

Analysis of Driver Behavior Based on Traffic Incidents for Driver Monitor Systems

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Abstract – Research is being conducted into a large number of on-board driver monitor systems as a means of reducing traffic accidents. In order to improve the effectiveness of these systems, it is necessary to detect the driver behavior and mental and physical state immediately before an accident, and to inform or warn the driver of the danger, or else to send an intervention signal to the pre-crash safety system and other advanced vehicle safety systems. Previous research has been conducted for conditions of apparent risk, and has used drive recorders to analyze the causes of accidents and to investigate and analyze driver behavior and other factors which are present immediately before an accident. This study involved an investigation of near-miss accidents (hereafter referred to as “incidents”) by means of interviews in order to determine the driver behavior and mental and physical state immediately before the incident, when there was the potential risk of an accident. The purpose of this study is to contribute to research concerning advanced vehicle safety systems. We will here provide an analysis of the results and propose direction for future research concerning driver monitor systems.

I. INTRODUCTION

The number of traffic accident fatalities in Japan declined for the sixth consecutive year in 2006, reaching the low 6,000s for the first time in 51 years⁽¹⁾. The decline in traffic accident fatalities was the result of revisions to the Road Traffic Law such as stronger enforcement of drinking and driving laws and mandatory seatbelt use. It was also due to comprehensive efforts including maintenance and improvement of the traffic environment and the greater installation of vehicle safety systems⁽²⁾. However, the number of injuries in traffic accidents exceeded 1 million for the eighth consecutive year (Figure 1). Reducing the number of traffic accidents themselves has become an urgent issue for the creation of a sustainable transportation society.

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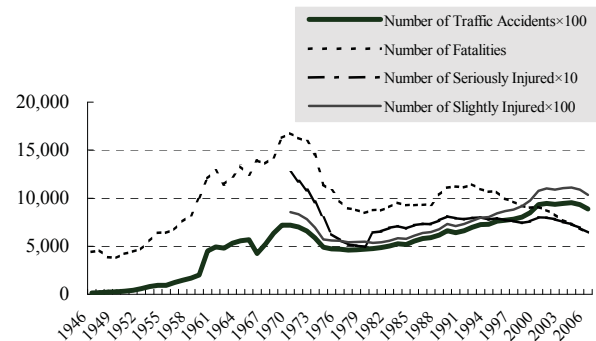


Figure1. Transition of road traffic accidents, fatalities, injuries in Japan [1]

Traffic accidents are thought to be caused by three interrelated factors: the driving environment, vehicle, and driver (Figure 2), and the majority of traffic accidents are thought to be the result of driver behavior immediately before the accident^{(3) (4) (5) (6) (7) (8)}. In addition to providing support for recognizing potential risks in the environment during ordinary driving, it is expected that advanced driving support systems will also play important roles by detecting driver physiological signals in real time, providing support for correct driving judgment, and performing intervention control.

Research has been conducted in recent years concerning vehicle driving support systems which directly detect driving environment information and the driver state, and which provide information, warnings, and driving support to the driver in response to driving risks. Some of these systems have already been marketed⁽⁹⁾ and have delivered some level of results (Table 1).

Table1. Example of driver monitor systems using physiological signals

Primary example		Details
Examples of research	Japan: Phase 1 and 2 ASV Promotion Project	Drowsiness warning system (heart rate [Toyota], eye opening [Nissan], other)
	EU-FP: AWAKE/AIDE	Drowsiness warning system (blinking, gaze direction, head movement, other)
	Germany: Daimler	Over-fatigue detection system (blinking, brainwaves, other) (PR material dated November 2006)
	Sweden: Saab	Attention warning system (gaze direction, blinking, other) (PR material dated November 2007)
Examples of systems introduced in Japan		(1) Sway warning system (Subaru, September 2003) (2) PCS with face direction detection system (Toyota, March 2006) (3) Drowsiness detection seat system (Mazda, February 2007)

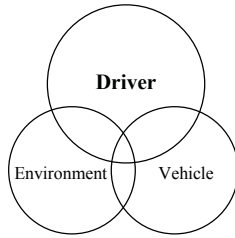


Figure2. Driver-Vehicle-Environment

Determining the driver state immediately before traffic accidents is one effective step in working to prevent accidents. Previously, investigation and analysis aimed at determining the cause of an accident and the driver behavior immediately before it utilized drive recorders^{(10) (11)}. However because these recorders are triggered by a sudden deceleration of the vehicle caused by a change in the driving environment, they operate in areas of apparent risk when an accident is relatively close at hand. They are unable to cover all areas of driver behavior, including areas of potential risk arising from the driver's mental/physical state.

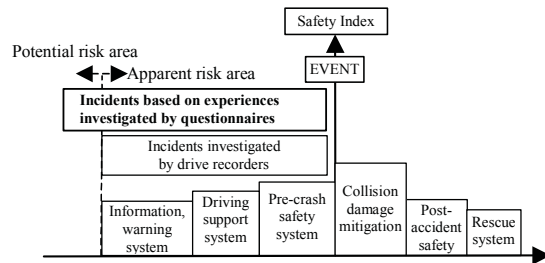


Figure3. Investigation area of traffic incidents experiences

In order to contribute to research concerning advanced vehicle safety systems, this study expanded the investigation area (Figure 3) to include the driving area of potential accident risk. We utilized an interview-based questionnaire in order to investigate traffic incidents in order to determine the driver behavior and mental and physical state immediately before an accident occurs.

II. ANALYSIS METHODS

2-1. Creation of Questions Related to Incident Frequency

This study defines "driver characteristics" as an overall concept that includes the driver behavior and mental and physical state of the driver, and analyzed the effects on incident occurrence based on three factors: the traffic incident, driver behavior, and mental and physical state.

- (1) For the traffic incidents, seven situations (Figure 4) were set as potential accident risks, based on the seven accident types that were set as traffic accident models in the Phase 3 ASV Promotion Project⁽¹²⁾ in Japan. Respondents were also permitted to describe freely any incidents which were different from those shown in the figure.

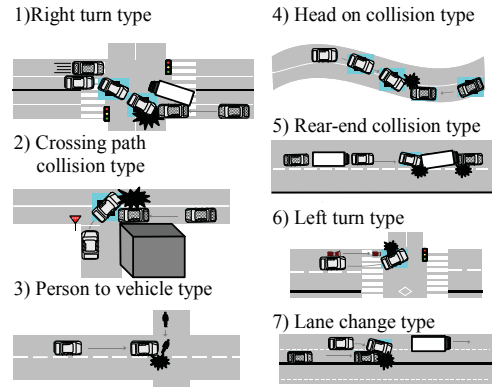


Figure4. Incidents categorization based on traffic accidents

The accident types were illustrated on the questionnaire page, and the contents of the questionnaire were explained to the respondent in advance. The respondent then completed the questionnaire concerning the incident which he and she encountered, and the contents of the questionnaire were checked.

- (2) For the driver behavior, 19 items were set concerning driver behavior immediately before the incident (no safety confirmation, inappropriate assumption, desultory driving, not look ahead carefully, etc.). These types of driver behavior were categorized based on Traffic law violations (as defined by the National Police Agency in Japan).
- (3) 10 items concerning mental and physical state (haste, lowered concentration, drowsiness, etc.) were set in the questionnaire, for a total of 29 selections for each of the seven accident types shown in Figure 4.
- (4) The basic questions for the questionnaire respondent included the following.

- [A] Eight items using the Epworth Sleepiness Scale method of evaluation⁽¹³⁾, which is used as a subjective evaluation method for daytime sleepiness.
- [B] To assess comprehensive driving aggression, which is related to the mental and physical state of haste, six items were selected from among 16 items related to irritation and hostility that were developed by Kasuga *et al*⁽¹⁵⁾ based on a Japanese version of the Buss-Perry method of evaluating aggression⁽¹⁴⁾. The score (Yes = 1, No = 0) total was set as a simplified index of comprehensive aggression.

Based on these results, we evaluated the subjective sleepiness and comprehensive aggression of the respondents.

2-2. Overview of the Questionnaire Investigation

The questionnaire investigation concerning incidents during normal driving was conducted on an interview basis using the created questionnaire form, with subjects consisting of consenting persons affiliated with Aichi Prefectural University in Japan. The number of respondents was 35, ranging in age from 19 to 57 (30 male, 5 female, average age 28.1), with an average of 9.1 years of driving experience.

III. ANALYSIS RESULTS

3-1. Analysis of the Traffic Incidents

The most frequent traffic incidents based on the accident types (Figure 5) were, in order, lane change, rear-end collision, and crossing path. On the other hand, the most frequent types of traffic accidents overall (figures from the National Police Agency in Japan, Figure 6) ⁽¹⁾ are rear-end collision, crossing path, and pedestrian and right turn. The lane change incidents which topped the questionnaire results were lower in terms of actual accidents. The difference between these figures is a matter that requires future study. From the questionnaire results, it was clear that the traffic incident types, with the exception of lane change, covered 93% of the seven accident models that are defined in the ASV Promotion Project in Japan.

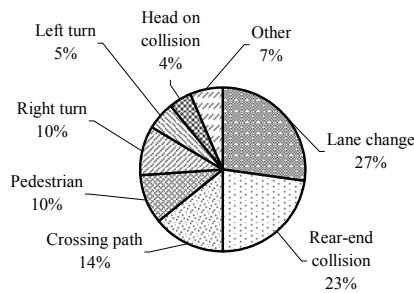


Figure5. Traffic Incidents based on the accidents category [1]

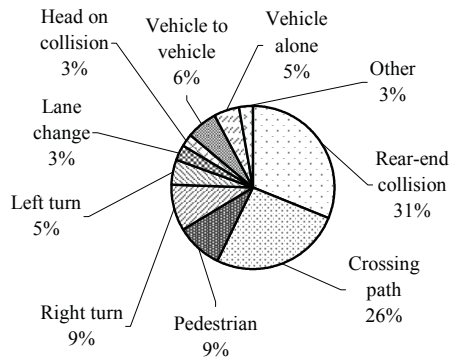


Figure6. Traffic Accidents based on the accidents category [1]

3-2. Analysis of Driver Behavior

The incidents were classified according to the driver behavior immediately before the incident, as shown in Table 2. The most frequent behaviors were, in order, *no safety confirmation* (28%), *inappropriate assumption* (28%), and *desultory driving* (21.5%). Here, *desultory driving* refers to diminished attention due to conversation, absence of mind, or drowsiness. *Normal* is defined as the driver concentrating on driving.

No safety confirmation consisted of a failure to confirm safety before acting. *Inappropriate assumption* consisted of “misprediction” (19.4%) and “lack of driving sense” (8.6%).

Mispredictions accounted for a little under 70% of the inappropriate assumptions.

Desultory driving consisted of “talking, absence of mind” (16.1%) and “drowsiness” (5.4%), with drowsiness accounting for 25% of the desultory driving behavior. *Not look ahead carefully* consisted of “operating in-vehicle equipment” (4.3%) and “glancing at outside objects” (3.2%), with glancing at outside objects accounting for a little over 40% of this type of behavior.

In contrast, the Traffic Law violations resulting in fatal traffic accidents, as released by the National Police Agency (Figure 7) ⁽¹⁾, are *no safety confirmation* (40%), *glance at the road* (22%), and *failure for hazard prediction* (15%). While the top position is the same in both sets of results, the second and lower positions are different in the results of the questionnaire investigation and actual accidents.

Table 2. Driving behaviors in the traffic incidents (n=93)

Driver behaviors	Experiences	Ratio (%)	Mental and physical states	Experiences	Ratio (%)
Desultory driving	20	21.5	Drowsiness	5	5.4
			Absence of mind	15	16.1
Not look ahead carefully	7	7.5	Glancing at the riad	3	3.2
			Operating in-vehicle equipments	4	4.3
No safety confirmation	26	28.0	Not confirming safety	26	28.0
Failure for hazard prediction	3	3.2	Lack of attention, assuming that the other gives away	3	3.2
Inappropriate assumption	26	28.0	Misprediction	18	19.4
			Lack of driving sense	8	8.6
Traffic environment	3	3.2	Misperception for road environments	3	3.2
Other	8	8.6	Normal	6	6.5
			Unknown	2	2.2

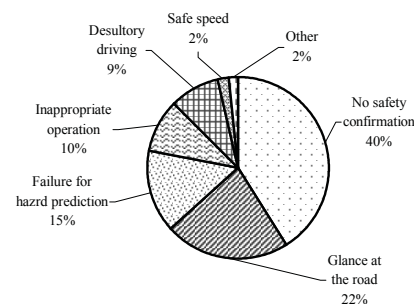


Figure7. Driving behaviors based on the Traffic Law violations [1]

3-3. Analysis of Driver Mental and Physical State

The most frequent mental and physical state of the drivers immediate before the incidents (Figure 9) were, in order, *haste* (28%), *lowered concentration* (25%), *normal* (11%), and *drowsiness* (8%). The top position of haste in the results matches the results of the investigation of driver mental and physical states immediately before accidents conducted by Maruyama (Figure 8) ⁽¹⁶⁾.

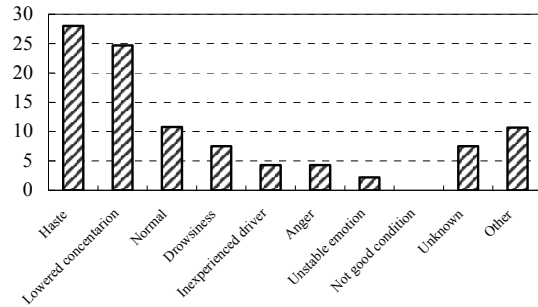


Figure 8. Driver's mental and physical states by traffic incidents (n=93)

3-4. Analysis of the Combination of Driver Behavior and Mental/Physical State

The combinations of the most frequent traffic incidents and their causes are shown in Table 3. The top combination, which is *lowered concentration* plus *desultory driving* is linked to *rear-end collision traffic incidents*.

When the individual combinations for each driver behavior are examined, we see that the mental and physical states related to *no safety confirmation* are *haste* and *lowered concentration*. For *inappropriate assumption*, they are *normal*, *haste*, and *lowered concentration*. For *desultory driving* and *not look ahead carefully*, the related mental and physical state is *lowered concentration*.

Analysis of the questionnaire results shows that lowered concentration is a strong factor, and this matches the results of Kasuga *et al* ⁽¹⁵⁾ which showed that a lack of attention (lowered concentration) during driving was related to many traffic incidents.

Table3. High occurrence rate of traffic incidents (n=93)

Rank	Mental and physical state	Driver behavior	Incident type	Number of responses	Ratio (%)
1	Lowered concentration	Desultory driving	Rear-end collision	4	4.30
2	Haste	No safety confirmation	Right turn	3	3.23
3	Haste	No safety confirmation	Lane change	2	2.15
	Haste	No safety confirmation	Crossing path collision	2	2.15
	Haste	Inappropriate assumption	Lane change	2	2.15
	Haste	Inappropriate assumption	Rear-end collision	2	2.15
	Normal	Inappropriate assumption	Lane change	2	2.15
	Lowered concentration	No safety confirmation	Left turn	2	2.15
	Lowered concentration	No safety confirmation	Lane change	2	2.15
	Lowered concentration	Not looking ahead carefully	Rear-end collision	2	2.15
	Lowered concentration	Desultory driving	Lane change	2	2.15
	Lowered concentration	Inappropriate assumption	Rear-end collision	2	2.15
	Normal	Inappropriate assumption	Crossing path collision	2	2.15
	Drowsiness	Desultory driving	Other	2	2.15

The above shows that driver characteristics that deserve attention include desultory driving (drowsiness, conversation, absence of mind) for driver behavior, and lowered concentration and haste for the driver's mental and physical state.

IV. REGRESSION ANALYSIS OF TRAFFIC INCIDENTS

4-1. Construction of a Driver Model

The number of respondents in the interview investigation was only 35, however statistically this is a sufficient number of samples to allow regression analysis. Previous research ⁽¹⁷⁾ concluded that the occurrence of traffic incidents is an ordinary phenomenon. Analysis of a scatter plot showed a correlation with subjective daytime sleepiness and comprehensive aggression. Therefore, we focused on these factors, and created the model Formula (1) using the occurrence of traffic incidents (Y) as the objective variable, the subjective daytime sleepiness score (X1) and comprehensive aggressiveness score (X2) as explanatory variables, and C_0 as a constant. We then performed regression analysis for a data confidence of 99% (level of significance 1%).

$$Y = aX1 + bX2 + C_0 \quad (1)$$

Table4. Results of regression analysis for occurrences of traffic incidents

Model	Statistic	Response variable Y	Explanatory Variable		C_0
		Occurrences of traffic incident	X1	X2	
1 N=87 Referred	Regression coefficient	-	0.24	-	0.65
	R,t	R=0.49	-	-	-
	P value	-	p<0.001	-	-
2 N=35	Regression coefficient	-	0.30	-	0.39
	R,t	R=0.60	t=4.34	-	t=0.81
	P value	-	0.0001	-	0.43
	Adjusted R-squared	R ² =0.34	-	-	-
3-1 N=35	Regression coefficient	-	-	0.25	1.96
	R,t	R=0.24	-	t=1.42	t=5.61
	P value	-	-	0.16	0.000003
	Adjusted R-squared	R ² =0.03	-	-	-
3-2 N=16 Comprehensive Aggression Scale ≥ 2	Regression coefficient	-	-	0.83	0.13
	R,t	R=0.74	-	t=4.08	t=0.23
	P value	-	-	0.001	0.82
	Adjusted R-squared	R ² =0.51	-	-	-

4-1-1. Traffic Incident Occurrences and Subjective Daytime Sleepiness Score

Regression model 2 in Table 4 shows the results of analysis related to the occurrence of traffic incidents and the subjective daytime sleepiness scores from the 35 respondents. Regression model 1 shows the result of a past study⁽¹⁸⁾ of the relationship between the subjective daytime sleepiness score and the number of traffic accidents experienced (including incidents). We compared the results from model 1 and model 2. The order of both models matched for the regression coefficient and intercept.

With the model 1 regression formula for the relationship between the frequency of traffic incidents and subjective daytime sleepiness scores obtained from the respondents of this investigation, the coefficient of correlation was 0.60 ($p < 0.01$), showing correlation between the two.

4-1-2. Traffic Incident Occurrence and Comprehensive Aggression Score

Regression models 3-1 and 3-2 in Table 4 show the result of analysis related to the occurrence of traffic incidents and the comprehensive aggression score. When the 35 university-affiliated persons are viewed as a whole, the coefficient of correlation of the model formulas for occurrence of traffic incidents and comprehensive aggression score is 0.24 ($p < 0.01$), which does not show a strong correlation between the two. Analysis of a scatter plot showed no correlation with a comprehensive aggression score of 1 or below, but showed correlation with a comprehensive aggression score of 2 or higher (corresponding to two or more of the question items). We therefore performed regression analysis using comprehensive aggression scores of 2 or higher, which resulted in a coefficient of correlation of 0.74 ($p < 0.01$). This confirms a strong correlation with comprehensive aggression scores of 2 or higher.

The above shows that there is correlation between the occurrence of traffic incidents and sleepiness and comprehensive aggression, verifying the results of the questionnaire analysis.

V. PROPOSALS FOR THE DIRECTION OF DRIVER MONITOR SYSTEM RESEARCH

Based on the results described above, it is clear that in addition to providing support for recognizing potential risks in the driving environment during ordinary driving, future advanced driving support systems could detect driver physiological information in real time, and effectively provide support for correct driving decisions and carry out intervention control. Figure 9 shows the functional concept for such an integrated advanced driving support system.

- (1) Detect risk factors in the environment and estimate the risk.
- (2) Detect and estimate the state of the driver, including mental, behavior, and physiological states, as well as specific behaviors.
- (3) Estimate the reliability of the driver's decision concerning risk (presence of human error).

- (4) Evaluate the driver capacity for receiving information and warnings. If the driver capacity is insufficient or the danger exceeds the human ability to react to it, the intelligent driving support system intervenes, either via the vehicle control system or directly, to operate the vehicle systems.

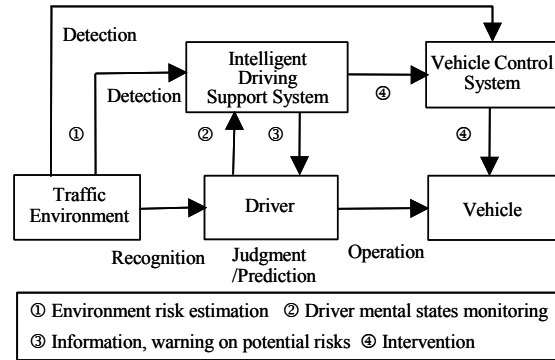


Figure9. Intelligent driving support system using driver's biophysical information

If this intelligent driving support system is created, the system will be able to reduce traffic accidents by obtaining signals related to the driver's mental and physical state, allowing safer driving that matches the driving environment and state of the driver. For example, in the case of traffic incidents rear-end collisions, when the driver's mental and physical state is one of lowered concentration, the driver monitor system detects driver *lowered concentration* and at the same time detects that the driver is insufficiently aware of the driving environment. In combination with information concerning the vehicle surroundings from the system which monitors them, the intelligent driving support system can then provide appropriate information to the driver, warn the driver, or intervene in control of the vehicles, reducing the opportunities for traffic incidents to be involved.

VI. CONCLUSIONS

The results from analysis of this interview-based questionnaire concerning traffic incidents make clear the following four points.

- (1) Types of traffic incidents cover 93% of the seven accident types that are defined in the Phase 3 ASV Promotion Project in Japan.
- (2) A clear correlation was found between the occurrence of traffic incidents and certain driver characteristics. For example, a mental/physical state of lowered concentration has an effect on the driver behavior described as "desultory driving." A mental and physical state of haste has an effect on the driver behavior described as "no safety confirmation."
- (3) There is correlation between the occurrence of traffic incidents and subjective daytime sleepiness and aggression.
- (4) In order to reduce the opportunities for traffic incidents to be involved, steps are needed to control factors related to

subjective daytime sleepiness and comprehensive aggression.

VII. FUTURE RESEARCH

Using a driving simulator, we intend to reproduce the driver behavior for the traffic incidents found in the results from this analysis of an interview-based questionnaire regarding to traffic incidents, and to collect physiological signals related to the corresponding mental and physical states, such as haste and lowered concentration, in order to verify this driver behavior. Based on these results, we will proceed with research and development aimed at the constituent technology needed to establish an integrated advanced driver monitor system, which can reduce opportunities for encounters with potential risks.

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