Traffic Safety Measures with Image Processing Sensors And Analysis of Vehicle Behaviors

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Summary

To develop effective and efficient traffic safety measures based on cooperation between drivers, vehicles and infrastructure corresponding to risk conditions at individual locations, the National Institute for Land and Infrastructure Management (NILIM) and the Advanced Cruise-Assist Highway System Research Association have been promoting R&D for the Advanced Cruise-Assist Highway Systems (AHS) with help of roadside equipment. The AHS image processing sensors developed for road management which detect dangerous phenomena also provide lots of precise individual vehicle's behavioral data. The obtained data can be used for the analysis of dangerous situations for the formation of traffic safety measures. This study analyzes data on vehicle behavior at accident-prone curves and reports on the feasibility of a AHS traffic safety service by examining the reduction of near miss or hazardous situations by transmitting automatically detected accident events to following vehicles.

Keywords: *Preventive traffic safety, AHS, image processing sensor, accident reduction, Prevention of latent danger*

1. Introduction

In Japan, the fatalities by traffic accidents during 2005 amounted to 6,871. This number declined by 6.6% from the previous year, while both the annual casualties (1,156,633) and total number of accidents (933,828) remain at a high level. The Ministry of Land, Infrastructure and Transport set the traffic accident rate as a political outcome indicator and has been reinforcing countermeasures by specifying the procedure for traffic safety measures which consists of selection of target locations, accident factor analysis, planning of countermeasures, and evaluation of taken measure effects, based on situation diagrams of occurred accidents.

The conventional fundamental data for traffic safety measures, reported fatal or injured accidents, are not sufficiently accumulated for individual traffic safety countermeasure planning. Further data accumulation of before and after implementing countermeasures is also required in order to grasp effectiveness of taken measures, which remains a long time till we achieve objective evaluation methods of taken measures in a shorter period. The authors propose a new traffic safety measures by quantitative understanding of vehicle behaviors in near miss situations and consequent efficient countermeasure planning and evaluations through fixed-point observations, by diverting the image processing sensors developed for Advanced Cruise-Assist Highway Systems (AHS) as an efficient data collectin device of vehicle behavior at specified locations.

2. Methods of Traffic Accidents Analysis focusing on Near Misses

In recent years, many fields of industries including railway and medical care, have applied the approach of preventing serious accidents through the prevention of near misses and unsafe actions based on the Heinrich's Law.[1)] Heinrich's Law, as the results of statistical analysis of disaster types caused by the same people, states that the ratio of occurrence frequencies of major injuries (accidents reported to insurance agents, etc.), minor injuries (superficial wounds or blows taken care of by first-aid), and no-injury accidents (accident that could have led to injury or property damage in unexpected situations accompanying the transport of people or material goods) is 1:29:300, and that thousands of unsafe actions and situations are presumed to exist behind them. Figure 1 shows a projection map of Heinrich's law to road traffic safety accidents.

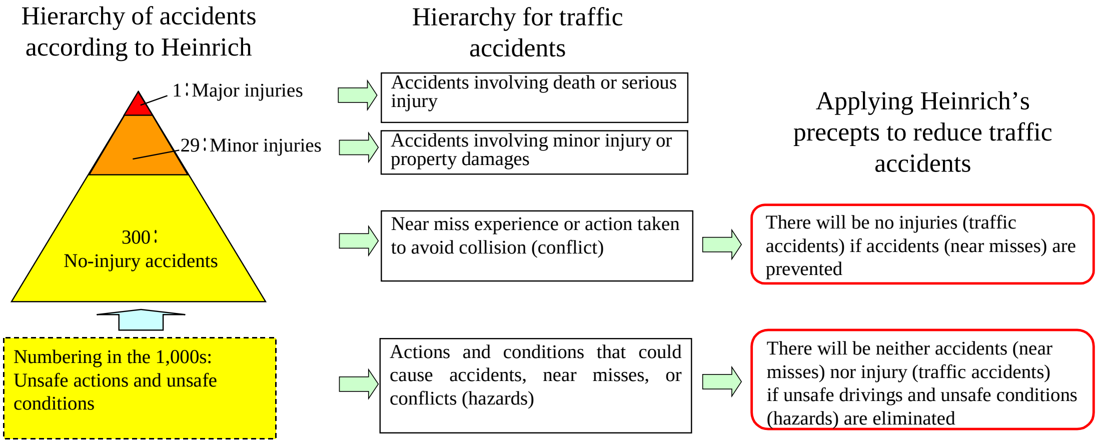


Figure1: Projection map of Heinrich's disaster hierarchy Law to traffic safety

In the case of road traffic, no-injury accidents correspond to conflicts when drivers subjectively experience near misses and objectively take actions to avoid collisions. Renge states[2)] that the basic concept corresponding to unsafe action or condition is hazard which increases accident probabilities, and that combination of several hazardous conditions will lead to an accident.

Heinrich offers the following two rules based on the above relationships:

(i) Injuries disappear if no-injury accidents are eliminated; and

(ii) No-injury accidents and injuries disappear if unsafe actions and conditions are both eliminated

To apply these rules to road traffic safety, reduction of near misses and conflicts, and elimination of hazards is supposed to be effective in eliminating traffic accidents.

At sharp curve sections on expressways, main causes of accidents are excess speeding at curve entry and poor visibility of a queue's rear ends or a stationary vehicle. Table

1 shows a list of indicators for analysis of vehicle behavior at these types of road sections.

Table 1: Objective Indicators Used for Curve Sections

Classification according to Heinrich's Law	Objective Indicators for Traffic Safety	
	Category	Example of indicator
No-injury accident	Actions taken to avoid collision (conflict)	Rapid deceleration, avoidance to prevent collision
Unsafe actions	Environment and conditions that could cause accidents or conflicts (hazards)	High speed when entering a curve, short headway
Unsafe conditions		Presence of standing or slowing vehicles, wet road surface

The authors propose "rapid deceleration" as a conflict indicator because many drivers are likely to experience rapid deceleration in near miss situations. In line with the report[3)] by Enke that the typical figures of rapid deceleration immediately before a collision are 0.5G or above, the authors define the cases of 0.5G or above within a curve as rapid deceleration.

3. Method of Micro Analysis of Traffic Behavior using AHS Cameras

Image processing sensors (AHS sensors) captured the behavior of individual vehicles and detected vehicle position and speed every 0.1 seconds, producing detailed data on acceleration and lane changes. This system realizes examination of conflicts that do not directly result in accidents and project conditions under which near misses occur. This type of ITS utilization leads to traffic safety countermeasure planning on the spot through efficient and large supply of thus far unknown vehicle behavioral data by the following procedure.

<u>Vehicle Behavior Data Collection</u>

A set of AHS sensors covering curve sections detects vehicle positions and speeds from image data by far infrared cameras or visual cameras with performance as indicated in Table 2. This system outputs three types of road traffic obstruction: stationary vehicles (4km/hour or below), slow-moving vehicles (14km/hour or below) and traffic jams (20km/hour or below).

Table 2: Sensor Performance

Sensor Type		Far Infrared	Visual
Detection interval		100 ms	100 ms
Accuracy of positioning	Longitudinal	±5 m	±5 m
	Lateral	±1 m	±1 m
Accuracy of speed		±5 km/hour	±10 km/hour or ±10%, whichever is greater
Reliability of incident detection		96% or more	90% or more

The data of curve entering speed and rapid deceleration of vehicles in case with obstruction on the road are summarized. To remove the cases of following driving behaviors in apparent congestion, the data of curve entering speed at less than a threshold (adopted 40km/h: congestion stipulation by the Metropolitan Expressway) are excluded.

Data Processing Algorithm

The curve entering speed is defined as the initially detected speed in the sensing area of about the first five meters of the curve (equivalent to one passenger car length). Based on the finding from driving simulation experiments[5)] that subjects generally continued rapid braking for one second or more once they recognized a stationary vehicle ahead, observed deceleration for each second is calculated from simple average of detected speed every 100 milliseconds. The maximal deceleration calculated from its moving average for each 0.5 seconds is used to analyze rapid braking situations.

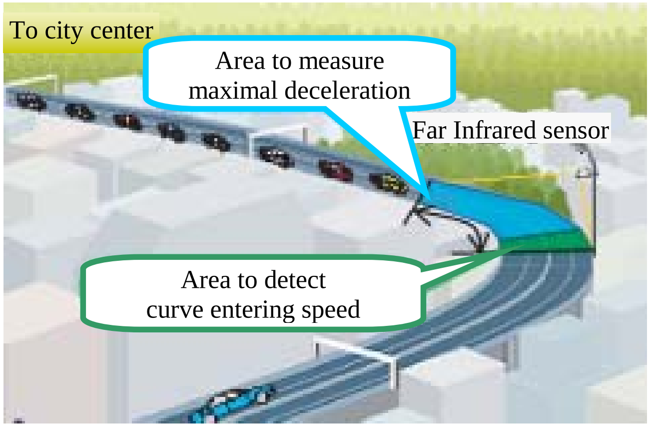


Figure 2: Scope of Detection for Each Indicator

4. Applied Cases to Actual Roads

Results of applied one case for urban expressway and another case for inter-urban expressway are discussed in this section .

Urban Expressway (Sangubashi Curve)

Figure 3: Overview of the Sangubashi Curve

The Sangubashi curve (Figure 3) on inbound Shinjuku Line #4 of the Metropolitan Expressway has a heavy traffic of about 47,000 vehicles per day through a sharp curve with the radius of 88 meters. In fiscal 2003, there occurred 181 accidents (including property damage) within 500-meter section around the curve. This accident-prone area recorded the worst number of accidents and accident rate in the Metropolitan Expressway before introducing the AHS countermeasures. The noise barrier walls inside along this curve even prevent drivers from securing enough stopping sight distance when driving faster than the design speed (50km/h). Four far infrared cameras were installed here and observations were conducted for one week in October 2003.

Traffic obstructions occurred about 2.6 hours per day on average, and hazards (unsafe conditions) such as traffic jams within the curve occurred daily (Table 3).

Table 3: Observed Traffic Obstruction (Sangubashi Curve)

Event Type	Time Period Detected (Hours/Day)
Stationary vehicle	0.7
Slow-moving vehicle	0.6
Traffic jam	1.3
Total	2.6

The distribution of maximal deceleration in case of traffic obstructions peaks at 0.2-0.3G and half of the vehicles decelerates at 0.3G or more in confronting traffic obstructions at the entering speed of 40km/h or above (Figure 4). As compared to the maximal deceleration for Adaptive Cruise Control Systems (ACC) (prescribed not to exceed 0.3 m/s^2 to avoid mistake for driving safety warning), these values apparently deviate from those in normal driving.

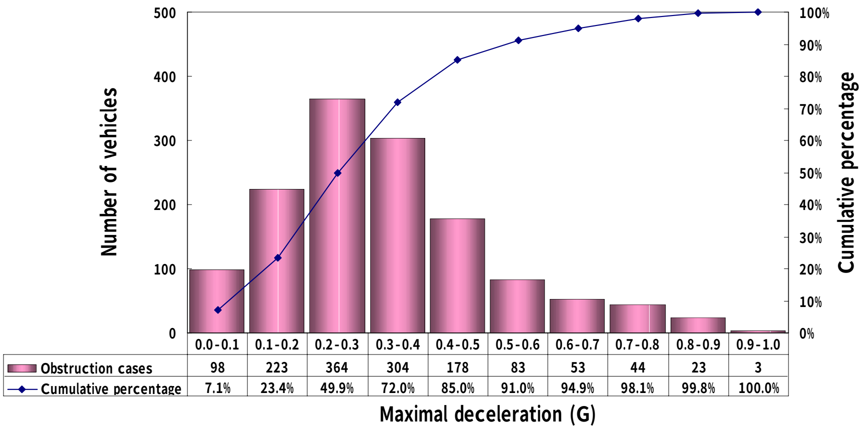


Figure 4: Maximal Deceleration
(Sangubashi: Cases of Obstruction)

196 vehicles, on the average, encountered some obstruction on the curve per day (Table 4). 29 of them, namely one sixth of vehicles, experienced rapid deceleration equivalent to accident cases when entered the curve and confronted traffic obstructions ahead. This ratio is as four times high as that of rapid deceleration without any obstructions (3.7%).

Table 4: Rapid Deceleration Cases (Sangubashi Curve)

Condition Ahead		Number of Entered Vehicles (Units/Day)	Number of Vehicles Rapidly Decelerated (Units/Day)	(%)
Obstruction		196	29	15.0%
	Stationary vehicle	22	5	22.7%
	Slow-moving vehicle	80	9	11.3%
	Traffic jam	94	15	16.0%
No obstruction (as reference)		20,106	753	3.7%
Total		20,302	782	3.9%

Rapid deceleration cases of obstruction ahead correspond to about 870 vehicles per month. To compare 11 accidents cases per month, behind one case of accident there existed 80 cases of rapid deceleration or near misses.

<u>Inter-Urban Expressway (Maitani Curve)</u>
The Maitani curve (Figure 5) on outbound National Highway #25 (Meihan National Highway) also has a heavy traffic of about 31,000 vehicles through a sharp curve with the minimal curve radius of 150 meters and the maximal (downward) slope of 6%. In this accident-prone curve section, 20 or more accidents with major injuries have occurred yearly from 2000 to 2002. Actual average curve entering speed (70 km/hour) exceeds the speed limit (60 km/hour), and side-wall or rear-end collisions often occurred due to speeding or skids. Two signboards were installed just prior to this curve to broadcast information on obstructions since June 2002, and five visual AHS cameras were newly installed. The vehicle behaviors were observed for one week in January 2005 with obstruction information broadcasting, and 3 days also in January 2005 without obstruction information broadcasting.

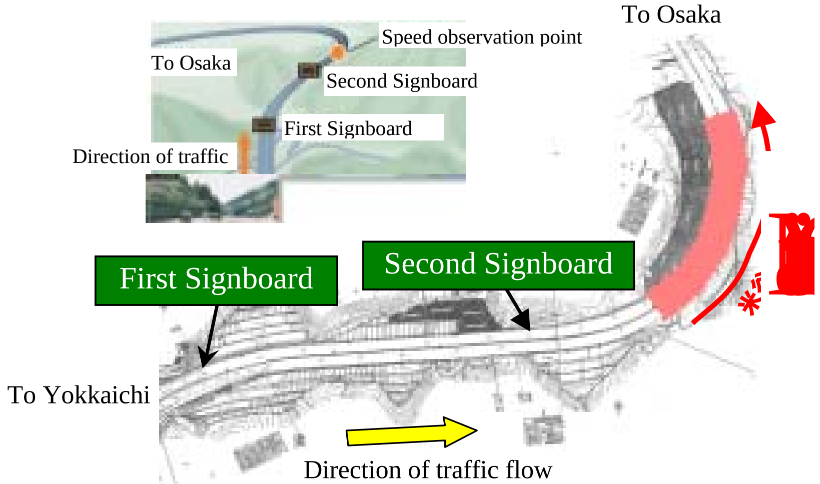


Figure 5: Overview of the Maitani Curve

Traffic obstruction cases occurred for 1.1 hours per day on the average (Table 5). The vehicle behavior data of before and after installation of two signboards to broadcast traffic obstruction information of curve sections are compared.

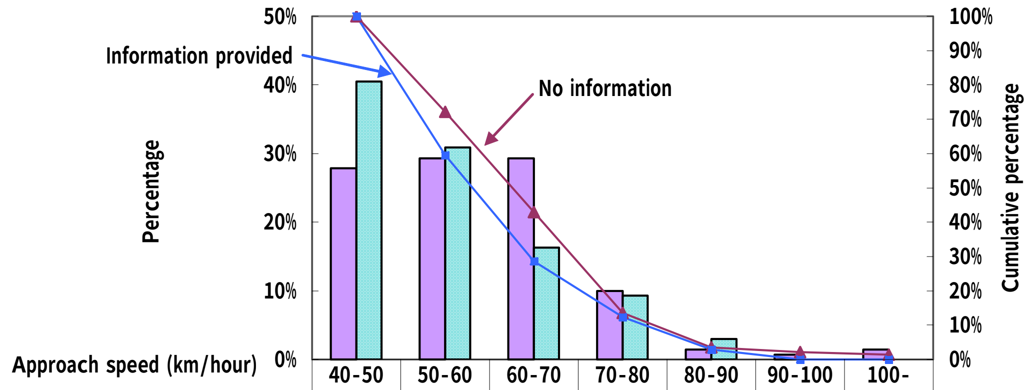
Table 5: Traffic Obstruction Cases (Maitani Curve)

Event Type	Time Period Detected (Hours/Day)
Stationary vehicle	0.0
Slow-moving vehicle	1.0
Traffic jam	0.1
Total	1.1

One fourth of vehicles at 40 km/hour or more rapidly decelerated without obstruction information, while just one sixth rapidly decelerated with the information when entering the curve and confronted some traffic obstruction (Table 6). This supports the idea that information provision on traffic obstructions within the curve contributes to reduce conflicts.

Table 6: Rapid Deceleration Cases
(Maitani: Cases of obstruction)

Information Broadcasting	Number of Entered Vehicles (Units/Day)	Number of Rapid Deceleration	
		(Units/Day)	(%)
Without	47	12	25.5%
With	77	13	16.9%



	40-50	50-60	60-70	70-80	80-90	90-100	100-
No information (N = 140)	27.9%	29.3%	29.3%	10.0%	1.4%	0.7%	1.4%
Information provided (N = 472)	40.5%	30.9%	16.3%	9.3%	3.0%	0.0%	0.0%
No information (Cumulative percentage)	100.0%	72.1%	42.9%	13.6%	3.6%	2.1%	1.4%
Information provided (Cumulative percentage)	100.0%	59.5%	28.6%	12.3%	3.0%	0.0%	0.0%

Figure 6: Curve Entering Speed (Maitani: Cases of Obstruction)

Comparison between with and without information provision at the distribution of curve entering speed in case of traffic obstruction in the curve also supports the effectiveness of information provision (Figure 6). The average speed in case without information was 59.0 km/hour; while that in case with information was 52.7 km/hour, which shows 6.3 km/hour decline in speed. The percentage of vehicles entering the curve at 60 km/hour or more declined by more than 30%, from 42.9% to 28.6% in case with information provision. These data revealed the effectiveness of information provision on traffic obstructions to suppress traveling speeds.

5. Traffic Safety Measure Using AHS Roadside Cameras

The following traffic safety procedure based on microscopic traffic behavior analysis using AHS sensors is derived from the examination at two actual roads:

First, Heinrich’s Law is found to be generally applicable to traffic accidents by the comparison of accident cases and conflict cases in a macroscopic level. This implies the possibility of exploring short-term traffic safety measures without waiting for data accumulation. This also proposes a new objective methodology for traffic safety planning founded in near miss data, in addition to the conventional approach founded in occurred accidents to utilize accident factor analysis that heavily relies on the experience of authorities in accident analysis, as the result of microscopic analysis of individual vehicle behavior. Thus a new methodology to reinforce traffic safety measures is obtained.

Furthermore, the success of alleviation in conflicts as rapid deceleration by informing following drivers of hazards as traffic jams in the curve ahead, by prompt information provision for driving safety support coordination to traffic conditions on the road, confirms the effectiveness of AHS image processing sensors also as preventive tools for traffic safety.

A new more scientific and prompt preventive traffic safety measure planning procedure can be expected to be developed with effective use of AHS image processing sensors.

Situations to apply AHS sensors as a traffic safety tool are as follows:

1) Plan-Do-Check-Action (PDCA) cycle of traffic safety measures in shorter period that consists of factor analysis, countermeasure planning, measure implementation, evaluation and improvement contributes to advanced traffic safety measures.
2) At accident-prone locations through sensor installation, objective countermeasure planning based on analysis of vehicle behavior become possible in addition to conventional accident factor analysis.
3) At potential risk locations, conflict data collected with sensors enable risk evaluation and factor analysis behind the risks.
4) Analysis of vehicle behavior changes in before and after countermeasure realizes efficient understanding of countermeasure effects in short period.
5) Provision of event information acquired with AHS sensors to users enables further application for preventive safety measures such as rear-end collision prevention.

6. Conclusion

This study revealed the following as the result of actual traffic data analysis:

1) A concept (Heinrich's Law) established in industrial accident field on the relationship between injuries and no-injury accidents was applicable to traffic safety issues and it was demonstrated that the reduction of near misses, conflicts and hazards lead to the decrease of traffic accidents.
2) At sharp curve sections with heavy traffic flow, disturbing events such as traffic congestion and stationary vehicles on road daily occur.
3) Around 20% of observed vehicles that entered curves made rapid decelerations (more than 0.5G), which confirmed greater number of conflicts than that of actualized accidents.
4) Comparison of vehicle behavior between with and without information provision confirms suppression of rapid deceleration and reduction of curve entering speed by information provision about obstructions ahead using roadside signboards.

To summarize, prevention of hazards such as other accidents and traffic congestion at curves with poor visibility is essential, because drivers there are not highly likely to sufficiently foresee encountering obstructions on access-controlled expressways without signals.
Moreover, in case of such hazardous conditions, information provision to drivers on traffic obstructions ahead is effective in reducing approaching speeds into curves and also results in fewer rapid decelerations within curves, which leads to safer driving.

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