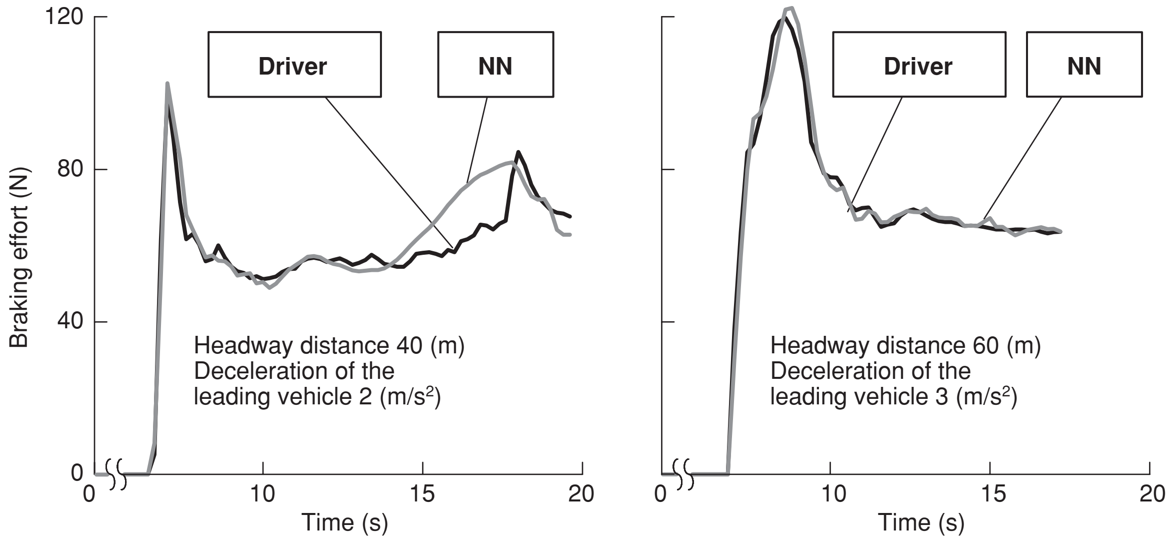

Fig. 2 Simulation of the driver's braking (Subject a)

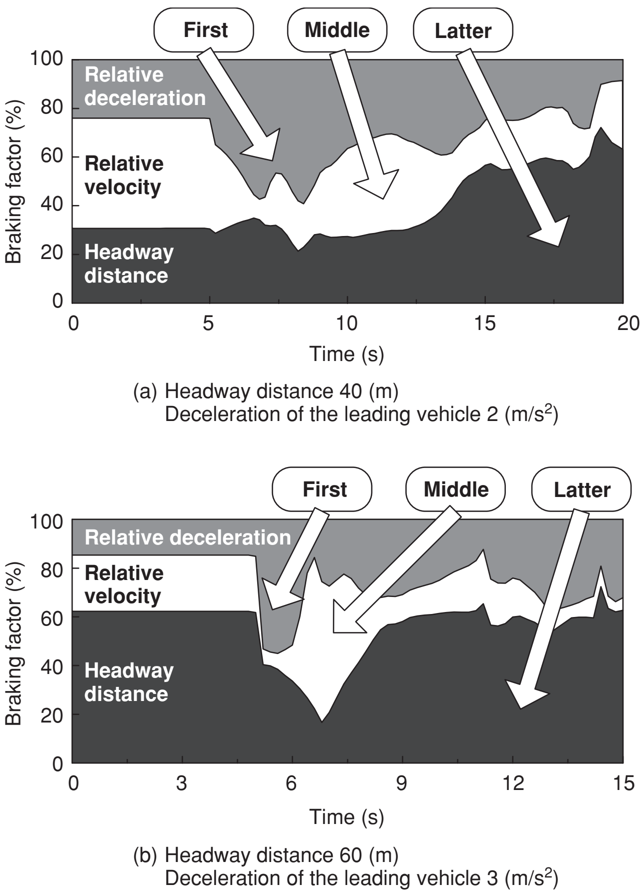

Fig. 3 Braking factors about the headway distance, the relative velocity and the relative deceleration (Subject a)

conditions and by other subjects. This shows that drivers start braking in the following sequence of braking factors, i.e., relative deceleration, relative velocity and headway distance due to the approach of a leading vehicle.

2.4 Control elements of braking support system

A braking support system sets the values of control elements based on the driver model and brakes in response to a driver. Several techniques are reported to build the Driver Model including NN[13-15], Fuzzy model[16], or Fuzzy Neural Network[17] as a combination of NN and Fuzzy model, and a technique to add physical quantities such as velocity and acceleration together with quantitative amounts such as the experience and personality of the driver up to the inputs for modeling[18]. Under this study, the Braking Support System is built by using clustering and NN. A Braking support system of clustering was constructed by two ranges, i.e., one is to brake before recognition of safety (braking range) and the other is to brake after recognition of safety (following range). The braking support system selected the values that represent control elements in each range from the priorities of braking factors. The control elements in the braking range are defined as a magnitude of maximum deceleration and rate of change in deceleration. Next, the control element that decides a change from the braking range to the following range is defined as a relative velocity. The control element in the following range is defined as a headway distance. For the timing of braking, a headway distance is used because only the visual information of the driver is applicable.

Fig. 4 shows a conceptual diagram of the braking support system. The braking support system is composed of the braking range and the following range. Braking in the braking range is divided into Braking Range AA and Braking Range BB. Braking in Braking Range BB represents the case where additional braking is required for compensation after the occurrence of maximum deceleration. Therefore, if a driver fully brakes in Braking Range AA, the system changes to the following range without causing Braking Range BB. The Readymade Driver Model classifies the control elements in each range by clustering, and sets the values of central tendency of group in the braking support system. For example, characteristics of start of braking are: I) headway distance at the time of start of braking; II) rate of change in deceleration until the vehicle reaches maximum deceleration; and III) maximum deceleration.

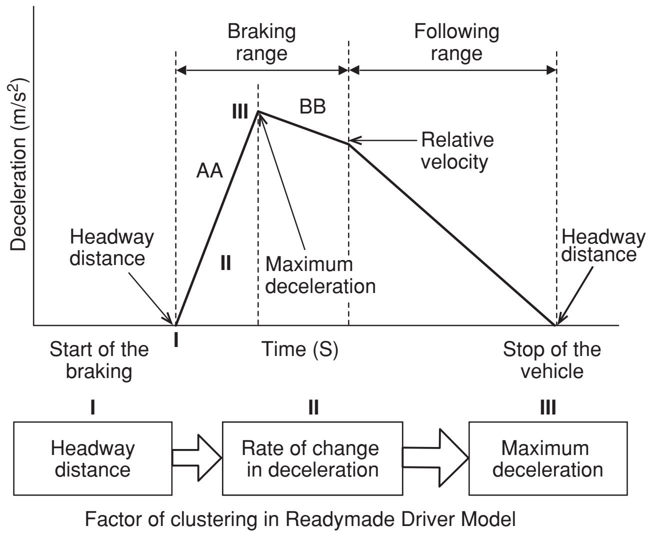

Fig. 4 Braking support system with braking factors

The expressions of velocities in Braking Range AA, Braking Range BB and the following range are shown below:

Braking Range AA

$$V = \int_0^t \alpha t dt = \frac{1}{2}\alpha t^2 + V_0 \quad (3)$$

α : The gradient of deceleration from the start of deceleration to the maximum deceleration;

V_0 : The velocity at the time of change to Braking Range AA;

t : The time after the change to Braking Range AA.

Braking Range BB

$$V' = \int_0^{t'} (\beta - \alpha t')dt' = -\frac{1}{2}\alpha t'^2 + \beta t' + V_0' \quad (4)$$

α : The gradient of deceleration after the change from the maximum deceleration to Braking Range BB;

β : The maximum deceleration;

V'_0 : The velocity at the time of change to Braking Range BB;

t' : The time after the change to Braking Range BB.

Following Range

$$V'' = \int_0^{t''} (\beta' - \alpha t'')dt'' = -\frac{1}{2}\alpha t''^2 + \beta' t'' + V_0'' \quad (5)$$

The following range has two cases, i.e., the case where Braking Range BB exists and the case where Braking Range BB does not exist.

<Case where Braking Range BB is Generated>

α : The gradient of deceleration after the change from Braking Range BB to the following range;

β' : The deceleration at the time of change to the following range;

V''_0 : The velocity at the time of change to the following range;

t'' : The time after the change to the following range.

<Case where Braking Range BB is not Generated>

α : The gradient of deceleration after the change from the maximum deceleration to the following range;

β' : The maximum deceleration;

V''_0 : The velocity at the time of change to the following range;

t'' : The time after the change to the following range.

3. DRIVER MODEL OF TBSS

3.1 Readymade Driver Model by clustering

The Readymade Driver Model classifies general characteristics of drivers into clusters, and reproduces the characteristics. The control elements subjected to clustering are a headway distance that decides the timing of braking, the maximum deceleration in the braking range, relative velocity in the following range, headway distance at the time when a vehicle stops. However, setting all control elements in the braking support system for evaluation imposes excessive loads on subjects. For this reason, the rating covered the scope from the start of braking by subjects to the following range that recognizes safety. Therefore, the relative velocity to show the timing of change to the following range and the headway distance at the time of stopping were set at the values that fit in with individual subjects. Readymade Driver Model under this research covers the timing of braking and braking in the braking range, and the control elements subjected to clustering are defined as the headway distance at the time of start of braking, rate of change in deceleration, and maximum deceleration. Fig. 5 shows the relations between the subjects and the standardized squared Euclidean distance after a cluster analysis with the Ward method. In Fig. 5, (a) represents a headway distance, (b) represents rate of change in deceleration, and (c) represents a maximum deceleration. The data use the results of the braking experiment described in Section 2.2. The number of clusters was decided by the subtractive clustering method. Fig. 5 shows the number of clusters and the representative values of each cluster. With these representative values, 18 control elements are set by the Readymade Driver Model in this research.

3.2 Tailormade Driver Model built on NN

The Tailormade Driver Model simulates characteristics of individual drivers. This research constructs the model by using the learning function of NN and having it learn characteristics of drivers. Fig. 6 shows the input and output of the Tailormade Driver Model. The input includes headway distance, relative velocity and relative deceleration, and the output is the deceleration of the simulator driver's vehicle. NN uses the deceleration caused by the driver's braking action as a teacher signal and repeatedly learns until the error from the value inferred becomes small.

The driver model built on NN was evaluated by braking simulation. This evaluation is aimed at determining that the model does not brake in a manner significantly different from braking by drivers. For the braking simulation, only the initial values of headway distance and deceleration of the leading vehicle are given, and the later braking is judged by NN. This is because braking by drivers cannot always be controlled by the same physical quantity, though the same trends are seen even under the same conditions. Therefore, NN grasps characteristics of a driver based on some data and reflect them in the model, rather than faithfully reproducing the manipulation once performed by the driver. Fig. 7 shows the changes in the headway distance between NN and the driver at Subject a and Subject g. NN braked in a manner similar to the driver, and it was found that the change in the headway distance was almost the same. As a re-

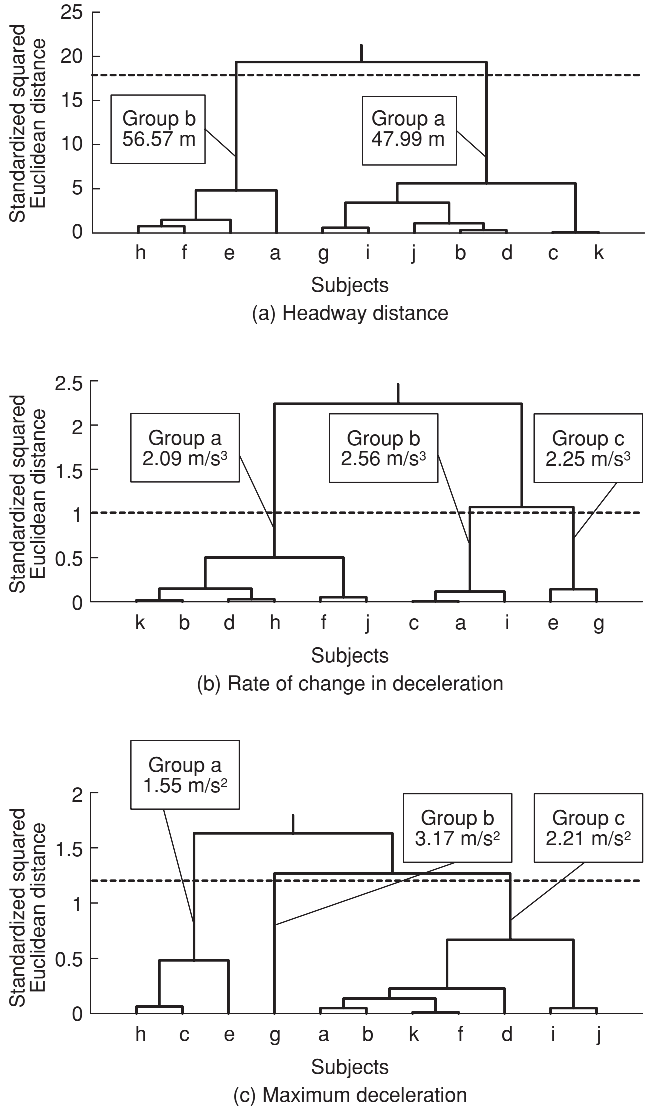

Fig. 5 Result of the cluster analysis

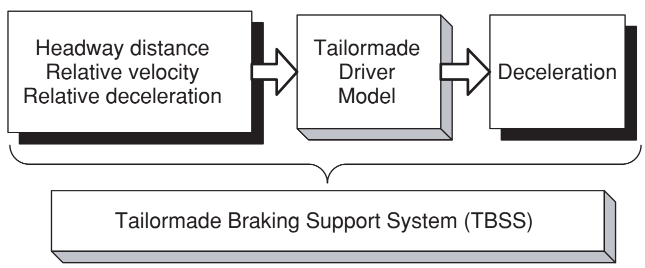

Fig. 6 Tailormade driver model of TBSS

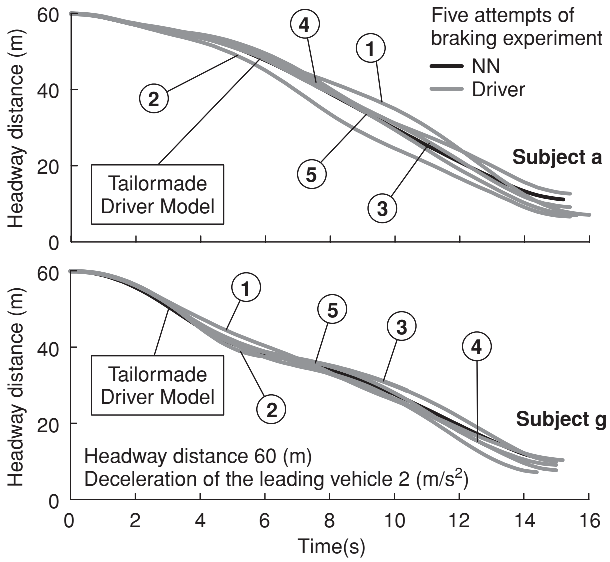

Fig. 7 Change in the headway distance between NN and the driver

sult of five attempts of braking experiments, it was found that the driver model built on NN could learn the characteristics of braking by a driver and model the driver. The changes in the headway distance at Subject a and Subject g are shown here. The same tendency was found as with other subjects. It is effective for TBSS to use this braking model as the main model.

4. EVALUATION OF TBSS

4.1 Experimental method and evaluation technique

The effect of the system was verified by using TBSS. The experiment was done by installing TBSS in a vehicle that was simulated by the driving simulator. TBSS followed a leading vehicle, and then supported braking as the simulator vehicle approaches the leading vehicle. In so doing, the driver conducted subjective ratings regarding the senses of security and safety about the "timing of braking" and "magnitude of braking and degree of approach" of the braking support. Fig. 8 shows the scale of the subjective rating of TBSS. For information, the system equipped with the Readymade Driver Model controls braking with Expressions (3), (4) and (5) mentioned above, and conducts evaluation by the same experimental method.

4.2 Results of the evaluation

In objective rating, comparisons were made in terms of headway distance and maximum deceleration at the time

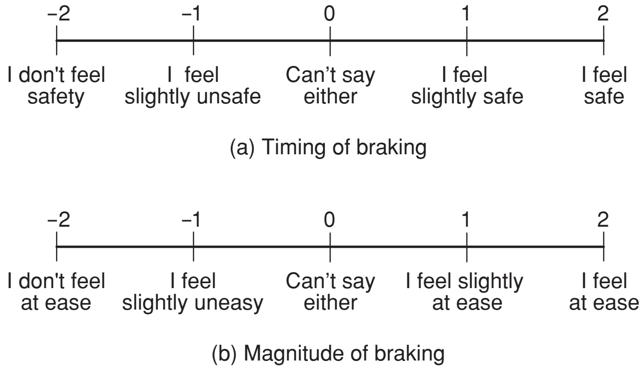

Fig. 8 Subjective rating scale about the braking support system

of start of braking. Fig. 9 show the differences between the average values of five attempts of the braking experiment and the set values of *Average*, Readymade and TBSS. *Average* represents the case where the averages of headway distance at the time of start of braking, rate of change in deceleration and maximum deceleration of all subjects are set in the system. The y-axis of Fig. 9(a) shows a larger effect of safety if the set value is larger than the average value of data on headway distance at the time of start of braking. If the set value is smaller than the average value of data on the maximum deceleration in Fig. 9(b), the effect of sense of security is large. Therefore, TBSS shows greater safety than *Average* and Readymade in the headway distance at the time of start of braking, and the same trend applies to the maximum deceleration.

Fig. 10 shows the relationship between subjects and subjective ratings regarding the headway distances at the time of start of braking, rates of change in deceleration and maximum decelerations of all subjects. In Fig. 10, (a) represents the rating of *Average*, (b) represents the rating of Readymade Driver Model, and (c) represents the rating of TBSS. When these systems are compared, the subjective rating of the Readymade Driver Model is better than that of the system that sets *Average*. However, as the ratings of Subject c and Subject i are negative, it was considered necessary to study further optimization of the system. For this purpose, it is considered effective to study the methodology to decide the number of clusters based on the quantity of sense of a human being, rather than objectively deciding it based on the distribution of data. According to the results of the subjective rating of TBSS, the subjects give a favorable evaluation to this system. Compared with the evaluations of the Readymade Driver Model, the subjective ratings of TBSS realized significant system optimization for drivers.

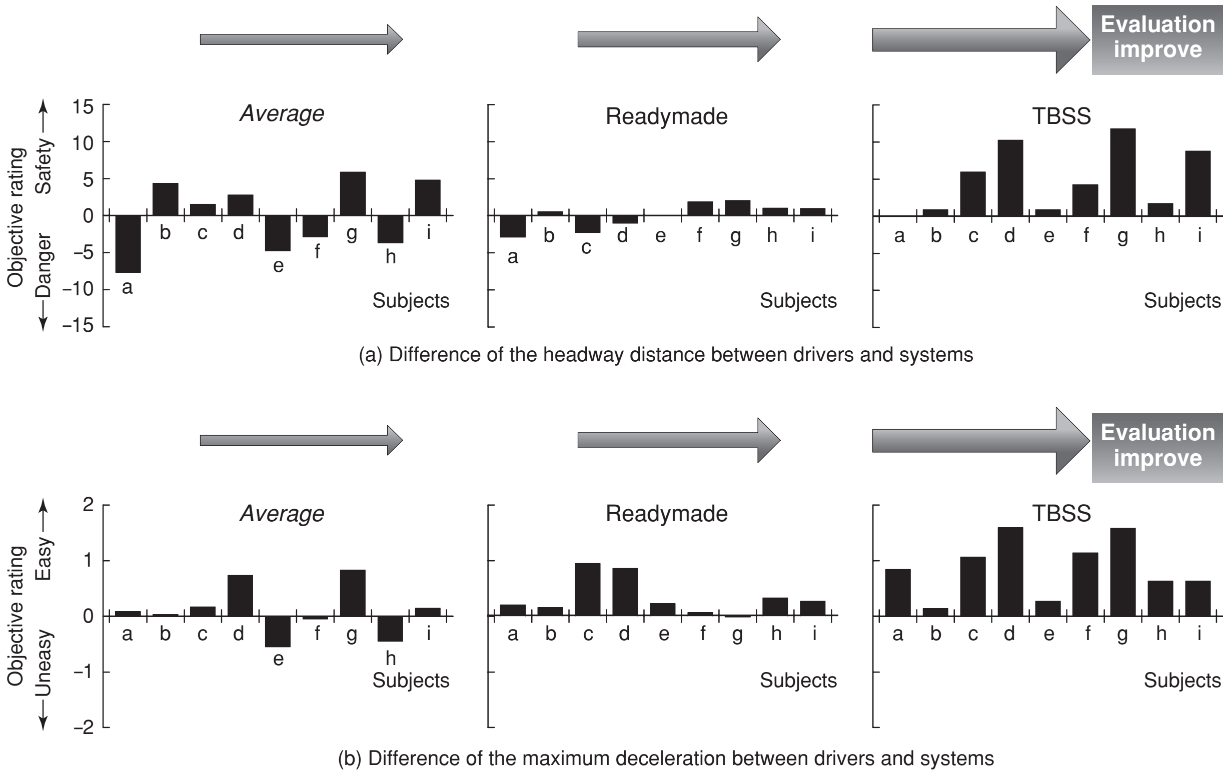

Fig. 9 Objective rating about the headway distances at the time of starting braking and the maximum deceleration

According to the objective and subjective ratings, it is assumed that the subjective ratings of TBSS are higher because its safety of the timing of braking is higher than that of *Average* and Readymade. As for the magnitude of braking, TBSS did not brake with unnecessarily vigorous deceleration because of the appropriate time of braking. It is assumed that the sense of security is improved by this point. Under this research, no results showed negative evaluations of TBSS.

4.3 Example of system operation

Fig. 11 shows a conceptual diagram that assumes a system to install a Readymade system and TDSS in a driver's license. Drivers' control characteristics learned by the Readymade system and an individual driver's control characteristics learned by TDSS are incorporated into the IC chip of the driver's license. This system can use the functions of TDSS, even if the driver changes vehicle.

5. CONCLUSION

As for the effect of driving support systems, it is important to support drivers without making them feel uncomfortable in consideration of improvement of safety and reduction in driving loads. If a driver uses an uncomfortable driving support system, the driver tends to stand ready to be supported by the system. In this case, even if the system brings driver safety, it does not give a sense of security. TDSS is aimed at satisfying individual drivers.

This research studied the construction of braking models of TBSS in TDSS and the effect of TBSS on drivers in terms of objective and subjective ratings. As a result, the following conclusions were drawn:

(1) The proportion of each braking factor for a driver varies in the period from the start of braking to stopping. In other words, "changes in braking factors" were found, i.e., drivers place importance first on the relative deceleration and second on the relative velocity in the first part of braking, and on the headway distance in the latter part of braking;
(2) The change in braking factors can be logically incorporated into the control elements of braking support system.
(3) Readymade Driver Model by clustering is an effective model to classify the attributes of drivers based on control characteristics and to be incorporated in the base system of TBSS;

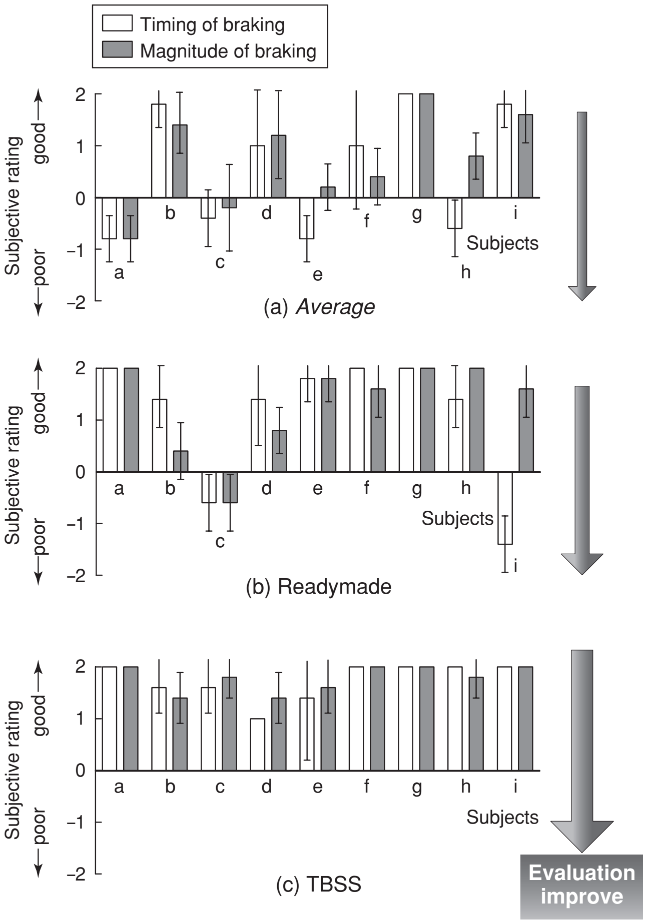

Fig. 10 Subjective rating about the timing of braking and the magnitude of braking

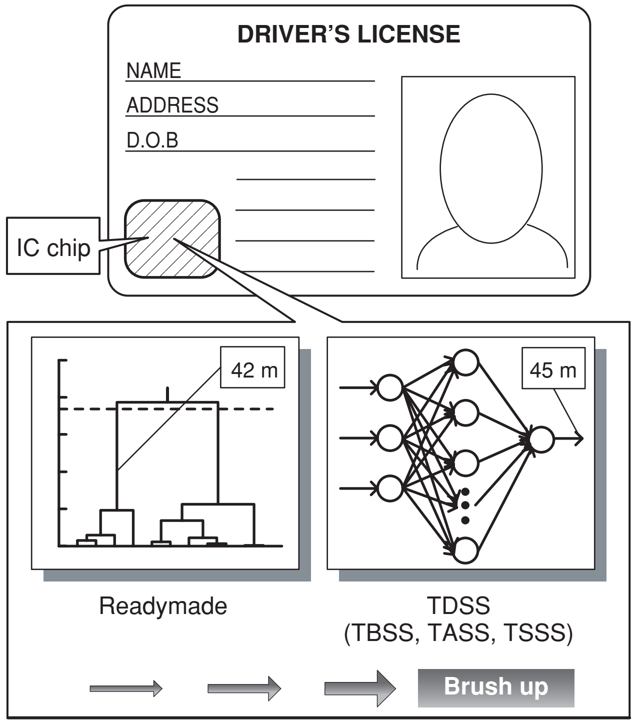

Fig. 11 Working example of the system with the driver's license

(4) As for TBSS by NN, both subjective and objective ratings on timing and magnitude of braking are favorable;
(5) TBSS is adaptable to the control characteristics of individual drivers and improves safety and the sense of security.

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