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Analytical Study of Human Errors causing Traffic Accidents from the view point of Consciousness Transition

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Abstract: The major human errors that have proven to be key factors in 80 to 90% of all traffic accidents include "distraction," taking one's eyes off the road while driving; "inattentiveness," switching one's consciousness from driving to other things; and "false perception" causing recognition mistakes in traffic due to visual illusions. To study human errors causing traffic accidents we evaluated evasive reaction time to an outside dangerous event under distraction and tried to analyze accident probability using reaction time, etc. The analysis integrates drivers' evasive reaction time to dangerous events with variations in driving performance caused by the state transition of driver's consciousness. Further more we estimate effectiveness of a warning system to the distraction.

1. INTRODUCTION

The major human errors that have proven to be key factors in 80 to 90% of all traffic accidents include "distraction," taking one's eyes off the road while driving; "inattentiveness," switching one's consciousness from driving to other things; and "false perception" causing recognition mistakes in traffic due to visual illusions. In recent years, newly developed driver-support systems that use advanced sensor technologies and communication technologies have been used to support driving operation and to prevent human error. However, there is no suitable method to evaluate their contribution to accident reduction. Experimental evaluation of variables such as shortened driver-reaction time for brake operation, for instance, is central to evaluation of the effectiveness of driver-support systems.

This paper describes a study result of rear-end collision frequency analysis using a probabilistic analysis model incorporating system reliability engineering to evaluate rear-end collision and evaluated response delay time under distraction due to various eye direction. The analysis integrates drivers' evasive reaction time to dangerous events with variations in driving performance caused by the state transition of driver's consciousness. And finally effectiveness of a distraction warning devise is also described.

2. MODELLING OF DRIVER UNDER REAR-END COLLISION

2.1 Accidents Due To Inconsistent Driving Performance

Generally, traffic accidents occur when driving performance falls below necessary levels for the traffic environment demands. Fig. 1 presents a conventional diagram of accident potential when driving performance declines due to causes such as long periods of driving. When considering the real world, accidents might easily happen when driving performance drops momentarily due to such things as monotonous driving (inattentiveness) or looking aside (distraction) (Fig. 2).

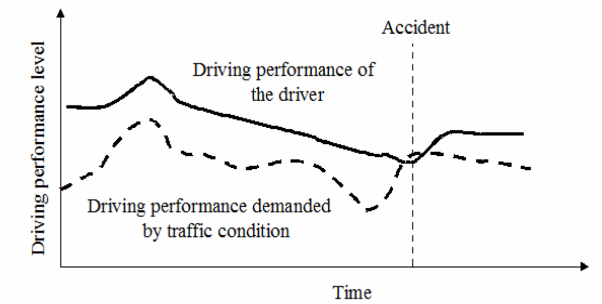

Fig. 1. Fluctuation of driving performance level

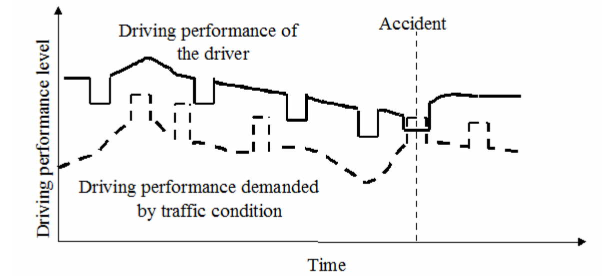

Fig. 2. Fluctuation of driving performance level considering short-time driver distraction

2.2. Modelling of rear-end collision

2.2.1. Causes Of Rear-end Collisions

Rear-end collisions might occur under the following conditions, with the exception of unavoidable situations when a vehicle appears at a timing such that no driver can avoid an accident.

· Driver attention on the road is low due to distractions.
· Driver is inattentive to a dangerous event such as sudden deceleration of a lead vehicle.
· Driving performance lapses and does not recover soon enough to avoid an accident. When driving performance does recover soon enough to avoid an accident, the driver has startled and surprised experience.

2.2.2. Modeling

The system reliability engineering is used usually when analysing electronics systems that have constant failure rate that means failure might occur any time and its rate is constant. We applied the system reliability engineering in analysing traffic accidents because the traffic accidents are considered to occur at random when considering all accidents due to various causes.

Fig. 3 depicts a sequence diagram of a rear-end collision. Symbols are defined as follows.

Q_f : Static probability that driving attention drops.
μ_f^* : Recovery rate of the driving performance in dangerous situations (1/s).
ω_{f0} : Frequency of dangerous situations (1/s).
t_{f0} : Delay time before rear-end collision (s).
μ_{f0} : Rate of rear-end collisions (1/s).

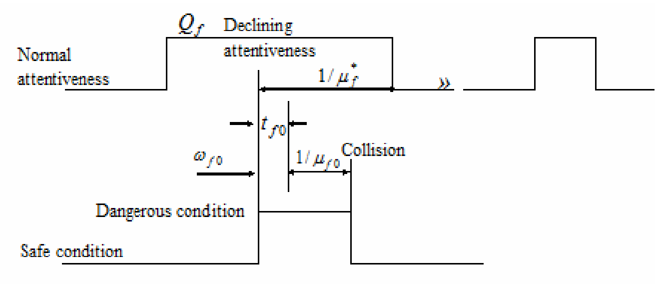

Fig. 3. Timing diagram for rear-end collisions

When modelling the delay time before rear-end collisions and the occurrence rate of rear-end collisions, we considered the following.

Although there is a normal distribution of time-to-collision after a dangerous situation such as sudden deceleration of a lead vehicle, the distribution under the mean time is low because a lead vehicle cannot stop instantaneously in the real world (Fig. 4). Fig. 5 plots the non-collision probability (solid line) and its approximation (dotted line). We approximated the degree of non-collision probability using the delay time before rear-end collision and the occurrence rate of rear-end collisions in this model.

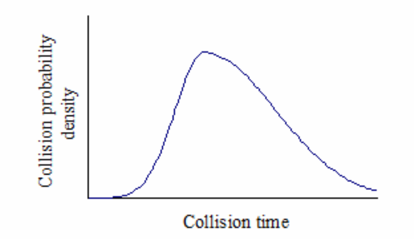

Fig. 4. Collision probability density

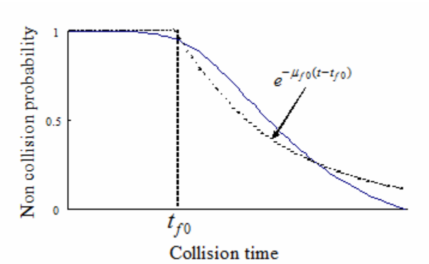

Fig. 5. Distribution of non-collision probability

We obtained the frequency of rear-end collisions through the following procedure.

(1) Static probability that driving attention drops

$$Q_f = \frac{1}{\lambda_f}\mu_f \qquad (1)$$

λ_f : Mean time to distraction
μ_f : Recovery rate of the driving performance in not dangerous situations (1/s).

(2) Frequency of dangerous events when driver's attention level is low ω_{f1} (2)

$$\omega_{f1} = Q_f \omega_{f0}$$

(3) Probability of accidents after dangerous events with low level of driver attention

$$p_f = \int_{t_{f0}}^{\infty} e^{-\mu_f^* t} e^{-\mu_{f0}(t-t_{f0})} \mu_{f0} dt$$

$$= \frac{\mu_{f0}}{\mu_f^* + \mu_{f0}} e^{-\mu_f^* t_{f0}} \qquad (3)$$

Assumptions are as follows.

· When driver attention recovers before a dangerous event occurs, no accident occurs.
· A collision occurs with a delay time t_0 after a dangerous event occurs.

(4) Frequency of accidents after dangerous events with low attention level ω_2

We derived the following formula from the two formulas above.

$$\omega_f = Q_f \omega_{f0} \frac{\mu_{f0}}{\mu_f^* + \mu_{f0}} e^{-\mu_f^* t_{f0}} \qquad (4)$$

This formula shows that a greater recovery rate for driving attention under dangerous situations effectively decreases accident frequency because it is included in the exponential formula.

3. EVALUATION OF RECOVERY RATE OF THE DRIVING PERFORMANCE IN DANGEROUS SITUATIONS

The model described in Section 3 has several parameters. The recovery rate of the driving performance in dangerous situations that is an important parameter in the model was evaluated by using Driving Simulator.

3.1 Evaluation Test

Evaluation test was practiced using a driving simulator. Fig. 6 shows a test scene of the driving simulator test.

Fig. 6. Test Scene using Driving Simulator

The test procedure is as follows.

(1) The subject follows the target vehicle.
(2) The subject moves his/her eye to a gazing point assigned by the evaluator.
(3) The target vehicle starts to decelerate.
(4) The subject applies a braking when he/she notifies the deceleration of the target vehicle.

When the subject is gazing at the fix point, a sub task is given to the subject as a work load. A simple metal arithmetic, an addition of single figure number was used.

Fig. 7 shows the gazing points to which the subject is instructed to move his/her eye as the distraction.

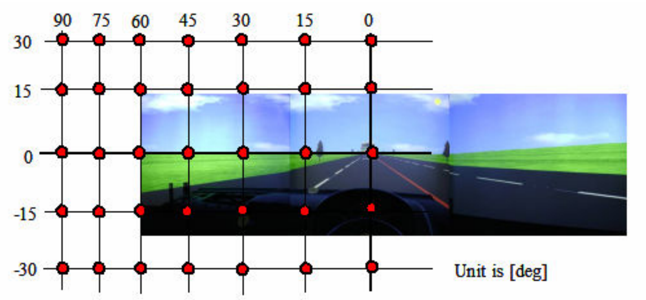

Fig. 7. Distraction points

The evaluation index is the delay time between the target vehicle deceleration and the brake application by the subject.

The number of the subjects is thirty, nineteen subjects of twenty to twenty nine years old and eleven subjects of thirty to fifty nine years old.

3.2 Evaluation Results

Fig. 8, 9 and 10 show the cumulative recovery ratio according to the horizontal, vertical direction, and the response delay time. For example, 90% of subjects who gaze at direct front (Horizontal direction=0 and Vertical direction=0) was able to recognize the target vehicle deceleration and apply a braking within 1s, but only 50% of subjects who gaze at left (Horizontal direction=-45) and down direction (Vertical direction=-15) was able to recognize the target vehicle deceleration and apply a braking within 2s.

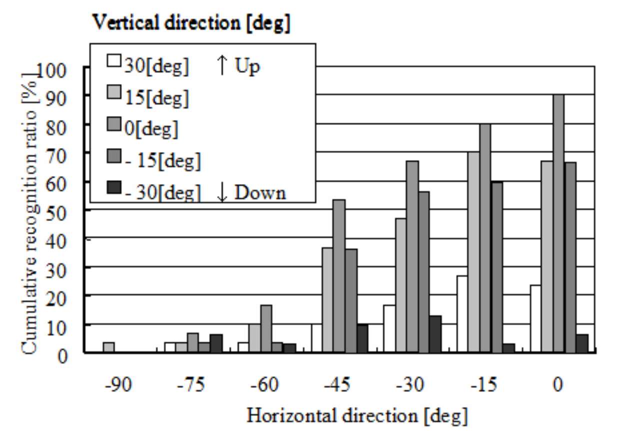

Fig. 8. Cumulative recognition ratio within 1s

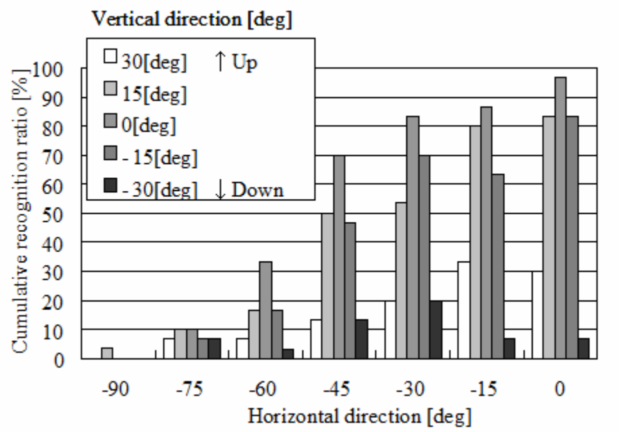

Fig. 9. Cumulative recognition ratio within 1.5s

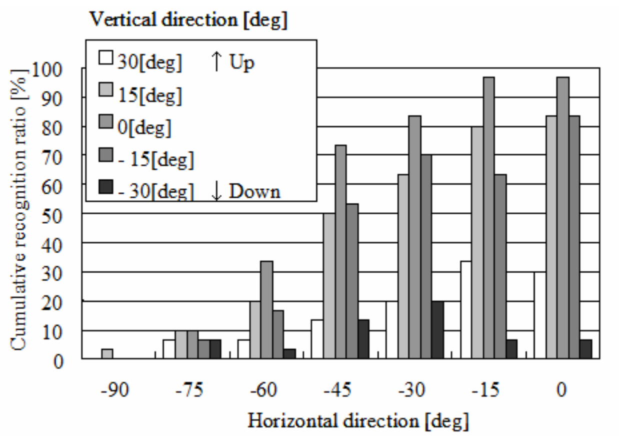

Fig. 10. Cumulative recognition ratio within 2s

3.3 Estimation of Mean Time To Recovery(MTTR) of Driving Performance In Dangerous Situations

3.3.1 MTTR Due To Eye Direction

MTTR is estimated based of Fig. 8, 9 and 10. Fig. 11 and 12 shows a time chart of the cumulative recovery probability for the horizontal angle of the eye direction, 15deg and 45deg as an example (Vertical angle is 0 deg). AS shown in the figures, the cumulative recovery probability increases according to exponential curve. The approximated exponential curve and its mean time to recovery are shown in the figures. The exponential curve follows an equation below.

$$R = 1 - e^{-\mu t} = 1 - e^{-\frac{t}{t_\mu}} \tag{5}$$

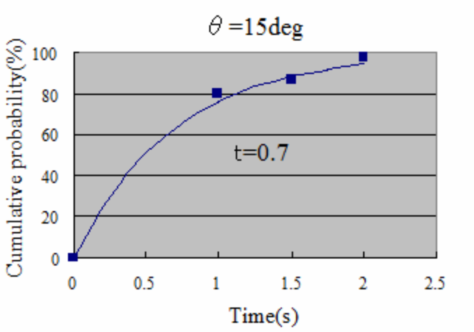

Fig. 11. Cumulative recovery probability, θ =15deg

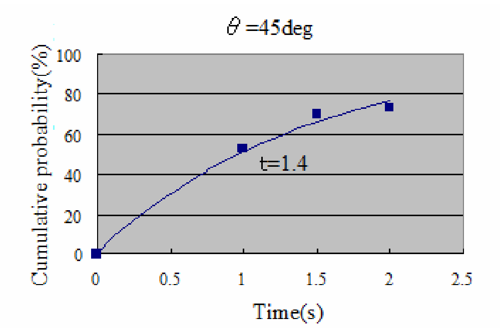

Fig. 12. Cumulative recovery probability, θ =45deg

Estimated MTTR of each eye direction is shown in Table 1.

Table 1. Estimated mean time to recovery of each eye direction(s)

		Horizontal angle(deg)					
		75	60	45	30	15	0
Vertical angle (deg)	0	10.0	4.5	1.4	0.9	0.7	0.5
	-15	15.0	8.0	2.5	1.4	1.2	0.9
	-30	15.0	20.0	15.0	10.0	20.0	15.0

3.3.2. Average of MTTR

The horizontal MTTR is averaged at first. The calculation procedure is explained in the case that the vertical angle is 0 degree. The distribution of eye movement is necessary to average. A distribution shown below is used in this study.

Distribution of eye movement: Normal distribution
Mean, m=0deg
Standard deviation, σ=30deg

Table 2 shows the calculation result. The average MTTR of vertical angle o degree is estimated at 1.3s.

Table 2. Average recovery time

Horizontal angle	Mean time to recovery	Section cumulative probability m=0, σ=30	Recovery rate * Cumulative probability
0	0.5		
(7.5)	(0.6)	0.38	0.23
15	0.7		
(22.5)	(0.8)	0.30	0.24
30	0.9		
(37.5)	(1.15)	0.18	0.21
45	1.4		
(52.5)	(2.95)	0.09	0.26
60	4.5		
(67.5)	(7.25)	0.03	0.24
75	10		
(82.5)	(12.5)	0.01	0.12
90	15		
	Average MTTR		1.3

Same calculation is applied to vertical angle -15 and -30 degree. Table 3 shows the calculation results. In the case where the vertical angle is -30 degree, the normal distribution whose mean value is 27.5 degree and standard distribution is 5 degree considering a radio or CD is an operation target.

Table 3. Average MTTR

Vertical angle	MTTR	Note
0	13.0	m=0, σ=30
-15	1.68	m=0, σ=25
-30	14.2	m=27.5, σ=5

Finally, average calculation is applied to the vertical direction.

Table 4 shows the calculation result. The distribution of eye movement is estimated based on the reference paper that includes a content shown in Table 5.

As shown in Table 4, the average MTTR considering all eye movement direction is estimated at about 1.5s.

Table 4. Horizontal and vertical average MTTR

Vertical angle	MTTR	Cumulative probability	MTTR * Cumulative probability
0	1.3	0.75	0.99
-15	1.68	0.24	0.4
-30	14.2	0.01	0.14
	Average MTTR		1.53

Table 5. Distraction distribution

Distraction items	Frequency (%)
Things Outside the Car	29.4
Adjusting Radio, CD, etc.	11.4
Other Occupants	10.9
Moving Objects in Car	4.3
Other Objects in Car	2.9
Vehicle Control	2.8
Eating, Drinking	1.7
Cell Phones	1.5
Smoking	0.9
Other Distractions	25.6
Unknown Distraction	8.6

4. FREQUENCY ESTIMATION OF REAR-END COLLISIONS

4.1. Frequency Estimation

Table 6 shows the parameters for estimating the frequency of rear-end collisions referring attached papers.

Table 6. Parameters for rear-end collisions

Parameter	Value	Content
$1/\lambda_f$	1(h)	63% driver may have a distraction after one hour.
$1/\mu_f$	1.75(s)	A little larger than $1/\mu_f^*$
Q_f	4.6E-4	See Equation (1).
$1/\mu_f^*$	1.5(s)	See Section 3.
ω_{f0}	5(/h)	Dangerous situations occur 5 times/h.
t_{f0}	3.5(s)	Average time before entering a collision area is 3.5s.
$1/\mu_{f0}$	3.5(s)	Average mean time to a collision is 3.5s.

Results are as follows.
(1) Frequency of dangerous situations when driver is distracted ω_{f1}

$$\omega_{f1} = Q_f \omega_{f0} = 2.4\times10^{-3}$$

This means that, on the average, a driver will encounter a dangerous situation where a rear-end collision might occur once every 400 hours.
(2) Probability of a rear-end collision in a dangerous situation

$$p_f = \int_{t_{f0}}^{\infty} e^{-\mu_f^* t} e^{-\mu_{f0}(t-t_{f0})} \mu_{f0} dt = \frac{\mu_{f0}}{\mu_f^* + \mu_{f0}} e^{-\mu_f^* t_{f0}}$$

$$= \frac{1}{1+\frac{3.5}{1.5}} e^{-\frac{1}{1.5}\times 3.5} = 0.029$$

This result agrees with Heinrich's Law that says there are many small accidents behind a serious accident.
(3) Frequency of rear-end collision when driver is inattentive.

$$\omega_f = Q_f \omega_{f0} \frac{\mu_{f0}}{\mu_f^* + \mu_{f0}} e^{-\mu_f^* t_{f0}} = 7.0\times10^{-5}$$

This means that an average driver might cause a rear-end collision once every 30 years.

4.2. Comparison with Accidents Statistics

(1)National road
(a)Accident statistics
Travelling distance: 2×10^{11}km
Accidents number: 48972
(b)Accidents number estimation using the model
Average speed: 8.3m/s (30km/h)
Traveling hour: 6.6×10^{8}h (2×10^{11}km / 30km/h)
Consequently
Estimated accidents number: $7.0\times10^{-5}\times6.6\times10^{8}$
$=4.6\times10^{4}$

The result is similar to that of the accidents statistics.

(2)Expressway
(a) Accident statistics
Travelling distance: 1×10^{11}km
Accidents number: 7961
(b) Accidents number estimation using the model
Average speed: 80km/h
Traveling hour: 1.25×10^{8}h (1×10^{11}km / 80km/h)
Consequently
Estimated accidents number: $7.0\times10^{-5}\times1.25\times10^{8}$
$=8.8\times10^{3}$

The result is a little larger than that of the accidents statistics because the expressway is safer than the national road, etc..

5. EFFECTIVENESS ESTIMATION OF DISTRACTION WARNING

A system that detects driver distraction and/or drowsiness condition, and issues a warning is under development. Here, effectiveness of the distraction warning is estimated.

5.1. Frequency Estimation of Rear-End Collisions

Fig. 13 shows the estimated frequency result using $1/\mu_f^*$ as a parameter. Accident frequency varies according to the average mean time to recovery.

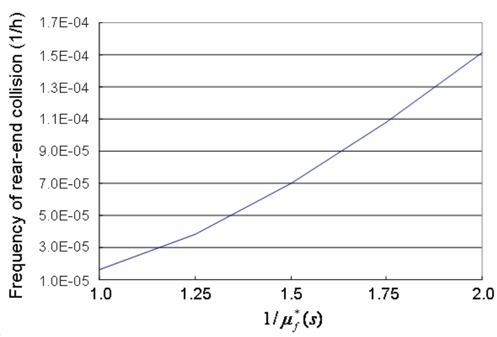

Fig. 13. Frequency of rear-end collision

5.2. Effectiveness Estimation of Distraction Warning

Specification of the distraction warning is assumed as follows.

·Warning timing: Distraction warning is issued at more than three second.

·Average mean time to recovery with warning: 0.75s (0.75s is estimated considering moving time of the head to the front and recognition time of dangerous situation)

Fig. 14 shows the time chart of driving performance recovery that include recovery process explained before and quick recovery process by the warning issued 3s later. And, approximated exponential curve that fits the recovery process after 3s is shown. The mean time to recovery of the approximated exponential curve is 1.2s. This value can be used to estimate effectiveness of the warning because the collision frequency is mainly affected by value after t_{f0} (See Equation (3)).

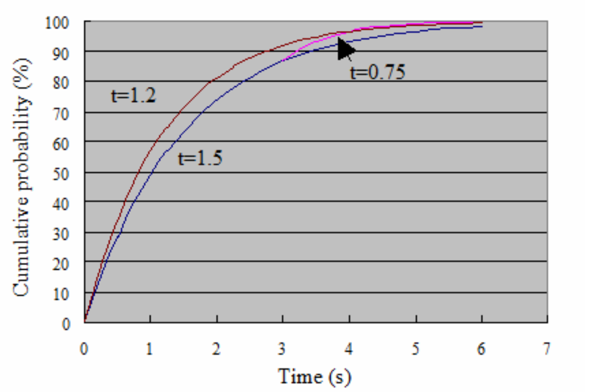

Fig. 14. Recovery process with warning

Appling the above result to Fig. 13, the rear-end collision frequency with the distraction warning is estimated at 3.5×10-5 /h. Consequently about half of rear-end collision due to distraction may be avoided by using the distraction warning.

6. CONCLUSION

Although drivers know well that their slight inattentiveness might cause traffic accidents, drivers tend to be off their guard because an accident did not occur fortunately because of not entering in dangerous situation by chance. But, our probabilistic analysis model integrating drivers' evasive reactions time to dangerous events with the fluctuation of driving performance caused by the changing state of consciousness demonstrates that drivers are always in potential danger behind the wheel.

Especially recovery time from distraction is important. The driver can not notify a dangerous situation at the front when moving his/her eyes far from the front direction. These situations might occur when operating audio systems, etc. and cause an accident unfortunately. It is most important for the driver not to move his/her eye from the front, but it is a little difficult due to human characteristics. Consequently, a distraction warning system that that detects driver distraction and/or drowsiness condition, and issues a warning is considered useful. The effectiveness of the system was evaluated in the paper. When the system works well, half of rear-end collision due to distraction may be avoided. But, it is important to avoid driver over-reliance on the system that causes more frequent distraction than before.

We hope that the results of this research would contribute to enhance traffic safety.

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