CONTROLLING TASK DEMANDS WHILE APPROACHING INTERSECTIONS

Toshihisa Sato and Motoyuki Akamatsu
National Institute of Advanced Industrial Science and Technology (AIST)
Tsukuba Central 6, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8566, JAPAN
toshihisa-sato@aist.go.jp
Yoji Miyazaki and Nobutatsu Nakamura
Service Platforms Research Laboratories, NEC Corporation
8916-47, Takayama-Cho, Ikoma, Nara, 630-0101, JAPAN
Kenji Hiramatsu and Shin'ichi Fukuzumi
Common Platform Software Research Laboratories, NEC Corporation
Igarashi Building, 11-5,Shibaura 2-chome, Minato-Ku, Tokyo 108-8557 JAPAN

ABSTRACT: This paper describes an investigation of how drivers control task demands while driving in an actual road environment. Field experiments using an AIST instrumented vehicle were conducted in Tsukuba (rural roads) and Tokyo (urban roads) to measure vehicle status and driver behaviour. Eight participants were instructed to drive in their usual manner for five trials. They were then instructed to drive with low task demands for another five trials. A Bayesian network model was applied to data on driving behaviour while approaching and stopping at intersections with red traffic lights. We investigated the behavioural indices that indicated a significant difference between the usual drives and the drives with low task demands. The model estimated results suggest that the drivers control the task demands using any one of the following behavioural indices: vehicle velocity, headway distance, accelerator pedal application, and brake pedal application. The behavioural indices indicating the differences are the same on both the rural and urban roads.

1 INTRODUCTION

1.1 Task demands while driving

Drivers adjust the task difficulty while driving in order to avoid road accidents. Task difficulty refers to the difficulty of driving tasks, e.g. moving straight, left and right turns, and curve negotiation, that drivers perform while reaching a destination. A concept of what determines the driving task difficulty has been presented in the task-capability interface model [1]. In this model, any driving behaviour performed to adjust the task difficulty can be described as an interaction between the driver's capability and the demands of the driving task. When the driver's capability exceeds the task demand, the task is easy and the driver completes the task successfully. When the demand exceeds the capability, this leads to a collision or a loss of control due to the driver's failure to accomplish the task.

The driver's capability is constrained by the physical and cognitive characteristics of the individual driver, including physical reach, reaction time, and information processing capacity. The capability is also constrained by resource allocation: the extent to which the driver is motivated to allocate the resources needed to carry out the driving task in order to maintain a capability level above the task demand. The driver's physical and mental states, such as fatigue, drowsiness, and distraction, also impact the driver's capability and can vary both between drivers and for the same driver at different times. The task demands are determined by operational features of the vehicle (its control characteristics, information display, etc.), environmental factors (visibility, road surfaces, curve radii, road signs and signals, etc.), and interactions with other road users (slowing down of a lead vehicle, crossing of pedestrians or bicycles, etc.). The demands are also influenced by human factors elements, including the choice of driving speeds and headway distances and the control of acceleration. For example, driving fast leads to high task demands and requires high driver capability, even on a wide and straight road without other vehicles. In contrast, driving slowly leads to low task demands, thus the possibility of traffic accidents is also low even when the driver does not allocate many resources to the driving task.

Advanced driver assistance systems now developed all over the world use vehicle-based sensors and/or infrastructure-based sensors to detect situations where the task demands increase suddenly due to an immediate change in traffic conditions, such as a traffic jam after a curve or a sudden deceleration of a leading vehicle. The systems support safe driving by providing the driver with warnings or by operating the vehicle automatically. When the base of the driving task demands is low, sudden changes in traffic conditions may not increase the task difficulty; specifically, the driver's capability remains higher than the increased task demands. Therefore, assistance systems that promote driving with low task demands may contribute to reducing the driving risk. In order to develop such assistance systems, it is essential to clarify how drivers control the driving task demands in an actual road environment.

1.2 Objective

This paper focuses on the human factors elements that determine the task demands. The aim is to investigate how the driver manages task demands on a real road. Conventionally, driving simulators have been used to investigate the influence of the task demands on a driver's behaviour (e.g., [2]). We conducted field experiments using an AIST instrumented vehicle in order to collect data on driver behaviour in different driving modes in an actual road environment. The driving behaviour was compared between typical drives and drives with low task demands. We focused on drives with low task demands because drives with high task demands had a high possibility of road accidents and therefore experiments involving these situations raise an ethical issue.

The field tests were carried out on both rural and urban roads, which present different road-traffic environments. Data collected on the different road-traffic environments will contribute to the investigation of differences in driver control methods in response to the different task demands. Driving behaviour consists of various tasks. This study deals with the task of stopping at intersections with a red traffic light. We analyzed behavioural data measured as the driver approached an intersection with traffic lights, with measurement continuing until the driver stopped at the intersection.

1.3 Research flow

Figure 1 presents the analysis flow of this study. First, we collected behavioural data on rural and urban roads during typical drives and drives with low task demands. The AIST instrumented vehicle used in the data collection can measure various kinds of data about the vehicle status as well as the driver's operations. Thus, a Bayesian network model was applied to the collected data on each road in order to estimate a behavioural index that would reveal significant differences in the behaviour between drives with different task demands. Finally, we clarified the contents of the drives with low task demands based on a comparison of the data distribution obtained from the Bayesian model estimation between typical drives and drives with low task demands.

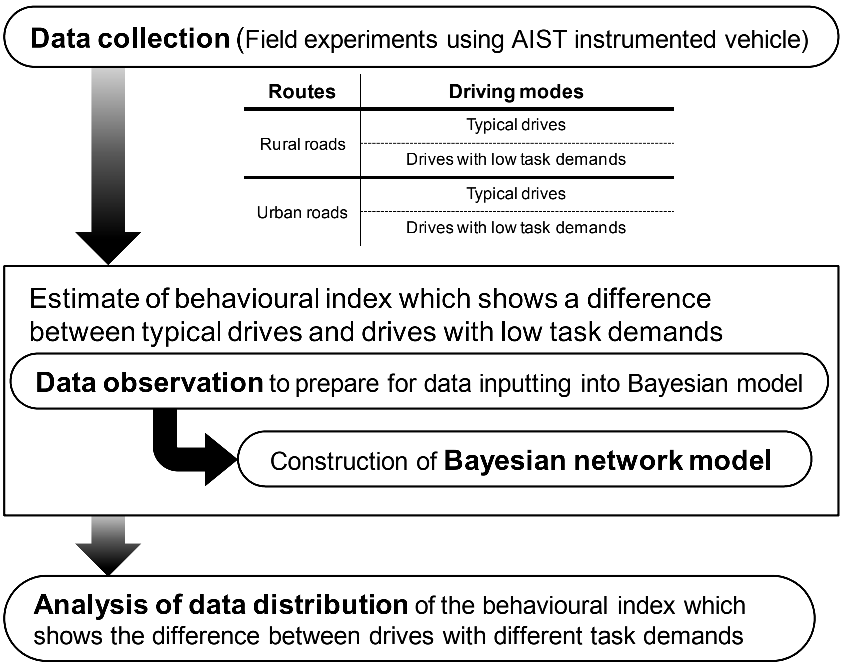

Fig. 1 Research flow to investigate how drivers control task demands

2 DATA COLLECTION

2.1 AIST instrumented vehicle

The AIST instrumented vehicle used in the experiments is equipped with various sensors and a recorder system (Fig. 2) (see reference [3] for details.). The instruments detect the vehicle driving state including the speed, acceleration, geographical position, and relative distances and speeds to leading and following vehicles. Driver operations, including steering, accelerating, and braking, are also measured. A total of five CCD cameras record visual images of the forward and rear traffic conditions and the lane position, as well as the driver's face.

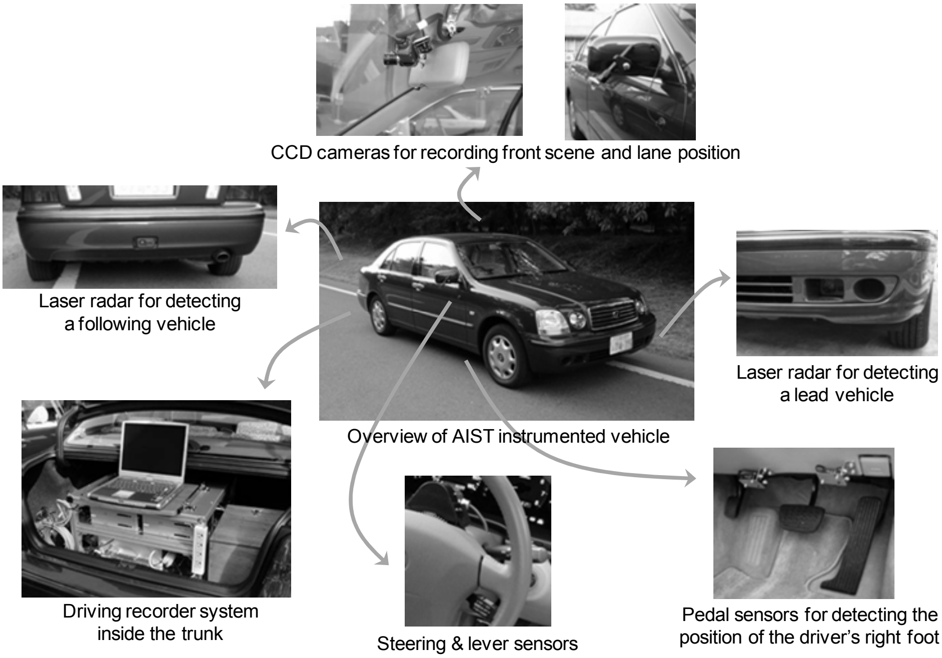

Fig. 2 AIST instrumented vehicle

2.2 Experiment methods

Repeated experiments were carried out to record driving behaviour on rural and urban roads. The selected driving route on rural roads was a 25min trip covering a distance of 14km (Fig. 3a). This route included from one to three traffic lanes, and the average driving speed of the rural route was 43km/h. The route had 26 intersections with a traffic light. The driving route on urban roads was a 20min trip covering 5km (Fig. 3b). There were two or three traffic lanes. The traffic volume of the urban route was high, and the average driving speed was 23km/h. There were 27 intersections with a traffic light on this route.

The participants drove on both the rural and urban routes during each experiment trial. After they drove on the rural routes, they travelled to the urban routes via motorways. The total driving time for one experiment trial including driving on the rural and urban routes was three hours and 30 minutes. The participants took a rest during the motorway segments and before and after the recorded drives on each route in order not to suffer fatigue due to long driving times.

(a) Rural roads in Tsukuba (b) Urban roads in Tokyo

Fig. 3 Photos of driving routes

The experimental drive was made once a day, and a total of 10 trials were conducted. The participants were instructed to drive in their usual manner (typical drives) for five trials and to drive in a more relaxed manner for the other five trials, to prevent driving fatigue (drives with low task demands). It was hypothesized that driving with high task demands would require high resource allocation to the driving task, and that the high concentration on driving would lead to fatigue. Therefore, preventing fatigue while driving corresponds to a condition in which the driver's capability is temporarily low, and in which drivers should control the task demands by performing driving operations that do not exceed the low driver capability. The order of the driving modes was changed between the rural and urban routes: participants made typical drives on the rural routes and then made drives with low task demands on the urban routes, or vice versa.

Eight drivers (four males and four females) participated in the experiments. The average age was 42.4 years (from 32 to 58 years old), and the average driving experience was 20.6 years (from 12 to 38 years). All of the participants drove a passenger car almost every day.

3 BAYESIAN NETWORK MODEL

In this study, we focused on the driver's behaviour when approaching and stopping at intersections with red traffic lights. It is difficult and inefficient to check separately whether the behavioural index measured in such situations indicates a difference between typical drives and drives with low task demands, because the instrumented vehicles collected a large variety of behavioural indices. Therefore, we applied a Bayesian network model [4] to the measured data sets in order to investigate the behavioural index automatically and comprehensively.

Before constructing the Bayesian network model, we investigated a data candidate and a range which were applied to the model, based on observation of time-series data collected as the participants approached and stopped at the intersections.

3.1 Data preparation

Figure 4 presents an example of the observation data used to prepare for the Bayesian model construction. These graphs plot the average driving speed of one participant while approaching a target intersection, as calculated within each drive mode. On the rural route, we observed time-series data beginning 200m from the target intersection, and the difference between typical drives and drives with low task demands was found between 200m and 100m from the intersection. On the urban route, we observed driving behaviour data beginning 100m from the target intersection because the range from 200m to 100m included an intersection before the target intersection. Observations made on the urban route suggest that the difference in driving speeds between different driving modes was found at a further range (from 100m to 60m) from the target intersection.

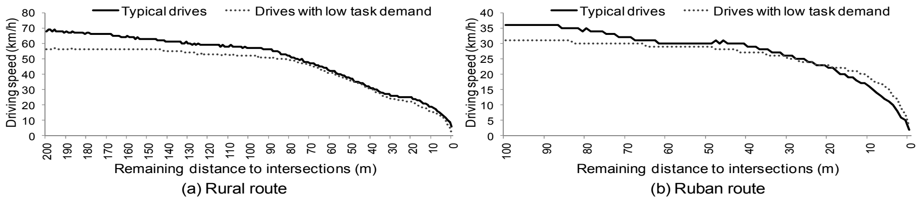

Fig. 4 Comparison of driving speeds between typical drives and drives with low task demands

In addition to the analysis of averages calculated from the behavioural data, we compared the behavioural indices at the onset of braking between the different driving modes. The comparison results imply that differences would be found in the driving speeds or headway distances at the onset of braking before stopping at intersections.

We selected a data range for input to the Bayesian network model as follows.

- Range further from intersections (rural route, from 200m to 100m; urban route, from 100m to 50m)
- Range closer to intersections (rural route, from 100m to 0m; urban route, from 50m to 0m)
- Onset of deceleration while approaching intersections

(The point at which the driver applies the brake in order to stop at intersections)

We found almost no differences in the speeds relative to a leading vehicle while approaching the intersections between typical drives and drives with low task demands. The relative speeds are determined by the deceleration of the leading vehicle, and thus the values on drives with low task demands are the same as those in the driver's usual driving.

We selected a data for input to the Bayesian network model as follows.

- Averages of longitudinal acceleration, driving speed, and headway distance in a range further from the intersections
- Integration values of acceleration application and brake application in a range further from the intersections
- Averages of longitudinal acceleration, driving speed, and headway distance in a range closer to the intersections
- Integration values of acceleration application and brake application in a range closer to the intersections

- Remaining distance to the intersection, remaining time to the intersection, driving speed, and headway distance, all at the onset of deceleration

We used the averaged values as representative values for the further and closer ranges. The integration values were used for the pedal application in order to take into account how the driver pressed on the pedals. We used 200m, a value beyond the detection area of the laser radar sensor, as the headway distance when there was no leading vehicle while approaching an intersection.

3.2 Model estimation results

We constructed Bayesian network models using the above data sets as well as the two driving modes (typical drives or drives with low task demands) and the number of traffic lanes at the intersections. The Bayesian models were applied to the behavioural data for each participant on each driving route. Table 1 presents the results of the Bayesian network model estimation, suggesting behavioural indices significantly differ between the two driving modes.

The model estimation results indicate that the participants can be categorized into the following two groups (except the participant ‘TD’). In one group (‘TA’, ‘TF’, and ‘TB’), the difference between the two driving modes is found in the behavioural indices in a range further from the intersections (called the “further-range group”); in another group (‘TH’, ‘TE’, ‘TC’, and ‘TG’), the behaviour in a range closer to the intersections and at the onset of braking influences the difference between the two driving modes (called the “closer-range group”).

Table 1 Results of Bayesian network model estimation: Behavioural indices indicating a significant difference between typical drives and drives with low task demands

Participants	Routes	Range further from intersections					Range closer to intersections					Onset of deceleration			
		Average acceleration	average speed	Average headway distance	Integration of accelerator pedal application	Integration of brake pedal application	Average acceleration	average speed	Average headway distance	Integration of accelerator pedal application	Integration of brake pedal application	Remainng distance to intersections	remaining time to intersection	Driving speed	Headway distance
TH (33 years old, Male)	Rural							●							
	Urban							●							
TE (58 years old, Female)	Rural									●					
	Urban									●					
TC (32 years old, Female)	Rural									●					
	Urban									●					
TG (56 years old, Male)	Rural													●	
	Urban									●				●	
TD (39 years old, Female)	Rural					●								●	
	Urban					●								●	
TA (33 years old, Male)	Rural		●												
	Urban		●												
TF (39 years old, Male)	Rural			●											
	Urban			●											
TB (49 years old, Female)	Rural			●											
	Urban			●											

Participant TD used the brake pedal application in the range further from the intersections and the driving speed at the onset of braking in order to control the task demands. In the further-range group, the driving speed and the headway distance were the behavioural indices that indicated a significant difference between the two driving modes. In the closer-range group, the driving speed and the accelerator pedal application were used to control the task demands.

Interestingly, the behavioural indices for the control of task demands on the rural route were the same as those on the urban roads for almost all of the participants, indicating that drivers managed the task demands when stopping at intersections with red traffic lights by means of the same behavioural indices both on rural and urban roads.

4 ANALYSIS OF DATA DISTRIBUTION

Figure 5 presents one example of the data distribution (for the driving speeds of the participants TA and TH) on the urban routes. The participants used slower driving speeds when driving with low task demands than during typical drives. This tendency was common to the behavioural indices, namely the driving speed, headway distance, accelerator pedal application, and brake pedal application, suggesting a significant difference between the two driving modes using the Bayesian model.

When instructed to maintain low task demands, driving speeds were slower in ranges further from and closer to the intersections and at the onset of braking. The headway distances were greater in the further range, the accelerator pedal was not applied in the closer range, and the brake pedal was not applied in the further range. The absence of accelerator pedal application in a range closer to the intersection suggests that the drivers decelerate earlier before stopping at the intersections. The absence of brake pedal application in a range further from the intersection indicates that the driver approaches the intersections more slowly. In fact, both the brake pedal application in the further range and the driving speed at the onset of braking were obtained from the Bayesian network model estimation for participant TD.

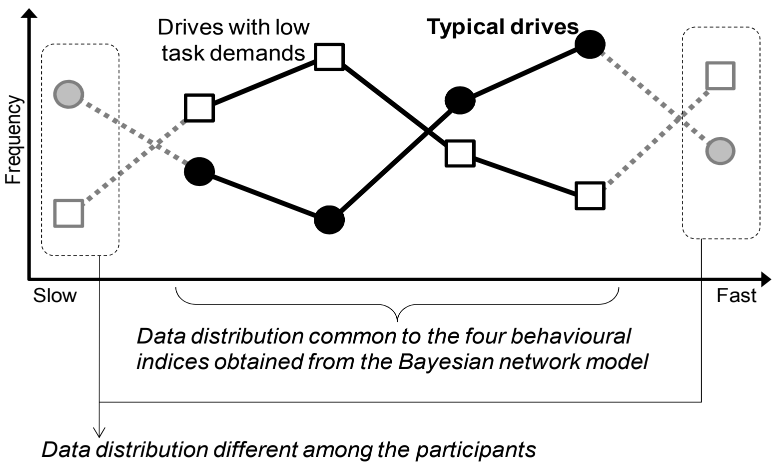

Fig. 5 Diagram of the data distribution (e.g. driving speeds)

We found that the data distribution had a feature common to the four behavioural indices obtained from the Bayesian network model and the different parts among the participants and the driving routes (see Fig. 5). In the different parts, the driving speeds of one participant were lower, even for typical drives, than those performing drives with low task demands on rural and urban roads. Another participant drove faster, even during drives with low task demands on urban routes. These different parts of the data distribution were also found in the other behavioural indices, namely the headway distance and accelerator pedal application. Observation of the driving scenes based on images captured via CCD cameras indicated that the following specific traffic conditions led to the different data distributions: the existence of a slow leading vehicle due to traffic congestion, and the absence of other vehicles around the driver (i.e. solo driving) on urban roads. There was a slow leading vehicle when the traffic flow was slow due to traffic congestion on the roads within the experiment route. Under these conditions, the participants used lower driving speeds even when the driving mode was a typical drive, or they applied the accelerator pedal or accepted shorter headway distances, even when driving with low task demands. The traffic volume was usually high on the urban roads used in the measured trials. However, in some cases there were no other vehicles around the participant's vehicle. When the participants drove at their own pace, they used higher driving speeds even on the drives with low traffic demands because the task demands of the traffic conditions were low. In such situations, on typical drives, the headway distances were longer due to the absence of a leading vehicle, or the participants approached the intersections at higher speeds and did not apply the accelerator pedal closer to the intersections (i.e., they decelerated earlier). Exclusion of these specific traffic conditions from the data analysis will contribute to enhancing the differences in driving behaviour between typical drives and drives with low task demands.

5 CONCLUSIONS

This paper describes how drivers control task demands while approaching an intersection with a traffic light. Field experiments were carried out on rural and urban roads to measure driver behaviour as well as to detect the instrumented vehicle status. Behavioural data were collected both when driving in the participant's typical manner and when driving under instructions to prevent fatigue by driving with low task demands. Data were applied to a Bayesian network model and analyzed to determine whether the behavioural indices indicate a significant difference between typical drives and drives with low task demands.

Drivers controlled the task demands using driving speed, headway distance, accelerator pedal operation, or brake pedal operation. The driver behaved so as to maintain a margin for movements of a leading vehicle in order to reduce the task demands. The ranges for controlling the task demands were in areas further from or closer to the intersection. The behavioural indices and the distances to the intersections that differed significantly between the two driving modes were the same on both rural and urban roads.

Driver assistance systems that encourage driving with low task demands will contribute to reducing the increase in driving task difficulty that occurs when traffic conditions surrounding the driver's vehicle suddenly change, e.g. a sudden deceleration of the leading vehicle. Our findings will also lead to advisory systems suggesting how drivers can reduce the task demands when their driving capability temporarily becomes low, e.g., when they feel fatigue or drowsiness.

6 REFERENCES

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