Center-linked Driver Support System

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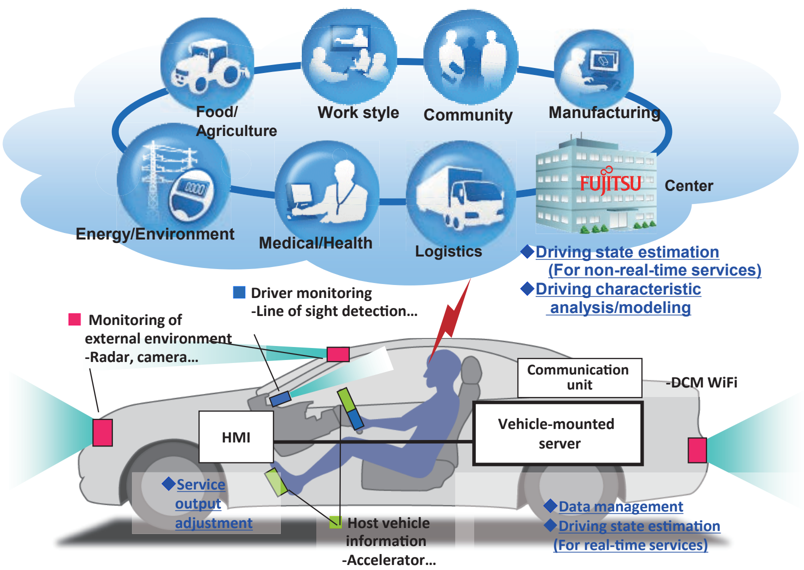

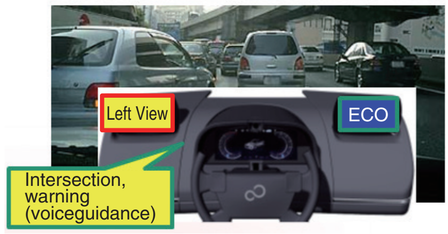

Abstract

In the future, it is expected that cars, like other things, will be connected to the society via the Internet and that various services will be increasingly provided using the network in the cabins. However, unlimited services provided to drivers during driving cars may distract them and interfere with safe driving. Therefore, in addition to improvement in comfort and convenience, the services should deliver better safety and security.

In order to solve the problem, we propose a center-linked driver support system that provides optimal services, depending on the driving situations, based on different types of information acquired by a linked center. This paper discusses the methods that the driver support system employs for estimating workload on individual drivers to estimate their driving states and for adapting the services to the states. Moreover, this paper elaborates the verified results of its effectiveness.

1 Introduction

Against backdrops of advancement of the Internet technology coupled with rapid spread of information terminals, the needs to gain information in the vehicle are growing. Therefore, an increasing number of services that can be used during driving are offered. Moreover, in the future, it is expected that cars, like other things, will be connected to the society via the Internet and that various services will be increasingly provided via the network.

However, only for emphasizing on comfort and convenience during driving, unlimited information provided to drivers may lead to driver distraction and interference with safe driving. In order to satisfy comfort, convenience and safety, optimal services should be provided, depending on driving state and situations of each driver.

Here, in order to provide service depending on driving states and situations, accurate driving state estimation is required. For the accurate estimation of the driving states, it is necessary to comprehensively analyze: external situations (external environment) such as the traffic environment; the state of the host vehicle such as "during acceleration;" and driver's state such as being tired and being distracted. However, conventional driver support systems determine these states and situations independently only in the host vehicle, and cannot use information of other vehicles, weather information and others which cannot be detected by the host vehicle, for the analysis. Further, for estimation of the driving state, the conventional systems analyze only real-time data acquired by the host vehicle without considering the driver's personal characteristics and the differences from others. Therefore, it is difficult for those systems to accurately estimate the driving states.

In order to solve this problem, we propose a "center-linked driver support system" capable of analyzing accumulated data, utilizing different types of information by linking the vehicle and the center.

2 Center-linked Driver Support System

2.1 Whole Idea of System

Fig. 1 shows the whole idea of the center-linked driver support system we propose.

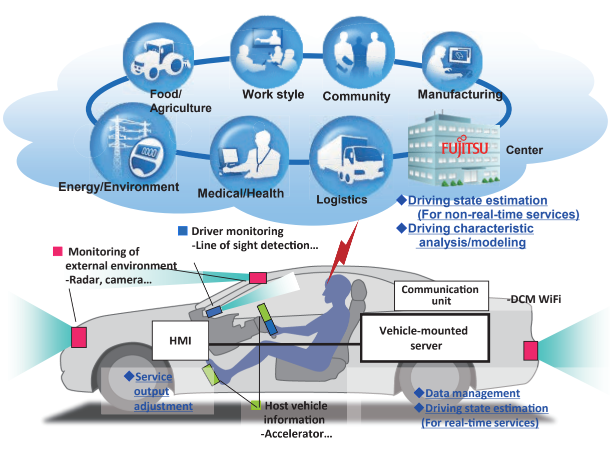

Fig.1 Center-linked Driver Support System

This system can use a large amount of and different types of information, by linking with the center, and can estimate the driving state, utilizing the information which cannot be acquired by the conventional systems. In addition, based on the statistical analysis of the data accumulated in the center and machine learning, the system can make analysis, considering characteristics for each driver such as driving characteristics.

Therefore, it is expected that the center-linked driver support system becomes possible to estimate the driving states adapted to each driver by utilizing different types of information on the external environment, the host vehicle and the driver, and also to provide services depending on the driving states and the situations. Moreover, we expect that, as the types and amount of utilized data increase, the analysis performance of driving states and the situations are improved and thus more advanced services can be realized.

2.2 Covered Services

Fig. 2 shows examples of services covered by this system by dividing the services into comfort/convenience and safety. We believe that the driver can be in more comfortable and safer state by a wide range of provided services depending on the driving state and the situations, excluding the area requiring control.

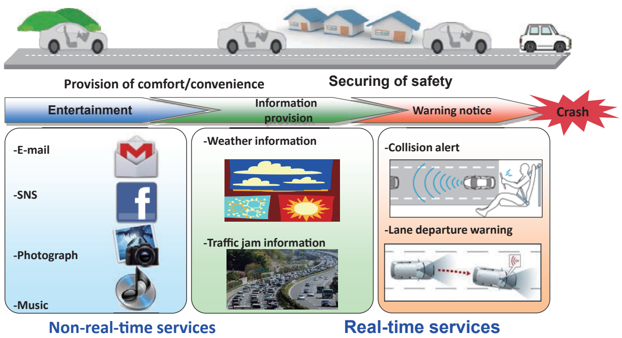

Fig.2 Provided Services

2.3 System Architecture

Next, the architecture of the center-linked driver support system is shown in **Fig. 3**.

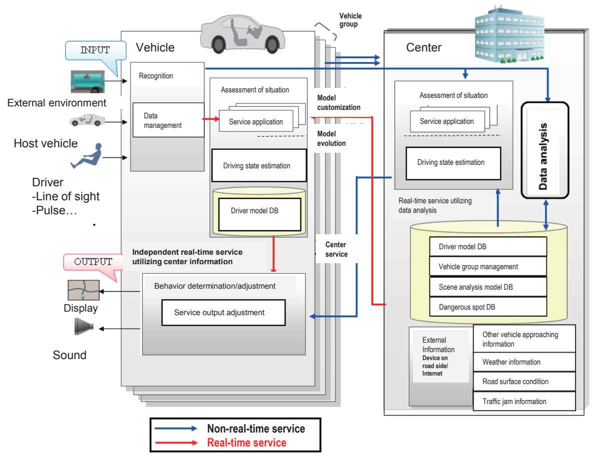

Fig.3 System Architecture

The vehicle-mounted terminal includes a data management function which manages data acquired from various sensors, a driving state estimation function for services requiring the high real-time performance such as collision alert, and a service output adjustment function which controls HMI output for providing optimal services to the driver.

On the other hand the center includes a driving state estimation function for services not requiring the high real-time performance such as entertainment services and a data analysis function which constructs a model representing personal driving behaviors based on the accumulated data. The driving state estimation function of the center comprehensively estimates situations based on the information on other vehicles and the infrastructure information in addition to the information on the host vehicle.

And, the characteristics of this system lie in that the process flow of the real-time service differs from that of the non-real-time services. Services in the comfort area do not require the high real-time performance, but for services in the safety area, the high-real-time performance is required because the system must identify risks and promptly give support to drivers. Therefore, it is not allowed that the process is delayed due to slow communication with the center. Therefore, the process flows are divided, depending on the necessity of the real-time performance. Thus, the services are provided without delay.

Each of process flows is explained. In the process flow of non-real-time services, first, data processed by the data management function of the vehicle-mounted terminal is transmitted to the center. Next, in the center, by utilizing different types of information, such as received data and the information on other vehicles, the driving states are estimated, taking the external environment, the host vehicle and the state of the driver into consideration. Then, the estimated result is transmitted to the vehicle-mounted terminal, and the vehicle-mounted terminal provides services depending on the driving states and the situations.

On the other hand, in the process flow of real-time services, first, the personal characteristic data analyzed by the center is downloaded to the vehicle-mounted terminal when the ignition is turned on. Next, by utilizing the real-time data during travelling of the host vehicle and the previously downloaded personal characteristic data, the vehicle-mounted terminal independently estimates the driving state of the driver, and provides services depending on it.

In addition, the data management function included in the vehicle-mounted terminal is also a characteristic of this system. In order to easily realize various services in the center, the data collected by the vehicle needs to be processed into an effective data set and the data set must be managed. Therefore, the data management function converts data formats which differ for each type of vehicle, based on certain rules (data expression, unit, etc.) to standardize them. In addition, the data traffic is minimized by dynamically changing the kind of uploaded data and the sampling rate based on services and the driving states and by optimizing the electronic format.

2.4 Workload Estimation and Personal Adaptation for Driving State Estimation

In the driving state estimation, we think that it is especially important to acquire the result matched to the state and feelings of the driver through the analysis of the states and the situations of the external environment, the host vehicle and the driver because if there is a significant difference between the result estimated by the system and the state/feelings of the driver, the driver feels annoyed or uncomfortable, and services are not accepted by the driver.

For a comfortable match of the estimated result with the state and the feelings of the driver, we think that it is important to estimate a workload state during driving of a vehicle because it is necessary to grasp workload of the driver given by tasks and information processing during the driving, in order to provide support without distracting him/her. However, even if the workload is the same, depending on the driving capability and the information processing capability of the driver, a margin left for additional tasks or information processing (degree of driver's margin) differs. If the degree of driver's margin differs, support contents provided to the driver also differ. Therefore, it is necessary to also grasp the degree of the driver's margin as one of the driving states, and to provide the driver support to control the workload such that the driver's margin becomes an appropriate value.

To clarify the estimation of the degree of the driver's margin, we define the expression (1), as an expression for obtaining the driver's margin, and the relevant variables in **Table 1**, and further **Fig. 4** shows the idea of appropriately adjusting the degree of the driver's margin.

Degree of driver's margin = Workload capacity − Workload ... (1)

Table 1 Variable for Estimation of Degree of Driver's Margin

Variable	Definition
Degree of driver's margin	The amount of tasks and the information processing amount which can be additionally performed
Workload capacity	The total amount of information/tasks which can be processed by the driver. (It depends on the personal information processing capability and driving capability)
Workload	The amount of information and tasks being processed by driver

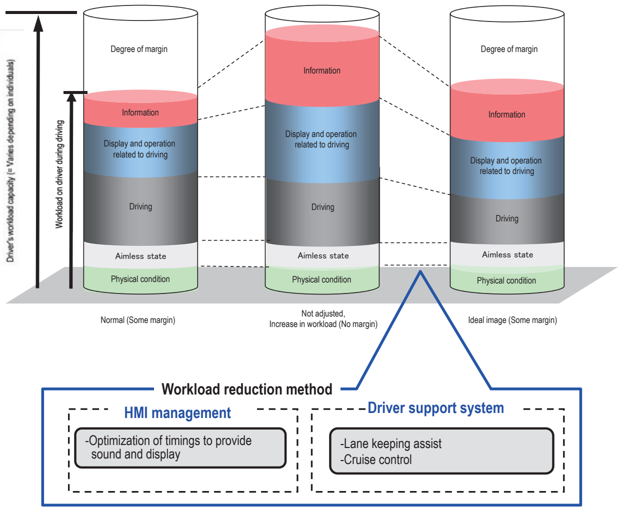

Fig.4 Appropriate Adjustment of Degree of Driver's Margin

In order to estimate the degree of the driver's margin, it is necessary to estimate the workload capacity and the workload. Chapter 3 of this paper will describe the details of our efforts to establish the method of estimating the workload to be controlled to adjust the degree of the driver's margin to an appropriate degree.

In addition, personal adaptation is required to estimate the driving states matched to the characteristics and the feelings of the driver. Therefore, in this system, a model is established that represents the driving behaviors of the driver by adding to the center a data analysis function that analyzes the driver's characteristics based on the accumulated data. In the driving state estimation, the data analysis tailored to each driver is realized by the use of the result acquired through the model.

Toward the realization of this personal adaptation, we have to clarify the analysis method of personal characteristics, the model establishment method, etc. Chapter 4 of this paper will describe the details of our efforts to estimate conditions as a study on the method of personal adaptation, considering the personal driving characteristics.

3 Study on Workload Estimation Method

3.1 Method of Estimating Workload from Driving Operations

As the method of estimating workload, the preceding study performed by Kurahashi et al.[1] finds that workloads are correlated with driving operations. Specifically, it is found that there is a correlation between four types of workloads (grasp of traffic conditions, grasp of road environment, interruption of driving pace and workload of vehicle control operations) calculated based on the Workload Sensitivity Questionnaire (WSQ)[2], which is a tool for quantifying workloads, and driving operations (the numbers of operations with the steering wheel, the accelerator and the brake pedal).

The four types of workloads defined by the WSQ are summarized in **Table 2**.

Table 2 WSQ Workload Definition

Type of workload	Details of workloads and examples of workload occurrence scenes
Grasp of traffic conditions	[Details] ・Workload due to the relation with surrounding traffics and the complexity of information capturing [Example of workload occurrence scene] ・Driving on a road where many cars are parked
Grasp of road environment	[Details] ・Workload due to changing, complicated and bad environment outside vehicle (such as roads and weather) [Example of workload occurrence scene] ・Driving on a road whose shape is frequently changed, such as fork road
Interruption of driving pace	[Details] ・Workload due to interruption to user's driving pace [Example of workload occurrence scene] ・Driving under a traffic jam condition in which the accelerator and the like are frequently operated
Vehicle control operation	[Details] ・Workload due to complexity of driving operations [Example of workload occurrence scene] ・Driving on a road such as mountain roads where the steering wheel is finely operated

Using the correlation between workloads and driving operations, we developed a logic which estimates the workload by counting the numbers of operations of the steering wheel, the accelerator and the brake pedal from travelling data, multiplying the numbers by weighing coefficients. The summary of the workload estimation logic is shown in **Fig. 5**.

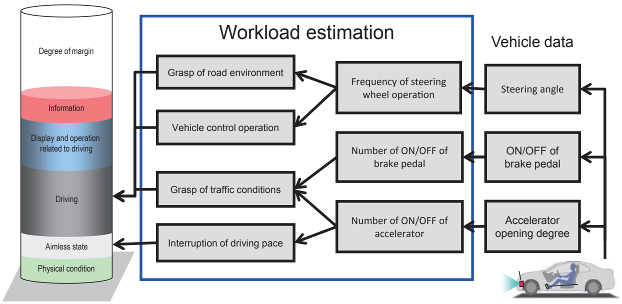

Fig.5 Workload Estimation Logic

Next, the expression for estimating workloads is described. w_1 is set to the workload of grasping traffic conditions, x, y and z are set to the number of operating the accelerator, the number of operating the brake pedal, and the number of operating the steering wheel, and a_1, b_1 and c_1 are set to contribution coefficients to w_1 of respective numbers of operations x, y and z obtained through the regression analysis. Then, the workload w_1 from grasping traffic conditions is obtained by the expression (2).

$$w_1 = a_1 \times x + b_1 \times y + c_1 \times z \ ... (2)$$

Next, depending on w_n, the function $f_n(w_n)$ returning integers from 1 to 4 is defined, and w_1 is converted to the integral workload estimation value W_1 by the expression (3).

$$W_1 = f_1(w_1) \ ... (3)$$

Similarly, the workload from grasping road environment was set to W_2, the workload from interruption of driving pace was set to W_3, the workload from vehicle control operation was set to W_4, and the workload estimation value was obtained. As shown in the expression (4), the workload W of the driver is obtained by the sum of W_1 to W_4.

$$W = W_1 + W_2 + W_3 + W_4 \ ... (4)$$

Here, we set a parameter, assuming that the workload W is an integer from 4 to 16 and that $W \geqq 12$ in a highly-loaded state.

3.2 Evaluation of Workload Estimation Logic

Before a performance evaluation on the workload estimation logic, we established first an environment for estimating workloads during driving by preparing a vehicle for the evaluation mounted with an evaluation PC that implements the workload estimation logic. Then, the subjects drove the vehicle on the actual roads as a test course. The subjects were 4 males in their 20s and 30s. The test course includes a possibly-high workload area (urban area) and a possibly-low workload area (main road). In addition, when the subjects felt highly-loaded during driving, they recorded the time points and the reasons for the loads that they felt.

As a result of the evaluation, workload estimation values were obtained based on the developed logic. **Fig. 6** shows the obtained workload estimation values of one of the subjects and the time points (scenes ① to ④) when he felt workloads. **Table 3** summarizes the reasons why the subject felt workload and the workload estimation values in respective scenes. In the scenes where the driver felt highly-load, the workload estimation values were high values of 15 or 16.

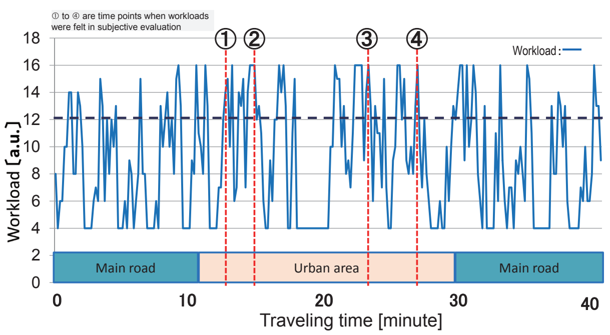

Fig.6 Results of Workload Estimation Using Developed Logic

Table 3 Results of Workload Estimation in Scene Giving Driver Workload

Scene	Reason why workload is felt	Workload estimation value
①	· Short distance from a car on the next lane waiting to turn right when passing through an intersection (Workload from grasping traffic conditions)	15 (High)
②	· Driving of a car while paying attention to the surroundings to avoid cars parked on the road (Workload from grasping traffic conditions)	16 (High)
③	· Driving of a car while paying attention to run-out of pedestrians · Driving of a car while paying attention to the surroundings to avoid cars parked on the road (Workload from grasping traffic conditions)	16 (High)
④	· Selection of a wrong lane that is only for right turn (Workload of grasping road environments)	16 (High)

(High): High workload estimation result

Next, we confirmed whether the same or similar results can be obtained from the test drive by other subjects. As the confirmation method, first, the scenes where the subject felt workloads in **Fig. 6** are defined as references of scenes of high workload (highly-loaded scenes). Then, we extracted scenes fitting the definition from traveling of other subjects, and examined whether the workload estimation values of those scenes showed high values. **Table 4** summarizes the defined highly-loaded scenes and the workload estimation results.

Table 4 Results of Workload Estimation in Scenes of High Workload Developed Logic

Scenes of high workload	Extracted number of scenes	Workload estimation value of extracted scene
A. An obstacle suddenly appears on a road with heavy traffic (Workload from grasping traffic conditions)	3	14 (High), 15 (High), 16 (High)
B. Driver avoids a car parked on the road immediately before turning left at an intersection (Workload from grasping traffic conditions)	3	16 (High), 4, 16 (High)
C. After selecting a wrong lane, driver changes the lane (Workload from grasping road environments)	1	12 (High)

(High): High workload estimation results

As a result, high workload values were output in six scenes out of seven highly-loaded scenes. Therefore, a high workload estimation value in a highly-loaded state is output by the use of the developed workload estimation method, which demonstrates the validity of the method of determining highly-loaded states. However, it is found a problem with the estimation method that the highly-loaded state is erroneously detected in a low workload scene and a problem with the evaluation method that only a small number of scenes are defined as the evaluation scenes. Therefore, we will improve the quality of the workload estimation method and the evaluation method.

4 Study on Concretization of Personal Adaptation

4.1 Problems of Conventional Front Collision Alert

In order to realize personal adaptation, it is necessary to concretize the analysis method of driving behaviors and the utilization method of the analysis results. Therefore, we examined to concretize the method for front collision alarm as an example.

A conventional front collision alerting system gives an alert at the predetermined timing without consideration of driving characteristics of each driver. Therefore, there is a problem of mismatch between the alert timing and the feeling of drivers during driving, so that the driver feels uncomfortable or uneasy with the alert. Therefore, we believed that the validity and acceptability of services would increase by taking the driving characteristics into account to adapt the alert timing to individual drivers.

First, problems are analyzed. As an index for collision risks, there is a Time to Collision (TTC) and the TTC is expressed by the expression (5).

TTC = Relative distance to obstacle / Relative speed of obstacle ... (5)

Fig. 7 is the chart showing driver's characteristics of inter-vehicular distance adjustment by TTC distribution on which the alert timings of the conventional system is overlapped. In a region surround by broken lines in **Fig. 7**, the system does not take the driving characteristics into consideration so that we think that measures for matching the alert timing with the driving characteristics are necessary.

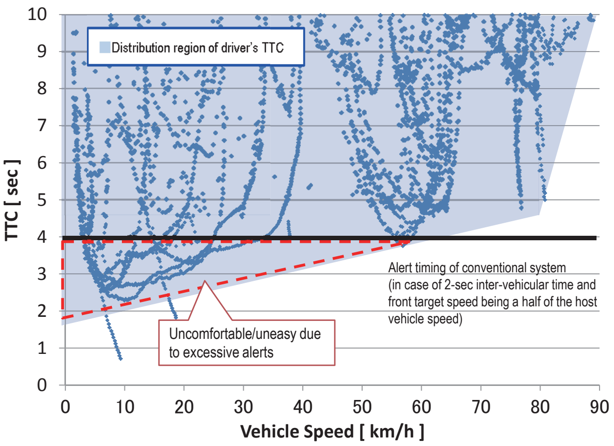

Fig.7 Alert Timing w/o Consideration of Driving Characteristics

In addition, when the TTC distributions of two drivers were compared, it was confirmed that the shapes of the distributions, including the mode value and the lower limit value, differ from each other. The results are shown in **Fig. 8**. **Fig. 8** shows the fact that the driving characteristics related to the inter-vehicular distance adjustment differ depending on drivers. Therefore, the timing needs to be optimized for each driver to match the alert timing with the driving characteristics.

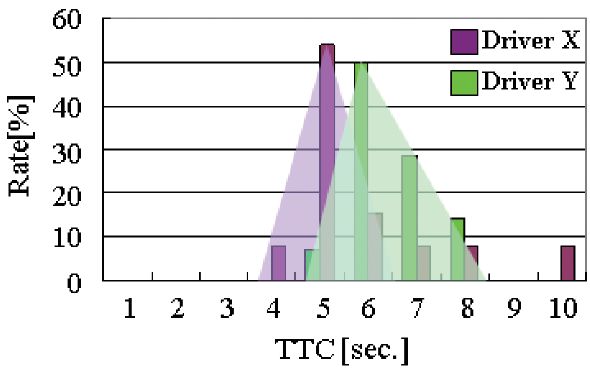

Fig.8 Individual Variation of TTC Distribution

4.2 Alert Timing Optimal for Drivers

In order to match the alert timing with the driving characteristics, it is necessary to analyze the driving characteristics using the TTC and to clarify a threshold value for determining the alert timing. Thus, we studied to set the threshold value as below.

It is considered, based on the TTC distribution in the preceding section, that the driver is driving the vehicle so as not to cause the TTC to be below a predetermined value, and that the lowest value varies depending on the vehicle speed. Therefore, we first divided the TTC into vehicle speed ranges, calculated a 90% value (=value x) on a side of lower value in the TTC distribution of each speed range, and then developed a hypothesis that the value x would be the TTC lower limit and would serve as the threshold value for determining the alert timing. **Fig. 9** shows the outline of how to set the threshold value. When the TTC distribution is a normal distribution, the average value is set to μ, and the standard deviation is set to σ. Then, the x value is obtained by the expression (6).

$$x = \mu - \sigma \times 1.67 \quad \text{... (6)}$$

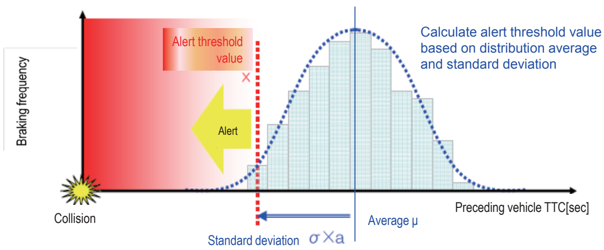

Fig.9 Threshold Setting for Alert Timing Using TTC Distribution

Moreover, by drawing a regression line based on the idea that the x value is proportional to the vehicle speed, we set determination threshold values for the entire vehicle speeds. Here, if the vehicle speed is set to Speed, the obtained regression line is expressed by the expression (7).

TTC = 0.071 × Speed + 1.67 ... (7)

Next, in order to verify the validity of the obtained threshold values, the relationship between the transition of the TTC and the threshold values was examined using travelling data different from travelling data used for setting the threshold values. As a result, as shown in **Fig. 10**, since it was confirmed that the driver is driving a vehicle so as not to cause the TTC to be below the threshold, the set threshold values are valid for determining the alert timing taking the driving characteristics into consideration.

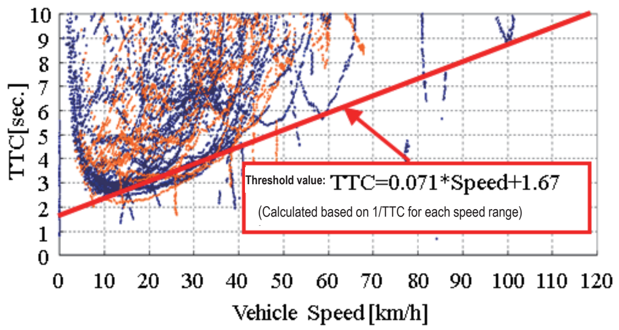

Fig.10 Alert Timing with Consideration of Driving Characteristics

In this way, we achieved concretization of the personal adaptation method for the front collision alert, taken as an example, using the determination threshold value taking driver's driving characteristics into consideration.

5 Conclusion

We proposed the center-linked driver support system which provides optimal services depending on driving states and situations by linking the vehicle and the center in order to realize both comfort and safety, and the system architecture thereof was shown.

In addition, since we believe that the workload estimation and personal adaptation are important for driving state estimation, we developed the method of estimating workloads, as a workload estimation method, based on driving operations, and obtained the evaluation results which suggest the validity of the method with respect to the determination of highly-loaded state. Moreover, as the study on concretization of personal adaptation, we clarified the alert timing adapted to individual by defining the determination threshold values taking the driving characteristics into consideration.

In the future, we aim to realize the driving state estimation with higher accuracy by utilizing a large amount of and various big data acquired from the center. Moreover, in addition to development of the system element technology, we will verify the viability of the entire system, and carry out the development to put the system into practice as early as possible.

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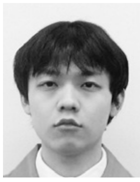

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