FRAMEWORK OF TAILORMADE DRIVING SUPPORT SYSTEMS AND NEURAL NETWORK DRIVER MODEL

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Drivers are positioned as the nucleus of driving helped by driving support systems of ITS. An automatic driving system in the future may release drivers partially from driving but will never release them completely. This is because automobiles are a door-to-door means of transport, and the concept of an automobile is a driver controlled vehicle system in essence. Therefore, it is desirable for driving support systems of automobiles to have a reasonable interface with a focus placed on personal characteristics of drivers. Today, various systems aimed at pre-crash safety of drivers and reduction in driving loads are being made fit for practical application. These systems have excellent mechanical functions but systems are not good enough to fit driving feelings. This is because the driver models of these systems are the same, though each driver has different driving characteristics.

Nowadays, tailormade medical treatment is receiving much attention in the field of medical care. It is also desirable for driving support systems to reflect the driving characteristics of individuals as much as possible, begin monitoring the driver when a driver starts driving and calculates the driver model, and supports them with a model that makes the driver feel quite normal. That is the construction of Tailormade Driving Support Systems (TDSS). This research proposes a concept and a framework of TDSS, and presents a driver model that uses a neural network to build the system. As for the feasibility of this system, the research selects braking as a typical constituent element, and illustrates and reviews the results of experiments and simulations.

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

1. INTRODUCTION

Human beings have a variety of personalities. The same goes for drivers, and such personalities are reflected in driving (movement) of each driver. If someone looks at bird's-eye view videos of traffic flows on expressways and in suburbia, all vehicles seem to be driving in the same manner. However, each vehicle drives on a road in a slightly different way. Even in a constant traffic flow, driving behavior of each driver has different personalities. For example, when a passenger sits in the front seat, the passenger may feel uneasy about too short a headway distance of the driver. If the driver does not press the brake pedal when someone wants the driver to do so, the passenger may step on the floor. Though the vehicle driven by such a driver is safe and does not crash into the leading vehicle, it does not give the driver a sense of relief. On the contrary, someone may feel tired about a driver who steps on the brake immediately when the stoplights of the leading vehicle light up despite an adequate headway distance, frequently repeating acceleration and deceleration. Though the difference between physical actions of such driving is not so large, these driving patterns create mental loads because of the delicate scale of evaluation of human beings.

In recent years, the research on ITS has been well under way, and driving support systems have been introduced in some vehicles, contributing to reduction in driving loads and improvement of safety, but there are many problems yet to be resolved. One of the problems is the suitability of this system to individual drivers. This means the difference between goods and products in nature.

In the field of medical care, the medical service that makes it possible to prevent and treat diseases in a manner suitable to individuals based on genetic codes, i.e., a research project aimed at tailormade medical treatment, is now under way as a result of progress of genome research. A lofty field like medical care that treats human life cannot be discussed by the same concept as that of designing automobiles, but the idea of tailormade service will be important as the basic concept of driving support systems and automatic driving in the future.

This paper proposes the framework of Tailormade Driving Support Systems (TDSS) to realize safe and comfortable driving support for individual drivers, and discusses the driver models that use neural networks to build this system. To seek the feasibility of realizing this system, this paper presents an example of results of simulator experiments on braking characteristics of drivers, and discusses how this system ought to be.

2. DEVELOPMENT OF TAILORMADE DRIVING SUPPORT SYSTEMS

2.1 Trends of Driving Support Systems

Automobiles have continued to evolve in a long history as a means of door-to-door mobility or expression of individual life styles. In addition to conventional automobile technology, nowadays, attention is also being given to new power system technology to help resolve energy and environmental issues and intelligent technology to improve safety and comfort. In the near future, these technologies are expected to become important key issues in the automobile industry[1-4].

As for ITS (Intelligent Transport Systems) in Japan, its overall concept was developed in 1996, and ITS has started entering its second phase. ASV (Advanced Safety Vehicle) that have a long history entered its third phase in 2001, and driving support systems that improve a pre-crash safety has entered a phase of practical use. HiDS (HONDA Intelligent Driver Support Systems) is a typical example, and composed of IHCC (Intelligent Highway Cruise Control) and LKAS (Lane Keep Assist System)[5, 6]. This system has superior functions to reduce driving loads of drivers and support safe driving, contributing to the construction of automatic driving systems in the future.

2.2 Concept of Tailormade Driving Support Systems

In general, it is important for new technology to have high cost performance and high social significance, and be highly evaluated by users. This trend is particularly strong in the field of safety systems that are applied to human-machine interfaces. Therefore, it is important for driving support systems to have nothing wrong with the functions to obtain the consent of individual users[7].

TDSS is one of the ways of further evolving the present driving support systems. Fig.1 is composed of Tailormade Braking Support System (TBSS) that supports braking behaviors, Tailormade Steering Support System (TSSS) that supports steering behaviors, and Tailormade Accelerating Support System (TASS) that supports accelerating behaviors. Each system controls the items listed in the figure.

Fig. 2 shows a concept of operation of TDSS. Individual drivers are clustered by a driving simulator in break down by type of drivers, i.e., readymade. Rough characteristics of driving are grasped in respect of accelerating behaviors, steering behaviors and braking behaviors. This is aimed at measuring a grounding in driving

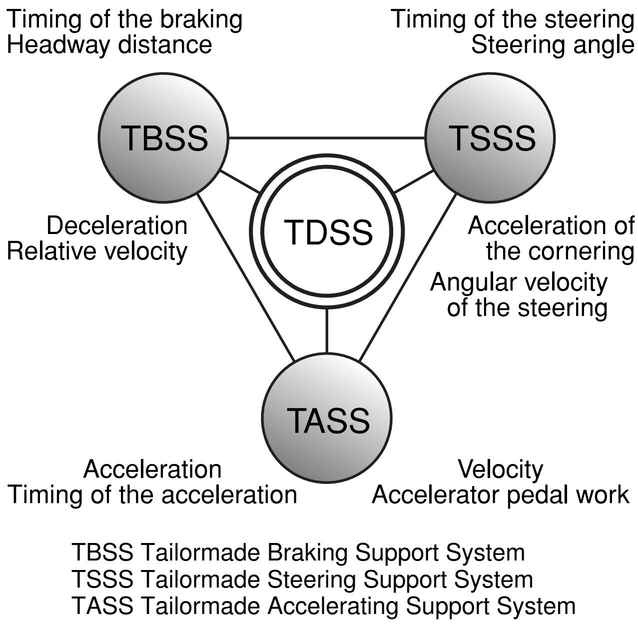
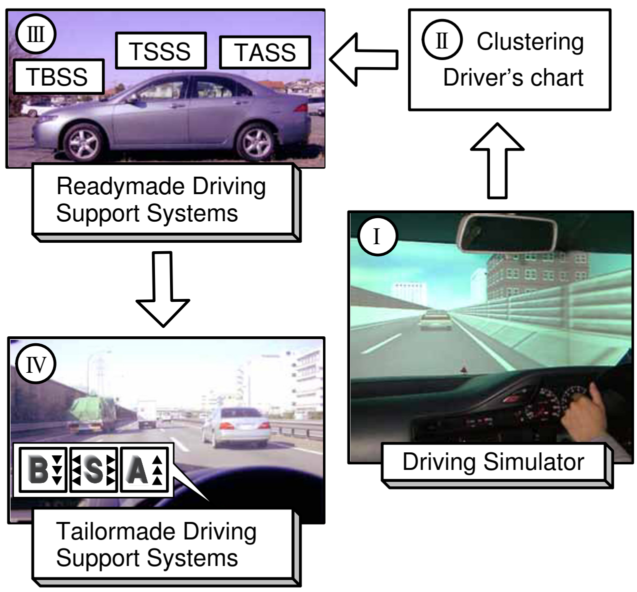


Fig. 1 Tailormade Driver Support Systems (TDSS)



I : Measuring driver's personal characteristics with Driving Simulator

II : Making the driver's chart

III : Construct of Readymade Driving Support Systems (TBSS,TSSS,TASS is carried on the vehicle)

IV : Construct of Tailormade Driving Support Systems (Driver model changes with learning the driver behavior)

Fig. 2 Working concept of TDSS

behaviors of the individual concerned, rather than providing driving education. Readymade Driver Model is developed based on this chart, this program is incorporated in a driving support system (Readymade Driving Support Systems), and a user buys this vehicle. Then, the user's routine driving behaviors are measured, and the Readymade Driver Model is brushed up, and driver models of TDSS are developed to optimize this system. As driving behaviors change with factors such as traffic conditions and aging, such factors are reflected in the support system to fit the individual concerned. From the viewpoint of driving norms, a specific scope is established to automatically restrain the behaviors that impair safety, even if such behaviors are the characteristics of the individual.

TDSS, will different from the existing driving support system, is an easy-to use system with a less uncomfortable feeling for each driver. Spread of this system is expected to have a wide range of effects on traffic including, among others, reduction in traffic accidents, improvement of safe driving by aged drivers, reduced driving load, correction of dangerous driving behavior, etc.

3. METHODS TO BUILD TAILORMADE DRIVING SUPPORT SYSTEMS

3.1 Driver Model

Fig. 3 shows a flowchart to build TDSS. The driver model is composed of Readymade Driver Model and Tailormade Driver Model.

Readymade Driver Model can roughly adapt to drivers, and it is used in an early stage before the construction of a Tailormade Driver Model. Drivers are classified by clustering into the models of "rude," "normal" and "slow." These models are closer to drivers, compared with the driver model prepared across a board scope.

Tailormade Driver Model can be applied to individual drivers. Though drivers belong to respective clusters of driving behaviors, drivers are different in clusters. Driver's levels may also change, depending on driving actions. The methods to build driver models include a fuzzy model and a neural network (NN) or a fuzzy neural network (FNN) that is the consolidation of the former two methods[8-15]. Making the most of learning function of NN, Tailormade Driver Model is brushed up and developed to a model that shows the driving characteristics of individuals. In other words, it is the same process as that of a driver who starts driving, experiences various situations and becomes skilled in driving. The model monitors how the driver controls driving in various scenes, and builds a system by learning the models that can reproduce such scenes.

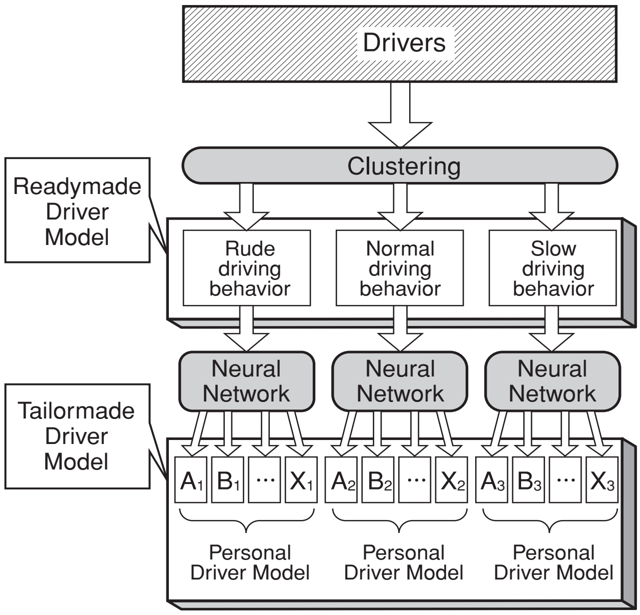


Fig. 3 Flow chart to construct TDSS

3.2 Readymade Driver Model

Readymade Driver Model classifies drivers into groups that show driver's rough characteristics, and reproduce such characteristics. For example, when braking behavior is reproduced, drivers are classified into those who start braking immediately when the stoplights of the leading vehicle light up, and those who start braking slowly while checking the state of approach to the leading vehicle. These types of drivers can be further classified into a variety of types of drivers. The same goes for acceleration and steering behavior. As the method of classification of these types of drivers, the cluster analysis method is used. For the cluster analysis, it is necessary to decide the factors of similarity. For example, the headway distance, acceleration timing, steering speed, etc., as shown in Fig. 1 are the factors. Fig. 4 shows an example of the results of cluster analysis performed based on these factors. The alphabet letters in this dendrogram represent individual drivers, and the Y axis is grouped by the line of X into Group I (A, G, E and D) and Group II (B, H, I, J, K, C and F). Fig. 4 shows the results of experiments of Readymade Driver Model described in 4.2 Readymade Driver Model in Braking. The headway distances shown in Fig. 4 are the represen-

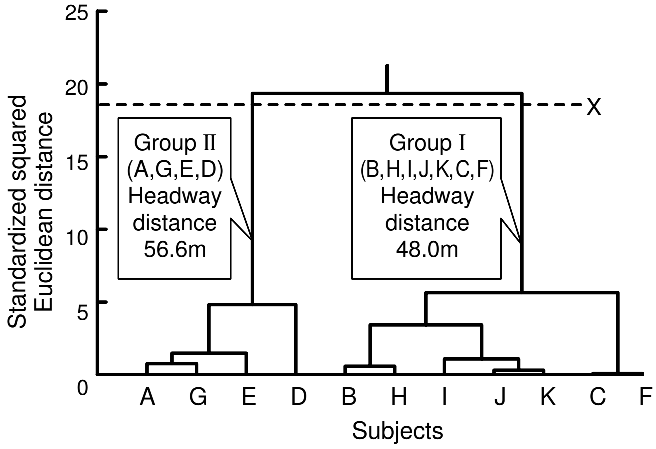


Fig. 4 Result of the cluster analysis

tative values of each group. Readymade Driver Model is composed by using the representative values of such groups.

3.3 Tailormade Driver Model

Tailormade Driver Model learns the operation of drivers and gradually adapts to individual drivers. The methods to build models include the fuzzy model, NN, FNN, etc., as mentioned earlier.

Fig. 5 shows NN composed of three layers, i.e., an input layer, a middle layer and an output layer. x_i, x_j and x_k represent inputs, y_R represents an output. For example, let us think about building the driver models of the strength of braking (braking effort) in consideration of difference of headway distances in the case where drivers control braking behavior. Here, the input is the headway distance, and the output is the braking effort as reasoning values. For the construction of this model, the reasoning values are learned to reduce an error by comparing the driver's braking effort (teacher signals), which measured in advance, and the reasoning values of braking effort. The learned NN can be handled as Tailormade Driver Model that makes the same output to input as individual drivers. An interactive support system that incorporates not only the driver's physical quantity of operation but also the driver's subjective opinions is also effective.

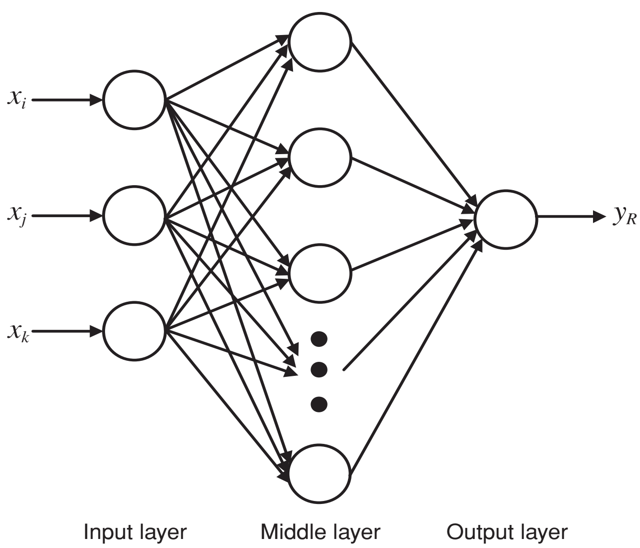


Fig. 5 Neural Network

NN used in this research made the number of the middle layer as 10 units, and the output function of units was composed of the sigmoid function shown in Equation (1). And w represents a connection weight, θ represents an offset of input.

$$f(X) = \frac{1}{1 + \exp(-X)} \quad \text{......} (1)$$

$$X = w_i x_i + w_j x_j + w_\kappa x_\kappa - \theta$$

An error E between the teacher signal y and reasoning values y_R is calculated by Equation (2). The connection weight is renewed by multiplying the learning rate α as a proportionality constant with Equation (3).

$$E = \frac{1}{2}(y - y_R)^2 \quad \text{......} (2)$$

$$\Delta w = -\alpha \frac{\partial E}{\partial w} \quad \text{......} (3)$$

4. EXAMINATION OF TAILORMADE BRAKING SUPPORT SYSTEM

4.1 Braking experiments by driving simulator

Driving experiments are conducted to obtain data on driver's braking. The experiments used a driving simulator that can ensure the safety of subjects and easily change experimental conditions. The driving simulator used in this research is shown in Fig. 6.

The experimental conditions are subject to driver's braking in the approach to a leading vehicle. This is the case where one's own vehicle brakes as it comes close to a leading vehicle due to the braking of the leading vehicle, when the one's own vehicle drives and keeps a constant headway distance between vehicles. The experiments were conducted by setting different headway distances and different decelerations of the leading vehicle. Table 1 shows the conditions set for the experiment. The drivers drive on an expressway simulated by the driving simulator at the speed of 27.8 m/s (100 km/h). Then, a leading vehicle is rendered on the screen of the simulator, and the drivers drive after the leading vehicle with the headway distances mentioned in Table 1. The leading vehicle brakes after driving a certain distance on the experiment course, and the own vehicle comes close to the leading vehicle. Then, the drivers apply brakes in usual way. This experiment measures the headway distances, relative velocity, relative deceleration, and the braking efforts that indicate the magnitudes of braking behavior. The experiment was done by 11 subjects in their twenties.

4.2 Readymade Driver Model in braking

Drivers were clustered by the headway distances at the time of starting braking. The dendrogram shown in Fig. 4 of 3.2 is the result of cluster analysis of headway distances at the time of starting braking with the Ward method. Here, it was found that the number of appropriate clusters was two, when it was calculated by the subtractive clustering method based on the results of this experiment. The clusters are drawn by the lines of X in the dendrogram of Fig. 4, and representative values are shown in the figure.

Next, an experiment was conducted by the driving simulator to review the validity of clustering of each driver. This experiment was conducted under the same conditions as that of the braking experiment. This time, however, the drivers do not brake, even if the leading vehicle comes close. Instead, the computer of the simulator automatically starts braking at the given headway distance of each cluster. In other words, the functions of driving support systems were constructed in the simulator by using Readymade Driver Model that automatically brakes at a certain headway distance. The headway distance, at which the simulator starts braking, is changed by the cluster to which the driver belongs. The subjects get aboard the simulator, and make the subjective rating (five phases) of admissibility of timing of starting braking after observation of braking by the simulator. Fig. 7 represents the results of subjective rating, and almost all of the drivers assessed that the braking by the simulator was acceptable. This shows the effectiveness of Readymade Driver Model. For clustering, the precision of this model can be improved not only by objective data such as headway distances but also addition of subjective rating of safety by drivers.

4.3 Tailormade Driver Model in braking

To seek the possibility of building models here, the braking that is considered most important among subsystems of TDSS is taken up, and driver's braking in the

View angle: Horizontal 2.36(rad) Up and down 0.52(rad)
Vehicle: Displacement 2500 ~ 3000(cm^3)

Fig. 6 Driving simulator

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

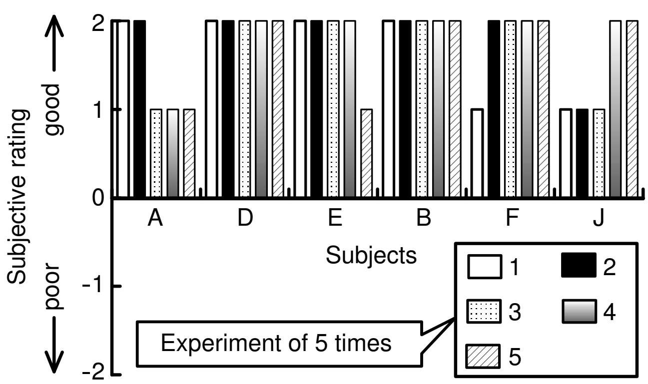


Fig. 7 Subjective rating about the timing of the braking

approach to a leading vehicle is covered.

As for the driver model of braking, the inputs are the headway distance, relative velocity, and relative deceleration, and the output is the braking effort. Fig. 8 shows Tailormade Driver Model of braking. NN learns from the data obtained by the braking experiment. The braking behavior in the experiment is largely different between the cases where the leading vehicle decelerates slowly or rapidly. Therefore, the inputs and teacher signals into NN are clustered[16]. Fig. 9 shows the system to build models. The factor of clustering uses the driving condition. The factors of clustering here are the free running time until drivers apply the brakes and the maximum deceleration that shows the strength of braking. The data

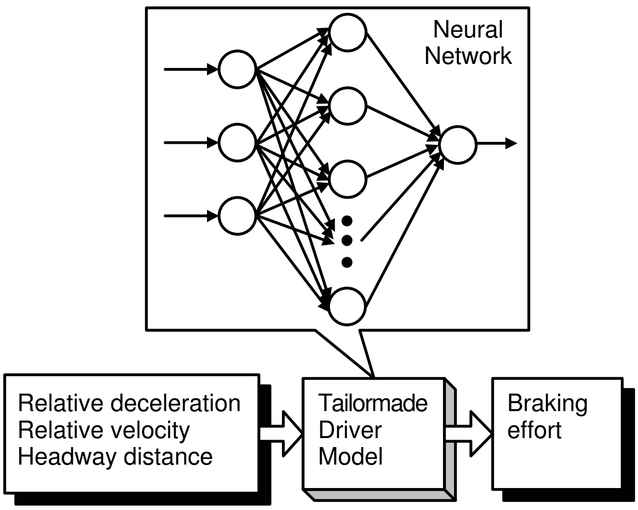


Fig. 8 Tailormade Driver Model

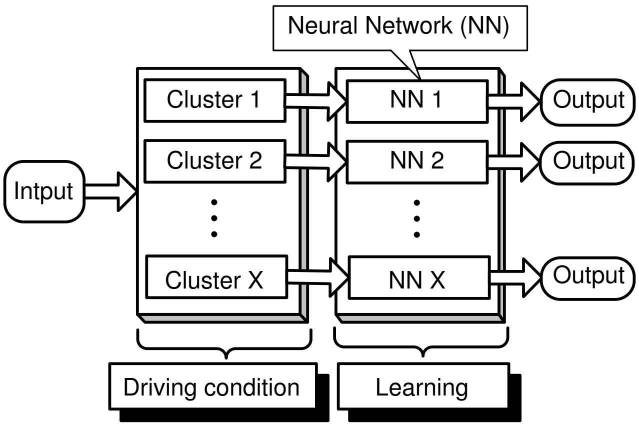


Fig. 9 System to construct the driver model

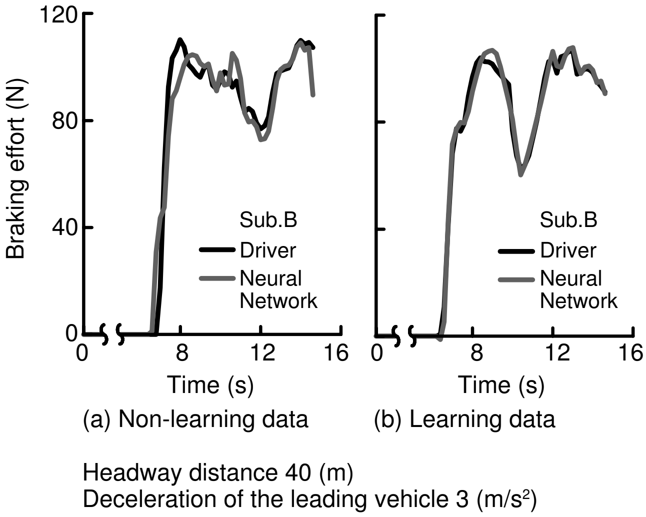


Fig.10 Simulation of the driver's braking

of each cluster are classified into learning data to be learned by NN and non-learning data. As a result of cut-and-try evaluation of relations with errors, it was found that the appropriate number of times of learning was 200.

Based on the conditions mentioned above, braking simulations were performed with the learned NN. These simulations were aimed at verifying whether the learned NN conducts the same braking behavior as drivers. Fig. 10 (a) shows an example of results of non-learning data simulations. It was found that the braking behavior by NN closely resembled the braking behavior by drivers, and also conforms to a variety of decelerations and headway distances. Fig. 10 (b) shows the simulation results of learning data. NN is consistent with the braking behavior by drivers.

As a result of the experiments and simulations mentioned above, it was confirmed that Tailormade Driver Model could adapt to individuals by learning with NN.

5. CONCLUSION

Constructing driving support systems by means of formulation of driving is efficient and economical. However, to effectively utilize the driving support systems that have physically excellent functions, user-friendliness and no sense of discomfort are important. TDSS incorporates driving behaviors of individual drivers in daily scenes of driving into driver models, aiming at providing drivers with added values of safety and peace of mind.

This research proposed a concept and a framework of TDSS, carried out braking experiments and simulations, and obtained the following results:

(1) TDSS are composed of TBSS, TSSS, and TASS;
(2) When this system is constructed, it is effective to incorporate Readymade Driver Model;
(3) As for Readymade Driver Model for braking, effective models can be developed by classification of drivers through clustering;
(4) It is effective to develop Tailormade Drive Model for braking with NN.

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