The History of Research and Development of Driving Simulators in Japan*

Kenichi YOSHIMOTO** and Takamasa SUETOMI***
** Department of Human-Robotics, Faculty of Engineering, Saitama Institute of Technology
1690 Fusaiji, Fukaya-shi, Saitama 369-0293, Japan
E-mail:yosimoto@sit.ac.jp
*** Technical Research Center, Mazda Motor Corporation
3-1 Shinchi, Fuchu-cho Aki-gun, Hiroshima 730-8670, Japan
E-mail:suetomi.t@mazda.co.jp

Abstract
In Japan, it became necessary to address the issue of traffic accidents in the 1960s, when traffic accidents increased rapidly with the spread of motorization within the nation. The need for driving simulators as a tool to tackle the problem was recognized, and a government-led development effort began. Manufacturers followed with their own efforts to develop driving simulators to aid in research of steering and stability. We introduce the history of hardship from the times when the technologies for display and motion systems developed for flight simulators were not readily usable for driving simulators.

Key words: Driving Simulator, Motion Cue, Visual Cue, Traffic Safety Trainer

1. Introduction
Before we discuss the history of Driving Simulator development in Japan, we will first present a broad overview of the evolution of Japanese motorization and the history of traffic accidents.

Japan’s motorization stemmed from a rapid increase in vehicle ownership which began in the 1960s (Fig. 1). Since then, we have seen the progress of motorization as ownership...
increase by 2 million per year over the 30 years spanning the late 1960s through the early 1990s. The rate of increase has dampened in recent years as we approach the 80 million mark in vehicle ownership.

The increase in ownership resulted in a corresponding increase in the number of accidents, and this resulted in two surges in number of traffic fatalities causing grave concern within the Japanese society. In the early 1960s, traffic fatalities increased past 12,000 per annum, even though ownership was less than 10 million. We call this the First War of Traffic. This first peak was overcome by improvement in the maintenance and enhancement of road facilities (i.e., servicing of crosswalks, deployment of guardrails and medians, and servicing of traffic signals and signs), as well as through focus on traffic safety education and promotion of emergency medical services.

Despite the continued increase in vehicle ownership numbers, we started to see a rapid decline in the accident rate per 10,000 vehicles. In 1979, the accident rate came down to 8,466, which is ½ of the peak value. Despite the decline in the accident rate, however, the fatality rate per 10,000 vehicles did not improve much past 2. Because ownership continued to increase, the fatalities started to increase again in the 1980s reaching 10,000 in 1988, up to a peak value of 11,452 in 1992. We call this increase the Second War of Traffic. This second peak is currently in the process of being overcome through improvements in Passive Safety Technologies (i.e., impact-resistant body frame, seatbelts, airbags, etc.) developed by the manufacturers. As a result, we are currently seeing fatality rates drop below 1.

Through these technologies, we anticipate that the total fatalities per year can be reduced to no greater than 5,600 per annum. Today, government, industry, and universities are working together to develop and promote Active Safety Technologies with a vision to create a society free from traffic accidents.

It was during the advent of Japan’s motorization in the early 1960s that driving simulators gained interest in our nation. In response to a sudden increase in the number of traffic accidents, the National Research Institute of Police Science initiated a project to scientifically investigate the cause of motor vehicle accidents. As part of this effort, a driving simulator development plan was carried out from 1961. In 1964, the research lab of Prince Motor Company developed a stability and maneuverability simulator with funding from the Ministry of International Trade and Industry. In 1967, the ministry’s National Research Institute Mechanical Engineering Laboratory commenced development of a high-speed driving simulator. The three simulators listed above required extensive effort to develop the simulated view, because computer graphics technology was not available. Motion simulation in these systems used an actual vehicle to simulate vertical vibration and roll due to steering, but was missing lateral and longitudinal acceleration. In the late 1970s, Toyota Central R&D Labs developed a simulator with motion feel that runs a real vehicle on a chassis dynamo with some amount of lateral movement. These systems will be introduced in Section 2.

The 1980s saw a dramatic improvement in computer processing capability, which enabled relatively inexpensive use of computer graphics technology. In 1984, the Mechanism & Control Laboratory of the University of Tokyo was the first in Japan to develop a driving simulator using in-house computer graphics to display a field of view for the operator and to use a 4 degrees-of-freedom motion system. This system is described in Section 3.

From the late 1980s, Japanese auto manufacturers also started to develop their own driving simulator systems. Here, we will introduce three systems with unique mechanisms. These are: an electric 4-DOF gimbals/rail motion system developed at Mazda’s R&D Center, Honda’s Riding Simulator, which uses a cradle-like swing mechanism that has the four degrees of freedom of roll, yaw, pitch, and lateral, plus a degree of freedom around the
steering axis, and Mitsubishi Motors’ system which uses a flat-belt chassis dynamometer to enable testing of dynamic characteristics including the performance limits of the vehicle. These systems are described in Section 4.

While the simulators described above were being developed for research and development, the National Police Agency started a project in the late 1960s to develop simulators for use in traffic safety training. The systems were successfully deployed for training of traffic act offenders and novice trainees. The history of this project is given in Section 5.

With the significant increase in development of Driver Assistance Systems featuring Active Safety Technology in the late 1990s, the various auto manufacturers, research centers, and universities employed and made use of full-fledged driving simulator systems for their development. As a conclusion, we present our views on use of driving simulators.

2. The Dawn of Driving Simulator Development in Japan

Driving simulator development started in earnest during the 1960s. At the time, computers were not readily available as they are today, so much effort was spent using analogue computers or electric circuits to obtain the motion and the driver’s simulated view.

2.1 National Research Institute of Police Science

A 16 mm film of an actual forward road view is presented to the driver with the reproduction speed being varied according to the speed of the vehicle driven on the chassis roller. Fig. 2 shows the system configuration and Fig. 3 shows the forward view shown on the screen.

![Fig. 2 System configuration of system at National Research Institute of Police Science](image1)

![Fig. 3 Front view of the screen](image2)
2.2 Prince Motor Company

This system provides a roll angle to the front half of the cabin, has force feedback on the steering wheel, and display of a forward view using a point source system. Because the system was designed for research of steering and stability characteristics, emphasis was placed on simulating the motion of the vehicle. The display system used a DC signal from an analogue computer to move opaque or partly translucent objects according to vehicle speed and attitude before a point source so that their shadows are projected on a screen.

A line-drawing system with no moving parts was also developed to obtain good response in high-speed simulation. The horizon is created by applying a saw-tooth waveform in the x direction of the CRT. A stair-step waveform is modulated by the inverse of the distance form the driver to the horizon and applied to the y direction. The lane marking is obtained by applying a saw-tooth wave in the y direction and a saw-tooth wave modulated by a line whose slope is proportional to the lane width in the x direction. The system can also represent the effects of side-slippage and change in yaw movement.

2.3 National Research Institute Mechanical Engineering Laboratory

This system uses a real vehicle placed on a driving simulation platform actuated by hydraulic servo systems to provide pitch and roll motion. The visual display is created by feeding the image of a scaled road environment model onto a screen (Fig. 6).

A 100:1 solid model of a road (Fig. 7) is fixed on an endless belt. The speed of the belt is varied according to the vehicle speed. Speeds from 0 to 180 km/h can be realized. The road model has gentle undulation, and items such as street lights, houses, guardrails, or trees are placed along the road. As shown in Fig. 7, the camera is moved from side to side according to the lateral position of the vehicle, and a mirror at the end of the camera is rotated according to the yaw motion.
2.4 Drum-type Driving Simulator of the Toyota Central R&D Labs

As shown in Fig. 8, this motion system uses a drum to provide a simulated road on which the tires of a real vehicle actually run. In this system, a vehicle runs on two drums that are 3.2 m in width and 5 m in circumference. Yaw motion and lateral motion are possible within the constraints of the drum width. The forward view is divided into the background and the lane marking, which are each given by an independent projector to be synthesized on the screen. Specialized optical and mirror mechanisms enable a synthesized image that responds correctly to the steering operation.

3. A Driving Simulator of Our Own Making

In the early 1980s, the full-scale driving simulators developed by Daimler-Benz and The Swedish Road and Traffic Research Institute were of the most well-known in the world. It is inevitable that the cost of developing and running systems with such high fidelity domes at extremely high cost. For fundamental studies of driver-vehicle-environment systems or feasibility studies which do not require flawless simulation, however, an inexpensive simulator capable of providing sufficient fidelity at a reasonable cost is of great value. This chapter presents a driving simulator system developed by the Mechanism & Control Laboratory at the University of Tokyo in 1985.

3.1 Outline of the Simulator

Fig. 9 shows the general system configuration of the driving simulator. This system is controlled by a 32-bit microprocessor. Data acquisition and computation of the vehicle dynamics are updated every 10 ms while the computer-generated scenery is updated every 50 ms.

Motion cues: The driver sits on a bucket seat and operates a steering wheel, accelerator and brake pedal. Four degrees of freedom; pitch, yaw, roll, and heave, are produced using four hydraulic cylinders. The motion of the compartment provides the
driver with motion cues that simulate those of actual driving. The driver senses acceleration and deceleration from the pitch motion, lateral acceleration from the roll motion, yaw rate from the yaw motion, and jolt from the heave motion. Low frequencies of the acceleration, deceleration, yaw rate and jolt are cut off by a simple high-pass filter in the control software.

![Fig. 9 Configuration of the Tokyo University simulator](image)

**Visual Cues**: A 27-inch TV monitor provides the driver with visual input as shown in Fig. 10. The monitor displays a computer-generated colored scene updated every 50 ms. Cars running on the opposite lane, leading cars, obstacles, simple traffic signs and signals can be shown. A computer-controlled speedometer is in front of the driver.

![Fig. 10 An example of a computer-generated scene](image)

**Audio Cues and Steering Torque**: Audio cues are produced by varying the speed of an audio tape recorder which reproduces a cruising sound recorded on an endless tape. Steering torque is produced by a direct-drive motor unit.
3.2 Validation of the Proposed Driver Behavior Model

We proposed a self-paced preview tracking control model to represent the behavior of a driver traveling along a curved road (Fig. 11). Using this model, the behavior of the driver-vehicle system can be investigated by means of digital simulation. Computer simulation results are compared with driving simulator experiments, and adequateness of the driver model is confirmed as shown in Fig. 12.

![Fig. 11 The precise driver model](image)

![Experimental traces on D.S. Computer simulation traces](image)

Fig. 12 Comparison between course tracking experiment and computer simulation
4. Japanese Driving Simulators with Distinctive Motion Systems

4.1 Mazda Driving Simulator

Mazda has developed a unique driving simulator which has a 4 DOF large-amplitude motion system with a high speed visual system to simulate real vehicle dynamics.

Motion System: Fig. 13 shows the mechanism of the four degrees-of-freedom motion system of the Mazda driving simulator. Consisting of a rotational mechanism that controls the three axes of roll, pitch, and yaw of the movable cabin and a linear mechanism that controls the horizontal motion of the cabin, it has a large moving range in each motion direction as shown in Table 1.

![Fig. 13 Mazda driving simulator motion system](image)

<table>
<thead>
<tr>
<th>Coordinate</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll</td>
<td>+/- 40 degrees</td>
</tr>
<tr>
<td>Pitch</td>
<td>+/- 40 degrees</td>
</tr>
<tr>
<td>Yaw</td>
<td>+/- 160 degrees</td>
</tr>
<tr>
<td>Linear</td>
<td>+/- 3.6 meters</td>
</tr>
</tbody>
</table>

By rotating the moving base around the yaw axis by 90 degrees, the linear mechanism can generate either longitudinal acceleration or lateral acceleration for the driver. As much as 0.8 G acceleration can be generated by actual linear motion and a further 0.64 G acceleration can be attained by applying pitch or roll rotation to the maximum angle of 40 degrees.

Visual and Audio System: The visual system displays a road image onto an 80-inch screen placed 1.2 meters in front of the driver. The field of view is 68 degrees horizontally and 20 degrees up and 14 degrees down from the horizontal plane. A full color (16.78 million colors) textured road and environment image is generated every 20 milliseconds by the road image generator.

Road curvatures were specified both horizontally and vertically to simulate a realistic highway. Texture was applied to the road surface in order to enhance the driver's perception of vehicle speed. Background items such as mountains and the sky were rotated according to vehicle movement.

To simulate the auditory environment of a car, sounds such as those from the engine, road, wind and tires were recorded in real environment. These recordings were stored in a digital sampler in the sound system. Based on signals indicating the engine rotational speed, throttle opening level, vehicle speed and tire slippage conditions from the host computer, the sound generator reproduced the corresponding stored sounds at the appropriate pitch.

4.2 Honda Riding Simulator

Honda developed a motorcycle riding simulator for education of riding safety. In 1988, the prototype riding simulator had a 7-axis design to enable the four degrees of freedom of the vehicle (roll, yaw, pitch, and lateral), plus the steering axis. The system used a unique
cradle-type swing mechanism with the aim of reproducing the acceleration feel accurately. However, because there was no centrifugal force from the turn, and the subtle variation in the acceleration in the roll direction was not the same as actual, it was found to be difficult to ride in the way that one would naturally expect.

For the purpose of a motorcycle riding simulator for safety riding education, it is important to give a sense of reality and to have an easy ride characteristic. It was found that the ease of ride can be obtained by suitable management of the roll behavior and the reproduction of yaw sensation. The mass-produced system based on this finding was commercialized from June 1996, mostly to motorcycle riding schools (Fig.15).

4.3 Mitsubishi Motors Flat-Belt Driving Simulator

The four-wheel flat belt type chassis dynamometer was developed by Mitsubishi Motors in 1990 to enable indoor testing of vehicle dynamic characteristics which had previously been tested on test courses. With flat “road surfaces” created by stretched steel belts, this facility simulates the tire-to-road contact conditions, and is able to give desired slip angles independently to the front and rear wheels by swiveling the flat belt units around their vertical axes as shown in Fig. 16.

This facility was the first of its kind in the world, and allowed safe indoor testing of the dynamic characteristics of experimental vehicles, including testing of performance limits. The visual system of the flat-belt driving simulator was totally renewed in 1995 to increase the reality and traffic generation capability.
5. Simulator for Traffic Safety Education

Since the latter half of the 1960s, a program of the National Police Agency of Japan introduced driving simulators to offender education and training of novice drivers. As with the research simulators, these systems evolved with the progress of imaging technology. At first, the system displayed a filmed motion picture of a real road while the student performed driving maneuvers. Although the media changed from 16 mm film to video and laser disk, the scene was not coordinated with the driver’s operations, and thus the system was not an interactive one (Fig. 17). Such systems only aimed to allow the student to experience scenes of a dangerous driving situation. Computer Graphics was introduced from the 1990s, allowing the scene to be coordinated with the driver’s operational actions. The interactive systems enable the student to experience an accident situation arising from operational error. Screen space was increased to three screens, and realistic scenes of special conditions such as night or rain have now become available (Fig. 18). A simple motion system has also been added to provide acceleration feel.

6. Conclusion

As described above, when we developed our own driving simulator in 1985, organizations such as Volkswagen, The Swedish Road and Traffic Research Institute, and Daimler-Benz had already started using large-scale moving-base simulator systems. However, our system was the first moving-base driving simulator developed in Japan, and thus various Japanese manufacturers came to see our system. Plans to make use of driving simulators were in progress in the US as well, and staff from organizations such as the University of Iowa and Ford Motor Company also paid visits to see the system and to have discussions. During such times, I often provided the following suggestion.

“Simulators use illusion to reproduce the feel of driving. Accordingly, it is impossible to create a system which has exactly the same response as a real vehicle. It is important to determine the exact purpose of using the simulator, and to develop one that suits this purpose. Rather than to create one expensive multi-purpose system, it is more cost-effective to create a number of special-purpose systems and to use them accordingly.”

Acknowledgements

I would like to thank Dr. Motoyuki Akamatsu of the National Institute of Advanced Industrial Science and Technology, Dr. Shunichi Doi of Kagawa University, Mr. Yukio
Miyamaru of Honda R&D Co., Ltd. and Mr. Tetsuo Mimuro of Mitsubishi Motor Corp. for providing valuable reference materials. I would also like to thank Mr. Haruhiko Sakata of Cedara Software for providing English translation, and, last but not least, Dr. Masanori Harada of the National Defense Academy for editing this paper.

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