EVALUATION OF ACTIVE SAFETY PERFORMANCE OF MAN-VEHICLE SYSTEM

Shun 'ichi Doi
Sueharu Nagiri
Yasushi Amano
Toyota Central R&D Labs., Inc.
Paper Number 98-S2-O-05

ABSTRACT

Human factors have been found to be the major cause of vehicle accidents. We studied the driver-vehicle closed-loop system. Using the motion-type driving simulator the active-safety performance of 100 ordinary drivers was examined for two conditions : obstacle avoidance and slippery curve control. From the resulting data a computer model was developed. After confirming the validity of the computer model, the active-safety performance of drivers under the two conditions was better understood and in the case of the slippery curve condition, driver assistant devices are feasible.

INTRODUCTION

In future transport systems, driver/ vehicle/ environment interactions are major issues in the active safety of vehicle operations. Almost all the causes of accidents are related to human factors involved in the driver's maneuvers: Recognition, judgement and operation. Improving the maneuverability of vehicle is urgent problems for vehicle-based technologies like collision avoidance systems. In this field of studies, it is indispensable for discussing the point of view of man-in-the-loop to consider active safety performance of vehicle.

Concerning to these problems, there are many prior studies about driver's behavior analysis with proving ground tests and driving simulators. The mathematical maneuver's modelings were also proposed for various driving situations from the results of the analysis. Under these considerations, it would be more important to obtain the ordinary driver's performances as well as expert drivers. The compromization with the driver's maneuver and the operation of vehicle would realize the real vehicle safety.

In this study, taking driver-vehicle closed loop into account, active safety performances of the system were analyzed in emergency situations. At first, under such critical conditions like sudden emerged obstacle avoidance, ordinary driver's avoiding maneuvers were examined using a motion-type driving simulator. According to the driver's maneuvers in various emergency conditions, a database of driving operational characteristics was constructed and a mathematical model of driver's operation was also derived from these data. By computational simulation with driver/vehicle closed loop model, the performance of the system was predicted. The agreements with predicted performance were verified from experimental results. Especially in the case of curved road running condition, assuming the sudden change of road surface to a slippery situation, the effect of an " assistant control of steering" was estimated from both the model simulations and experiments by the driving simulator.

EMERGENCY AVOIDANCE EXPERIMENTS

Experimental Procedure

The driving simulator used in this study is illustrated (Figure 1.). The simulator is constructed with the moving base of two degrees of freedom, namely roll and lateral motions. On the moving base, the systems are mounted with driving cockpit and visual screen. Driving seat is installed in the half-cut vehicle body and the visual scenes given by computer graphics systems according to the driver's operations. Both of the motion and visual systems are controlled by computational vehicle model driven by the driver. The projected visual angle is 60 degrees wide at the screen located in 2.5 m ahead from the driver. Inside the cockpit, there are equipped imitating systems for steering reactions and induced small vibrations and interior noise corresponding to the state of the running conditions.

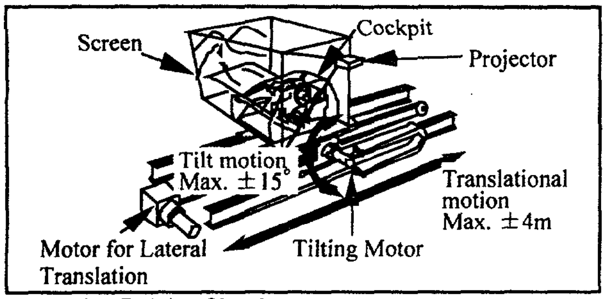

Figure 1. Driving Simulator.

The motion base is moved laterally by chained belts along the pair of lateral rails and rotatively by another motor installed in the bottom of the cockpit. In the systems, the lateral motion is controlled proportionally by the calculated lateral displacements of the vehicle model and the rotational motion is also controlled according to the centripetal acceleration by the vehicle speed and the road curvature of supposed situations. Using these equipments, driver's behaviors and vehicle performances are measured quantitatively in the same time.

The vehicle model used in the simulator has three degrees of freedom, namely longitudinal and lateral and yawing motions. The tires are modeled by Magic-Formula equation with combined status of lateral and longitudinal acting forces. The vehicle dynamics is calculated by personal computer from the input signals of the driver, accelerator pedal stroke, brake pedal stroke and steering wheel angle. The calculation interval of vehicle dynamics is 10 milliseconds.

Two kinds of experimental tasks for emergency avoidance are examined. One is a sudden emerged moving obstacle during running on the road and another is an unexpected slippery surface during curve running (Figure 2.). These tasks are supposed to be ordinary road and indicated vehicle speed is about 60 km/h for each subject. The experimental subjects are all ordinary drivers, and the number is 100, including 20% female drivers and the age from twenties to fifties

Driver's Maneuvers in Emergency

Driving behaviors were examined by imitating obstacle emerging behind walls and surface change on curved road. From the results of obstacle avoidance, the database of driver's operational characteristics depended on the modes of maneuver is constructed. The modes of avoidance are divided into associated operation of braking and steering and single operation. Averaged values of each steering and braking maneuvers are also shown (Table 1.).

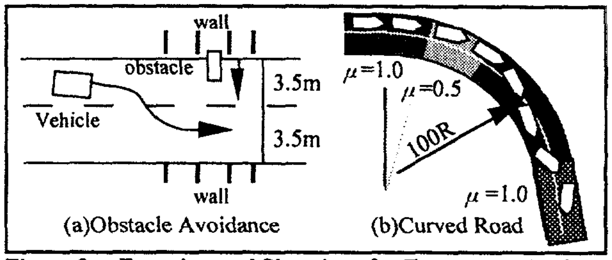

Figure 2. Experimental Situations for Emergency Avoidance.

Table 1.
Characteristics Values of Driver's Maneuvers

modes of maneuver	success /fail	steering maneuvers			braking maneuvers		
		τ sec	$\dot{\delta}$ max	δ max	τ b	Tb sec	Bs %
total panel's operations	all	0.72	355	104	0.74	0.39	65
	s	0.73	372	121	0.69	0.36	67
	f	0.70	333	85	0.78	0.41	63
case of associated operation	s	0.70	369	132	0.70	0.37	64
	f	0.72	316	101	0.76	0.40	62
case of single operation	s	0.55	378	102	0.63	0.36	80
	f	0.59	421	111	0.80	0.42	65

τ :Steering reaction time(sec)
$\dot{\delta}$ max :Maximum steering velocity(degree/sec)
δ max :Maximum steering angle(degree)
τ b :Braking reaction time(sec)
Tb :Braking time const(sec)
Bs :Braking stroke(%)

The examples for individual operational characteristics are histogramically shown (Figure 3.). From these database, the difference of reaction time between the case of success and fail (collision) and the amount of each operation are clarified

Next the observation of driving managing behaviors in curved road leads to the relation between reaction time and steering velocity in the case of slippery region (Figure 4.). From the result, the reaction time is distributed in the center of 0.7 seconds after encountering slippery surface and the maximum steering velocity is distributed around 400 degree/s. In that case, the driver's maneuvers are depended on the individual situations and their experiences. In these

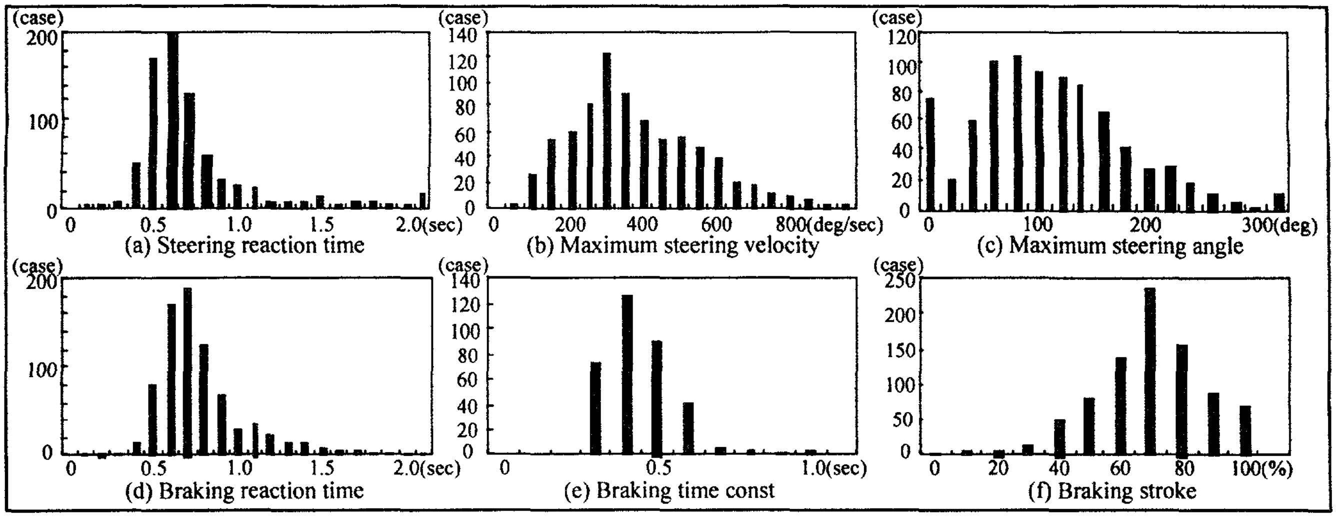

Figure 3. Examples of Driver's Maneuvers.

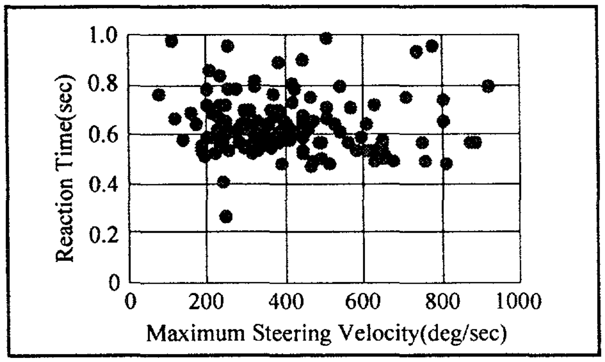

Figure 4. Reaction Time and Steering Velocity on Curved Road Management.

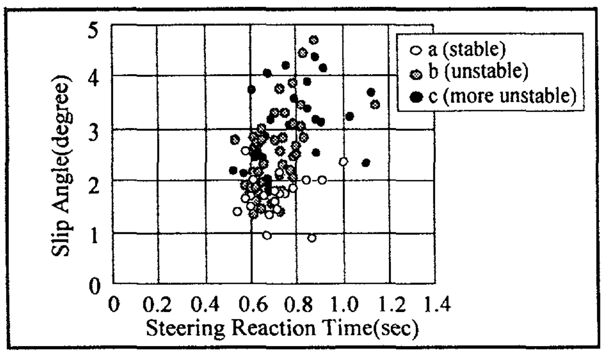

Figure 5. Steering Maneuver and Slip Angle of Vehicle.

cases, managing behaviors are classified into three cases, road-departure towards inside of the road, outside and divergent scattering. The reaction time seems to be depended on slip angle of the vehicle (Figure 5.). The driver manages the vehicle inclination along the progressive direction noticing the change of road surface.The amounts of the data points of scattering are depended on the slip angle of the vehicle. Thus each driver manages his maneuvers consulting with a man/vehicle system in such a critical situation.

DRIVER'S BEHAVIORS MODELING AND PERFORMANCE EVALUATION

Driver Operating Model

Mathematical driver operating model is derived from experimental data of above mentioned situations. The model is constructed with steering (lateral control) and the braking (longitudinal) operation.

The parts of steering operation are based on the variable preview time and variable preview point. These are constructed by the three parts, prediction, target course generation and steering control block. In the prediction block, it is assumed that the driver involves the simple vehicle model and predicts the future vehicle position and vehicle state values. In the target course generation block, driver's operating model generates the course of before and after the obstacle emerging. In the steering control block, steering angle is derived as a type of integral control that minimizes the both of corrected steering angle and the deviation

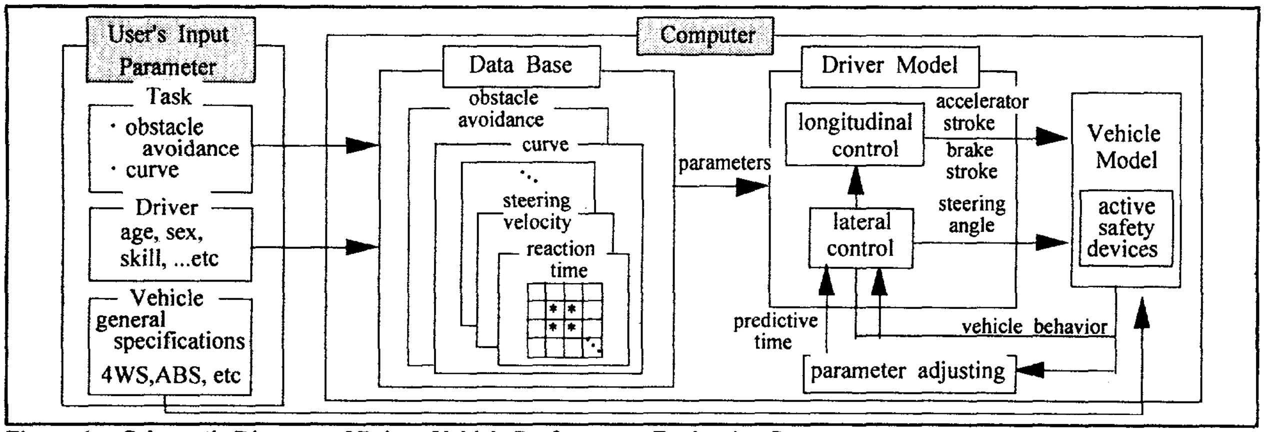

Figure 6. Schematic Diagram of Driver-Vehicle Performance Evaluation System.

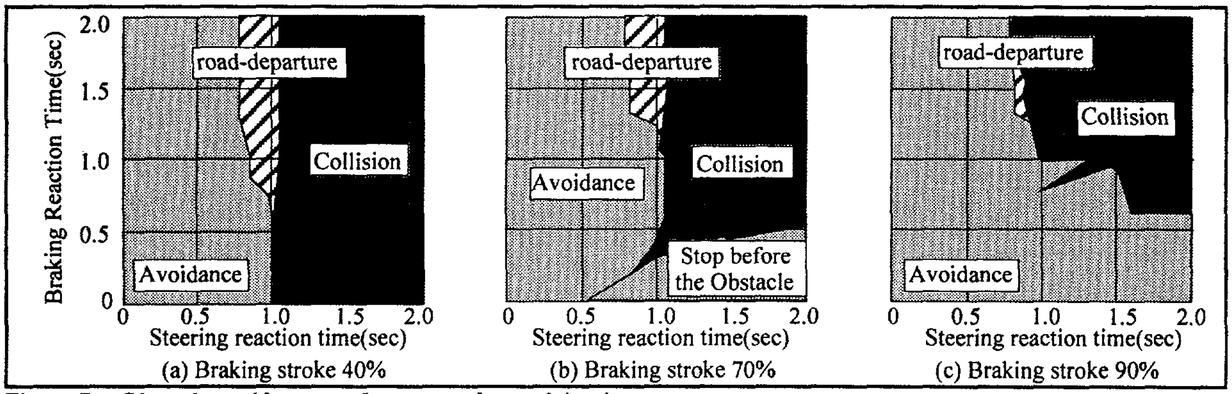

Figure 7. Obstacle avoidance performances due to driver's maneuvers.

between generated course and predicted course.

The braking operation is expressed with the first order delay system with lag time from the basis of experimental results. Here, the lag time is equivalent to the braking reaction time. The gain of the first order delay system is the maximum brake pedal stroke. The time constant value corresponds to the time from the beginning of braking operation to reach the maximum brake pedal stroke.

Combining the driver model and vehicle motion model, using the database, driver-vehicle performance is calculated for various tasks (Figure 6.). The block diagram is shown from user's input parameter as supposed road, selecting data and calculating the models, to the last part of vehicle performances on the emergent situations.

Avoiding Performance Estimation

The obstacle avoidance performance is estimated by the simulation as below. In the case of emerging obstacle, supposing vehicle speed is 60 km/h, the gap length to the obstacle is 40m in time of obstacle start to emerge, the avoiding performance is evaluated for associated behaviors with braking and steering. The driver's skill is supposed to be below the averaged,namely maximum steering velocity is 200 degree/s. The obstacle avoidance performance is shown with braking stroke as the functions of brake and steering reaction time (Figure 7.). The performance is classified to three patterns ; avoidance, namely success to avoid theobstacle, the collision to the obstacle and the road-departure from the road edge. The figure shows the influence of avoiding ability concerned with both of brake and steering reaction time. The drivers who operate in lager steering reaction time than 1.0 second would came into collision to the obstacle. On the contrary, even if for rapid steering, delayed braking action over 0.8 second leads to the road-departure from the road edge. According to the amount of brake stroke, the avoiding ability would be increased with the stroke and braking assistance and these system would be effective for poor power drivers.

Managing Performance Estimation

Another emergent situation is sudden surface change to slippery condition during curved road. In the case that surface is changed from 1.0 to 0.5 in rear wheel, supposing vehicle speed is 70km/h and the curvature of the road is 100m, the managing performance of the vehicle is evaluated in three kinds of steering reaction time (Figure 8.). In these cases, the prediction time in the driver model is supposed to be changed from 0.7 to 0.5 second before and after the low frictional area.

The estimated results are shown in the figure that there are three patterns for managing performance on slippery curved roads. These phenomena is also derived from the driver-vehicle active safety performance.

VERIFICATION OF DRIVER'S ASSISTANCE BY STEERING CONTROL

Driver's assistance in emergent situation would be of necessity to improve driver-vehicle closed loop performance. Supposing the assistant steering controls, the effect of the controls on the performance were estimated. Calculation conditions were the same with Figure 8. In the case of without control X, with differential steering control Y and with yawrate feed back control Z, the estimated vehicle trajectories, steering angles and front steer angle at that time are shown (Figure 9.). From the results, every controlled case is effective for preventing the divergent phenomena of the vehicle after entering the low frictional area. The controlled case is stable in the trajectory of the vehicle and would be estimated to stay within the lane.

Next, supposing the similar control system into the vehicle model of the driving simulator, the driving behaviors in the imitated environmental conditions are examined for several subjects. The results are shown in the vehicle trajectories and steering angles at these occasions (Figure 10.).

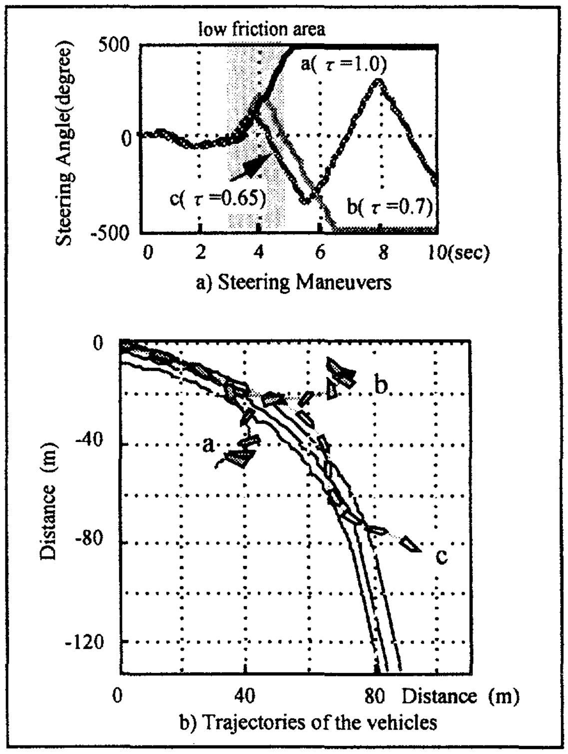

Figure 8. Simulation Results for Different Reaction Time.

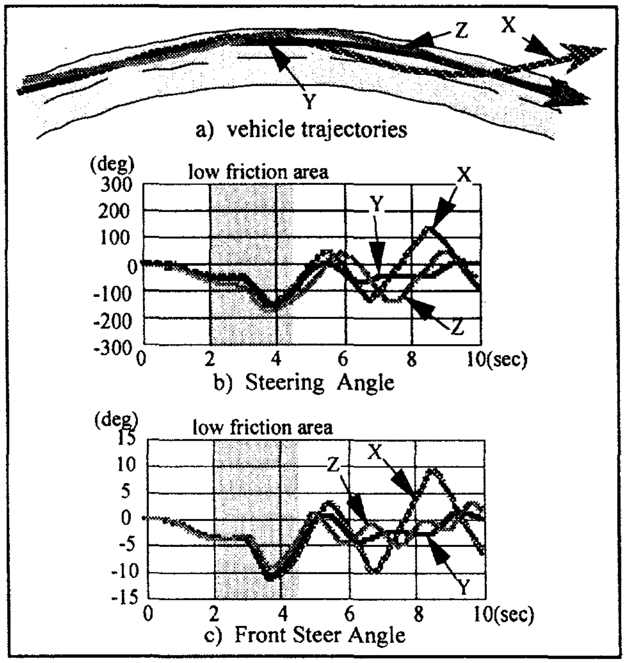

Figure 9. Simulation Results for Steering Control.

Comparing with the experimental results and the estimated behaviors, the trajectories of the vehicles were very similar with each other and steering maneuvers were well improved. The subjective judgements of the drivers were better for steering feeling and the recovery of vehicle direction was fairly improved. Thus the driver managing performance of the emergent situations was evaluated with estimation of the effect of assistant steering control.

CONCLUSION

The avoiding behaviors are examined for ordinary drivers in emergent situations using driving simulator. From observations of the maneuvers, the mathematical driver model is derived and the active safety performance of driver-vehicle system is discussed from both of the computer simulations and the simulator experiments. The features of evaluation methods in this study are summarized as followings.

(1) Supposing two kinds of emergent situation, characteristics of avoiding maneuvers are examined and the database is constructed for ordinary drivers. The reaction times of braking and steering in emergency avoidance, the operational velocities, and the amount of each action are classified. The avaraged values for each are obtained finally.

(2) Computational analyzing system for driver-vehicle performance is constructed with the experimental database of operational maneuvers and vehicle performance model including driver's operations. Regarding the change of curvatures, surface conditions and driver property as well as vehicle characteristics, the vehicle motion road performance is evaluated as the results of driver's emergent operations and the vehicle responses.

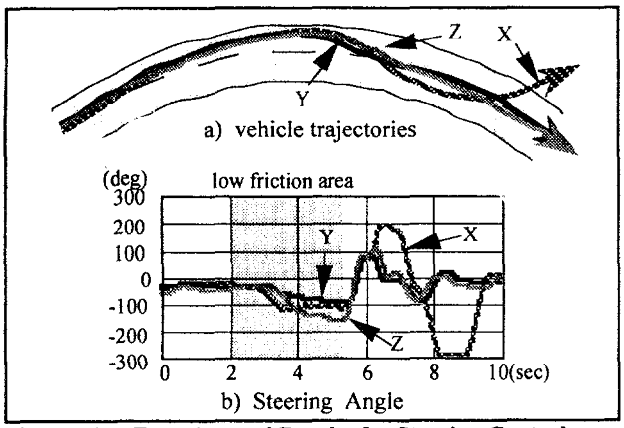

Figure 10. Experimental Results for Steering Control.

(3) Using the analyzing system, avoiding performance in sudden emerging obstacle and managing performance in slippery curve running are estimated. These results are shown to be effective for evaluating the active safety performance of driver-vehicle system.

(4) Applying the evaluation methods to driver aid devices, the effect of driver's assistance by steering control is predicted with the computational estimation and verified from the driving simulation experiments.

Finally taking these evaluation methods, it should be more effective and adequate for designing the driving safety devices to make a better human interface to future transport systems.

REFERENCES

W. Kading., et al. " The Advanced Daimler-Benz Driving Simulator ". SAE. 950175. 1995.

G. Bertollini., et al. " The General Motors Driving Simulator ". SAE. 940179. 1994.

J.A. Greenberg., et al. " The Ford Driving Simulator ". SAE. 940176. 1994.

J.S. Freeman., et al. " The Iowa Driving Simulator ; An Implementation and Application Overview". SAE. 950174. 1995.

D.T. Mcruer, and H.R. Jex, : " A Review of Quasi-Linear Pilot Models ", Trans. on Human in Electronics, Vol..HFE-8, No.3 (1967), pp.231-249.

J.R. Mclean, and E.R. Hoffmann,: " The Effects of Restricted Preview on Driver Steering Control and Performance", Human Factors, 15-4 (1973), pp.421-430.

L.D. Reid., " A Survey of Recent Driver Steering Behavior

Models Suited to Accident Studies ", Acid Anal. & Prev., 15-1. 1983, 23-40.

Allen, R.W., et al., "Analysis and Computer Simulation of Driver/Vehicle Interaction", SAE 871086. 1987.

S.Doi, S.Nagiri, K.Takei, " Study of Driver's Operation in Emergency Avoidance Using Driving Simulator ". Preprints of 7th IFAC/IFORS Symposium on Transportation Systems. Volume 2. 1994, PP.453-458.

A.Yamamoto, " Influence of ABS on Rollover Accidents". 15th International Technical Conference on the Enhanced Safety of Vehicles. No.96-S5-O-04. May 13-17, 1996.

S.Nagiri, Y.Amano, S.Doi, " An Analysis of Driver's Avoiding Maneuver in Emergent Situation ", 4th World Congress on Intelligent Transport Systems. Oct. 21-24, 1997.