Concept of Super Smart Vehicle Systems and Their Relation to Advanced Vehicle Control Systems

SADAYUKI TSUGAWA

The Super Smart Vehicle System (SSVS), proposed under support of the Japanese Ministry of International Trade and Industry, is a new information system that 20 to 30 years from now will solve problems caused by automobiles and automobile traffic. Its solutions will be based on previous research and development of driver information systems and vehicle control systems in Japan. The current status and problems of automobiles and automobile traffic in Japan are described. Large cities in Japan are characterized by excessively high density, which is the main cause of the problems. Then histories of vehicle control systems are explained. Japan has a long history in vehicle control systems, which include driver assistance systems and automatic driving systems. Advanced vehicle control systems (AVCSs) are a main research theme of the SSVS. The SSVS deals with four fields: information systems for a single vehicle, for inter-vehicles, and for vehicle-to-road relations; and studies on vehicle-to-driver relations. Some of system candidates relating to AVCS proposed for the SSVS are introduced.

Traffic accidents, congestion, and pollution caused by automobiles have been becoming more serious in Japan. Many systems for traffic management, driver information, and vehicle control have been studied and developed in Japan since the 1960s in efforts to solve the problems. Traffic control and surveillance systems were already installed in major cities in the 1970s. The number of control centers in Japan runs into 160. In addition, experiments of navigation systems have been conducted. A large-scale experiment of a dynamic route guidance system called the Comprehensive Automobile Traffic Control System (CACS) (*1*) was conducted in Tokyo in the 1970s; it aimed at increasing the efficiency of automobile traffic and decreasing traffic accidents and congestion. Experiments of the Advanced Mobile Traffic Information and Communication System (AMTICS) (*2*) and the Road/Automobile Communication System (RACS) (*3*), both navigation systems, were conducted in the mid-1980s. Now onboard navigation systems are commercially available.

Vehicle control systems such as collision warning systems and automatic driving systems have been studied in Japan since the 1950s, and some of them have been commercially available. However, automatic driving systems still remain in the area of research.

Mechanical Engineering Laboratory, Agency of Industrial Science and Technology, Ministry of International Trade and Industry, Namiki 1-2, Tsukuba-shi, Ibaraki-ken, 305 Japan.

For solving the problem, we have proposed an information system for automobiles and automobile traffic for 20 to 30 years from now. The Super Smart Vehicle System (SSVS) (*4*), based on the info-mobility concept (*5*), is an information system for drivers. Its purpose is making safety and efficiency compatible while taking aging and pollution into account.

The current status of automobile traffic and the history of vehicle control systems in Japan will be introduced; these are the background of the SSVS proposal. After the background and the info-mobility concept are introduced, the SSVS will be explained; some systems relating to advanced vehicle control systems (AVCSs) will be described in detail.

STATUS OF AUTOMOBILE TRAFFIC IN JAPAN

Japan is a mountainous country with little flatland, which leads to an excessive density of population and automobiles in cities. This high density, a major characteristic of Japan, has caused the problems.

Automobiles and Japanese Society

The number of automobiles has been rapidly increasing in Japan in recent years, as shown in Figure 1, and it became 58 million in October 1990. It is expected that there will be 64 million automobiles in 1995 and 72 million in 2000.

The role of automobiles has increased as well. Figure 2 shows the volume of passenger traffic by various means of transportation. The volume of passenger traffic by automobile has increased in indexes of the number of passengers and the passenger distance of travel.

The trend in cargo traffic by automobile is similar to that of passenger traffic by automobile. The ratio of cargo traffic by motor trucks is more than 90 percent in weight and more than 50 percent in weight distance. The role of motor trucks is much larger in Japan than in Europe or the United States.

Although the number of automobiles and drivers has been increasing, roads are not necessarily sufficient. The length of paved roads per vehicle is 14 mi in Japan, 17 mi in western Germany, and 20 mi in the United States. The length of expressways per 100 vehicles is 8 mi in Japan, 29 mi in western Germany, and 47 mi in the United States.

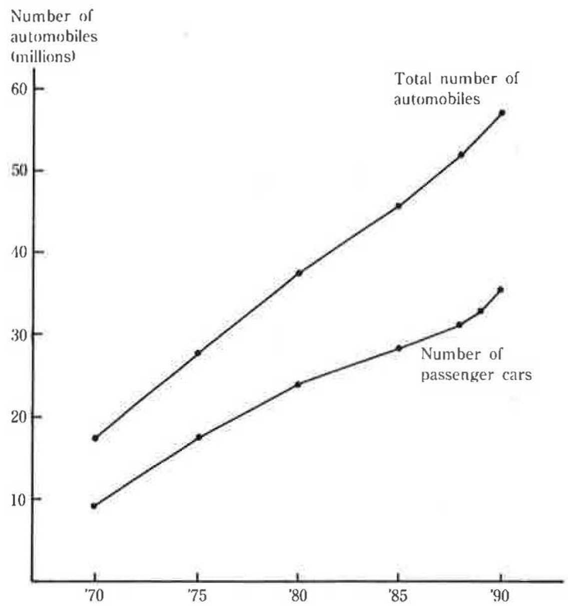


FIGURE 1 Numbers of automobiles (four-wheeled vehicles) and passenger cars.

Problems of Automobile Traffic

Accidents

As shown in Figure 3, the annual number of fatalities by traffic accidents began to increase in 1987, and it exceeded 10,000 in 1988. Fatal accidents have the following characteristics: first, there is a significant increase in fatalities for people between 16 and 24 and over 65 years of age. Second, fatalities of drivers and passengers have increased much more than those of pedestrians. Third, nighttime accidents have increased much more than daytime accidents, and the ratio of fatal accidents at night is higher than that in the day. Finally, accidents have increased during weekends. Sundays accounted for the most fatalities in 1989, and Saturdays did in 1990. Table 1 summarizes the characteristics of the accidents.

In addition, accidents and fatalities on expressways have also been increasing. Since the expressways became longer, obviously the total number of accidents and fatalities has increased. However, the ratio of accidents and fatalities on the expressways with the index of vehicle distance has also increased.

Congestion

Traffic congestion is also a serious problem, not only in large cities such as Tokyo and Osaka but also in rural cities. In Tokyo the average delay at one major intersection was 3.3 hr/day in 1983 and 5.1 hr/day in 1989. Also in Tokyo along urban expressways the average delay at one point was 4.6 hr/day in 1983 and 7.9 hr/day in 1989.

The delays caused by traffic congestion have resulted in a great deal of loss in social and economical activities. It was estimated that all the driving hours including the delays were 20.37 billion person-hr/year in 1980, but that it would have been 15.77 billion person-hr had there been no traffic congestion. Thus, the loss was 4.6 billion person-hr/year, which equals 2.19 million workers.

Factors in Future Automobile Traffic

Because the problems caused by automobiles and automobile traffic have become serious even recently, it is expected that they will become much more serious because the number of automobiles and drivers will grow—even though constructing roads will become harder because of the high price and shortage of lands. In addition, some factors will affect automobile traffic in the future: aging and the increase of female drivers and foreign people.

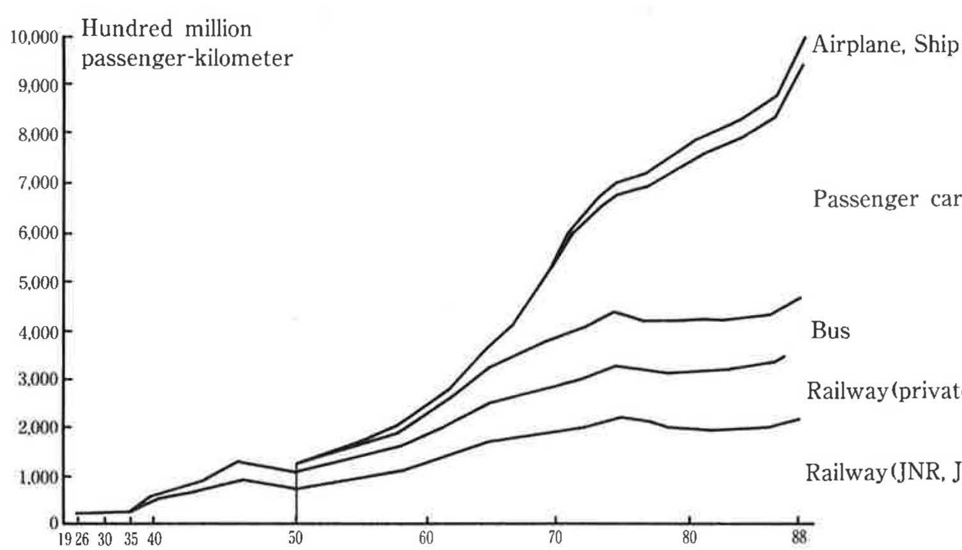


FIGURE 2 Passenger traffic.

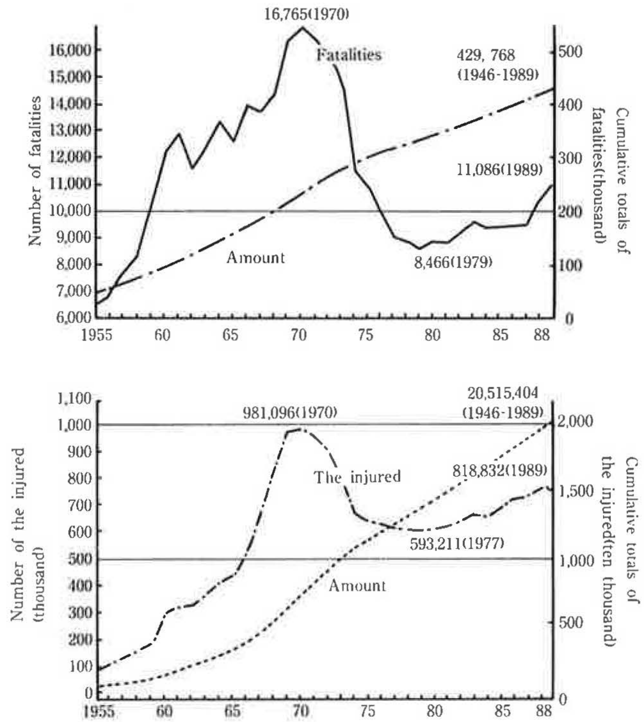


FIGURE 3 Numbers of (*top*) fatalities and (*bottom*) injuries from traffic accidents.

Aging is an important issue in automobiles and automobile traffic in terms of the increase of aged drivers and shortage of labor force, in particular, drivers of heavy-duty trucks. It is expected that at the beginning of 21st century, 20 percent of the people will be aged.

The increase of female drivers should also be taken into account. Their rate of increase is much larger than that of male drivers. The ratio of female drivers in the female population was 27.9 percent in 1980 and 43.5 percent in 1989. Besides, fatalities of female drivers have increased at a higher rate than that of male drivers. In 1989 the number of fatalities of female drivers was 362, which was 2.7 times the number in 1979; meanwhile, the number of female drivers increased 1.9 times.

TABLE 1 Characteristics of Accidents

		1979	1990
Number of fatalities	all ages	8466(100)	11227(133)
	ages between 16 and 24	1845(100)	3158(171)
	ages over 65	1613(100)	2673(166)
Number of fatalities of	drivers/passengers	2998(100)	4501(150)
drivers and pedestrians	pedestrians	2888(100)	3042(105)
Number of accidents	daytime	349536(100)	437134(125)
in the daytime and nighttime		[4071(100)]	[4610(113)]
[ ]:fatal accidents	nighttime	122110(100)	205963(169)
		[3977(100)]	[6041(152)]
Number of fatal accidents per day	weekdays	21.1	27.9
in weekdays and at weekends	weekends	24.4	32.4

The third factor is the increase of foreign people and foreign drivers. This requires that information for drivers be not only in Japanese but also in English, for example. Actually, message signs in Japanese as well as English are becoming common.

HISTORY OF VEHICLE CONTROL SYSTEMS IN JAPAN

System candidates proposed in the SSVS study have roots in vehicle control systems that have been developed since the 1960s. These are technological backgrounds for the proposal of the SSVS. The vehicle control systems can be classified as driver assistance systems and automatic driving systems. The driver assistance systems include a collision warning system and a lane detection system. The automatic driving systems include an automated vehicle system with inductive cable and an autonomous vehicle with machine vision.

Driver Assistance Systems

Studies on driver assistance systems have been conducted in many fields in Japan. Obstacle warning systems in the vicinity of an automobile using ultrasonic are already commercially available. Here, a laser radar system and a lane detection system based on machine vision will be explained. Although radar systems were studied also in Japan and many papers have been published, the systems have not yet become commercially available. In addition, driver perceptual enhancement systems have not yet been opened in Japan; these will not be referred to, either.

Laser Radar System

After the first development of a laser radar system for obstacle warning using a semiconductor laser in Japan (*6*), a new laser radar system was developed for heavy-duty trucks (*7*). The gap between the truck and the leading vehicle within 100 m is measured by the emission of infrared laser pulses of 70-nsec duration at 6 kHz. Their speeds and decelerations are recorded, and the driver is warned when necessary.

Lane Detection System

Lane detection systems have been used for visual navigation systems of mobile robots and intelligent vehicles. In the Personal Vehicle System (PVS; more detail later), white lines beside a road or lane markers are detected for lateral control.

Here, a lane marker detecting system for warning a driver of lane deviation is described. A study of a lane detecting system using machine vision with stereo television cameras has been conducted in the Mechanical Engineering Laboratory (MEL) (*8*). The system is characterized by real-time operation to detect lane markers in the field of view with a range of 4.5 to 21 m. It consists of two television cameras and hard-wired logic for video signal processing. Figure 4 shows

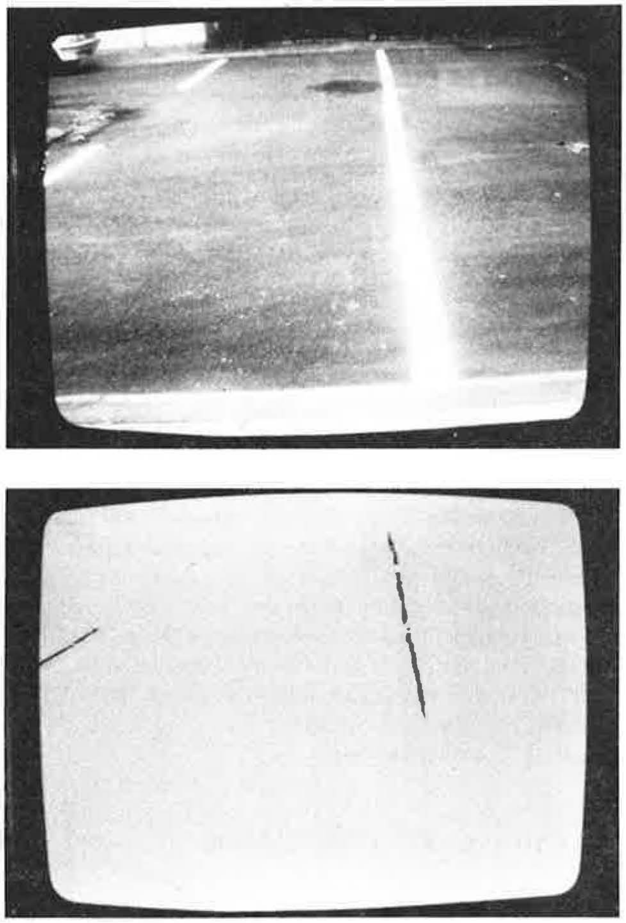


FIGURE 4 Detection of lane markers: (*top*) an original scene and (*bottom*) detected lane markers (courtesy of Takeshi Hirose, MEL).

an original scene and lane markers, where only lane markers are detected.

Automatic Driving Systems

Automated Vehicle with Machine Vision

Studies on automatic driving systems were started from the employment of inductive cable systems in Japan, as in the United States and Europe. In 1967 an automated vehicle developed by MEL was driven stably at 100 km/hr (*9*).

After the research on the automated vehicle with inductive cable, to eliminate restrictions on the system with inductive cable, a new system using machine vision was begun at MEL in the 1970s. The world's first automated vehicle with machine vision was developed at MEL, and it was named the Intelligent Vehicle (Figure 5). It ran autonomously at 30 km/hr while avoiding obstacles and guardrails (*10*). The steering control is based on table look-up. The machine vision consists of stereo television cameras and hard-wired logic for processing video signals to detect obstacles in the field of view between 5 to 20 m with a viewing angle of 40 degrees. The obstacle detection system features real-time processing. After scanning one image, which takes 33 msec, the presence and locations of obstacles are detected with another 2 msec of processing. The principle of obstacle detection is based on parallax: an obstacle yields images of the same heights on television cameras, but figures on a road yield those of different heights because of the positions of the television cameras on the vehicle. Figure 6 shows an original image of a scene and the location of obstacles in the quantized field of view.

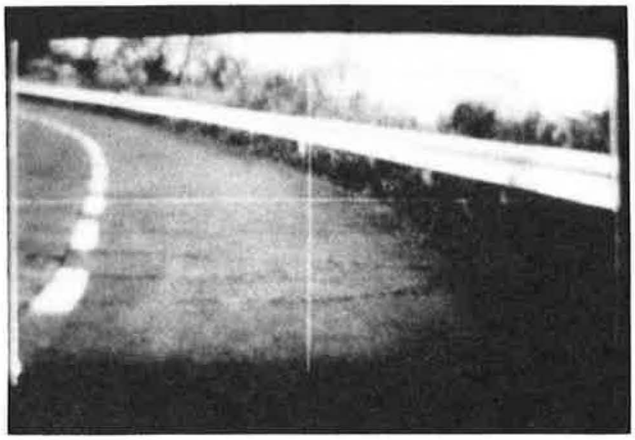
In 1984 the Intelligent Vehicle was equipped with a dead-reckoning system using a differential odometer. Thus, the vehicle had functions of navigation and obstacle detection, which led to a completely autonomous vehicle (*11*). The vehicle was driven autonomously from its starting point to its goal while avoiding an obstacle after its goal was assigned and route planning was performed.

The Intelligent Vehicle was an experimental system. It was driven only under well-defined conditions; the performance entirely depends on weather, brightness, and direction of light.

Personal Vehicle System

In 1987 a study on a new Intelligent Vehicle named the PVS (*12*) was started. Figure 7 shows the PVS. It has functions of navigation and obstacle detection. Machine vision of the PVS has five television cameras; three of them are for detecting white lines indicating a lane, and the other two are for detecting obstacles. The PVS also has a dead-reckoning system that uses a differential odometer to locate its position. It enables the PVS to navigate from its starting point to its goal along an optimal route. In addition, the PVS has another obstacle detection system with a laser radar system. In 1989

FIGURE 5 Intelligent Vehicle.



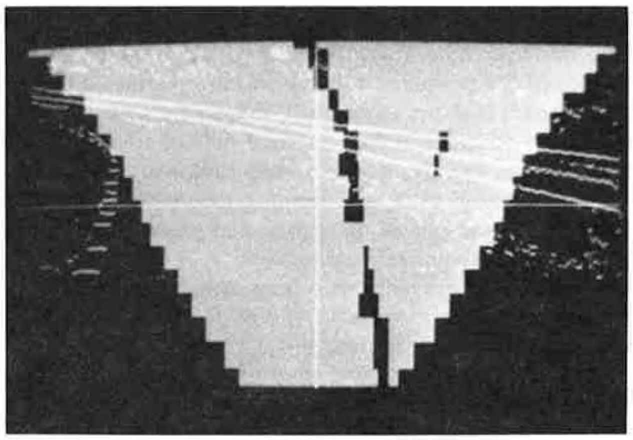


FIGURE 6 **Obstacle detection for Intelligent Vehicle: (*a*) an original scene and (*b*) obstacles (guardrail) detected in the field of view (courtesy of Takeshi Hirose, MEL).**

the PVS ran at 30 km/hr along straight lanes and 10 km/hr along curved lanes on a special proving ground and at 60 km/hr along a straight lane on another proving ground.

The PVS was remodeled in 1990 and 1991: the three cameras for lane detection were removed and a single camera on a turntable was installed inside the windshield. Experiments under rainy conditions or at night were conducted.

Vehicle-to-Vehicle Communication Systems

Vehicle-to-vehicle communication systems have a wide range of variations; they are applicable to many systems in driver information systems and vehicle control systems. In Japan, vehicle-to-vehicle communication has been studied at the Association of Electronic Technology for Automobile Traffic and Driving (JSK) since 1981 (*13*).

After the studies on the Intelligent Vehicle, an application of vehicle-to-vehicle communication to control of a group of autonomous vehicles was started at MEL in 1984 (*14,15*). It aims at a vehicle-following system with small gaps between vehicles. The system is called the soft-linked vehicle system after linking with vehicle-to-vehicle communication. Experiments using automated guided vehicles for factory automation

FIGURE 7 PVS.

were conducted to investigate the vehicle-to-vehicle communication with infrared and the control algorithms.

Simulation studies on a vehicle-following system with vehicle-to-vehicle communication have also been conducted (*16*). Simulation results of comparisons between vehicle following with the communication and vehicle following with human drivers show that the vehicle-following system with vehicle-to-vehicle communication helps increase road capacity and decrease rear-end collisions.

SSVS AND AVCS-RELATED SYSTEMS

Info-Mobility Concept

Recently we proposed a framework for info-mobility (*5*). The info-mobility system consists of information systems covering a mobility system. As shown in Figure 8, the mobility system consists of a driver subsystem, a vehicle subsystem, and a road environment subsystem. These subsystems are essential to automobile driving. However, the mobility system does not suffice for safe and efficient driving. It is pointed out that traffic accidents and congestion are caused by discord—or "gaps"—among the three subsystems. What fills the gaps is information systems; therefore, information systems make automobile driving safer and more efficient. The info-mobility consists of the mobility system and the information systems to cover it. As pointed out in intelligent vehicle-highway sys-

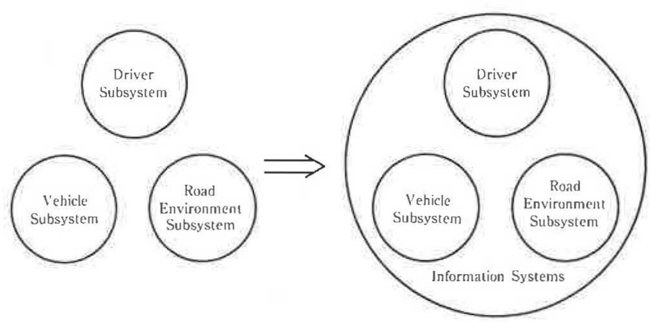


FIGURE 8 Mobility system (*left*) and info-mobility system (*right*).

tems, the information systems include advanced traffic management systems, advanced driver information systems, and AVCSs. Advanced traffic management systems are located mainly at the road environment subsystems, the advanced driver information systems are located mainly between the driver subsystem and the road environment subsystem, and the AVCSs are located mainly around the vehicle subsystem.

The SSVS is one way to realize the info-mobility concept.

SSVS and AVCS

In 1990, JSK started the 2-year preliminary study program on the SSVS under support of the Japanese Ministry of International Trade and Industry to promote the research and development of information systems for automobiles and automobile traffic to be used in 20 to 30 years (*17,18*).

The SSVS has been proposed on the basis of the previous work on driver information systems such as the CACS and vehicle control systems such as the Intelligent Vehicle and the PVS. It is AVCS that will provide substantial solutions to the future problems of traffic accidents and congestion, because the effects of traffic management systems and driver information systems are indirect to the problems and, therefore, bounded. For example, the safety of automobile traffic at nonsignalized intersections will not be guaranteed to the same degree as at signalized intersections. In addition, a dynamic route guidance system will not effectively shorten traveling time when the ratio of automobiles with on-board equipment is more than 50 percent (*19*). Thus, the main theme of the SSVS will be AVCS.

AVCS-Related Systems

The research themes of the SSVS are

1. Information systems for a single vehicle,
2. Information systems for inter-vehicles,
3. Information systems for vehicle-to-road relations, and
4. Studies on vehicle-to-driver relations.

Combining the fields and the purposes of the SSVS, a cooperative driving system, a control configured vehicle system with ultra-little vehicles, an active driver assistance system, an intelligent intersection system, and intelligent logistics and sensor systems represented by machine vision have been proposed, as shown in Figure 9.

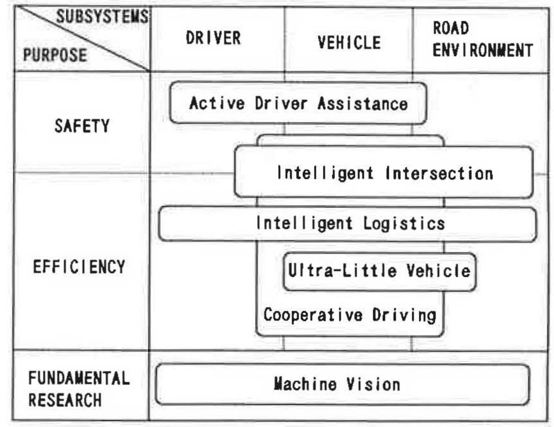


FIGURE 9 System candidates for SSVS.

Cooperative Driving System

The system coordinates driving of automobiles with radar systems and vehicle-to-vehicle communication systems to increase safety and efficiency. If each automobile communicates with other automobiles, and information is given to drivers while driving as shown in Figure 10, the effective road capacity would grow, lane changing and merging would be eased, and safety would be increased. Vehicle-to-vehicle communication is performed either directly among vehicles or indirectly through inductive cables under road surfaces or coaxial leakage cables beside roads.

Control Configured Vehicle System with Ultra-Little Vehicles

In the system, ultra-little vehicles with high performance are driven either independent of each other or linked to form platoons of two-by-one to four-by-four vehicles linked by mechanical coupling or vehicle-to-vehicle communication. The vehicles have functions of access to each other for linking using an omnidirectional radar and control for cooperative driving among vehicles linked together as well as drive-by-wire to ease driving under linking. The vehicle, either a one- or two-seater with a payload of 1 ton, for example, is about 0.8 m wide and 2 m long, which is half in the width and length of a normal automobile. The vehicle is shown in Figure 11. The capacity or payload is based on current use of automobiles, especially those in the downtowns of large cities. The system will help decrease congestion and increase the effective use of roads.

Active Driver Assistance System

The system not only assists a driver by indicating the presence of obstacles in the direction of movement as well as the presence of other vehicles and pedestrians near the driver's vehicle, but also drives automatically for a short time if the

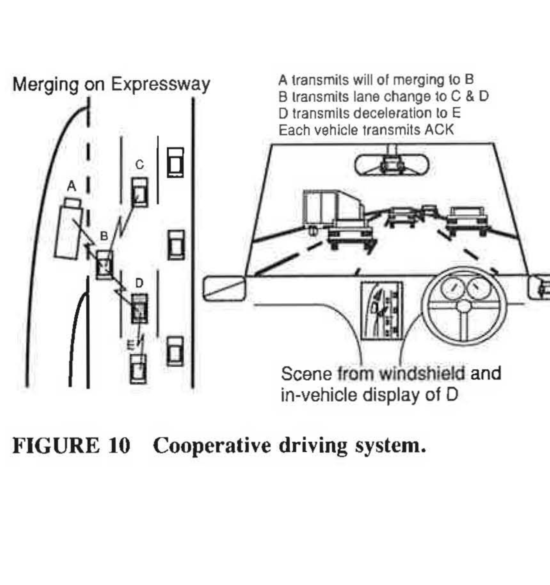


FIGURE 10 Cooperative driving system.

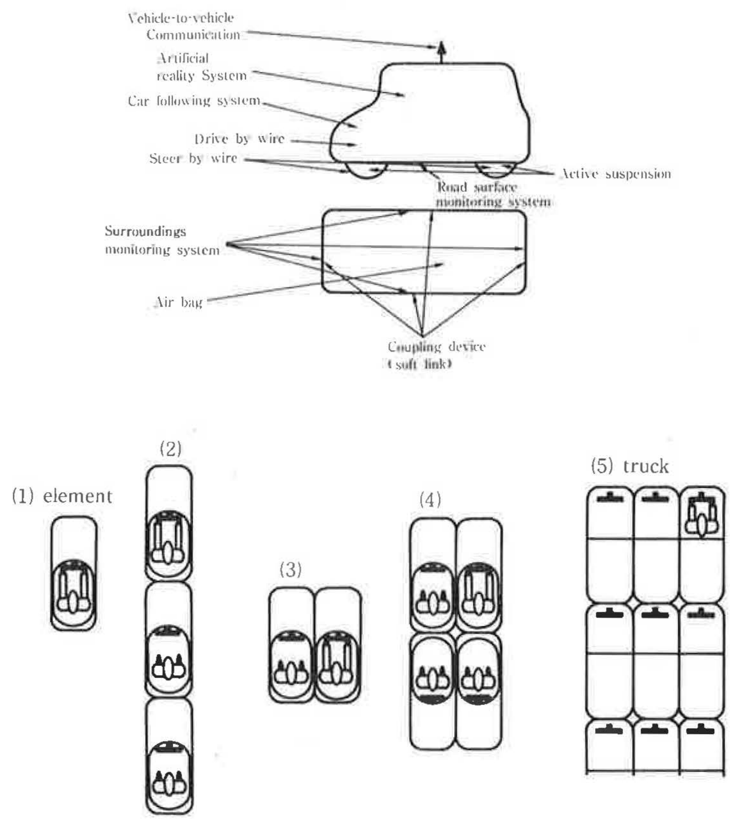


FIGURE 11 Control configured vehicle system with ultra-little vehicles: (*top*) element vehicle and its functions, and (*bottom*) examples of vehicle systems.

driver dozes off or suddenly gets sick. The system will be applicable to an assistance system at high-speed driving or for the aged and the handicapped. The vehicle is equipped with a sensor system including machine vision, a processing system for driver assistance and for automatic driving, a display system for a driver, and an actuator system to steer, accelerate, and brake the vehicle. In this system human factors will play an important role.

Automatic driving will be classified in two categories. One is a steady-state system in which the vehicle is driven without a driver as a default state. It can be called automatic chauffeuring. The other is an unsteady-state system, which is the active driver assistance system described here.

Intelligent Intersection System

It would be effective in decreasing accidents if intersections were made intelligent, because accidents at intersections account for 60 percent of all accidents in Japan. It would also increase road capacity. The intelligent intersection system warns drivers who are ignoring traffic signals, indicates the presence of pedestrians and bicycles to drivers, provides a bird's-eye view of an intersection to drivers, and tells the speeds and directions of vehicle movement—which is called a guide light system. The guide light system provides information on directions and speeds of vehicles by lengths of lights on roads.

CONCLUSION

Automobile traffic in Japan today is characterized by excessively high density: a narrow land, shortage of roads, and a great number of automobiles and drivers. Nevertheless, in Japan automobiles are one of life's necessities. The SSVS is aiming at a solution to the problems that will be caused by automobiles and automobile traffic 20 to 30 years from now. In this paper, based on the SSVS reports of FY 1990 and 1991, the status of automobile traffic in Japan was explained and the research and development history of the vehicle control systems was described. Drawing on previous work in Japan, we have proposed the SSVS. The SSVS is one way of realizing the new concept of info-mobility. Some AVCS-related systems proposed for the SSVS have been introduced. When developing the SSVS, driver acceptance and social acceptance of the systems should be considered.

REFERENCES

1. S. Matsumoto et al. Comprehensive Automobile Traffic Control System (in Japanese). *Journal of IECE*, Vol. 62, No. 8, 1979, pp. 870–887.
2. H. Okamoto. The Progress of AMTICS. *Proc., 22nd ISATA*, Vol. 1, 1990, pp. 215–222.
3. K. Takada et al. RACS: Results of the First Overall Field Trial. *Proc., 22nd ISATA*, Vol. 1, 1990, pp. 223–230.

4. S. Tsugawa et al. Super Smart Vehicle System—Its Concept and Preliminary Works. *Proc., 1991 Vehicle Navigation and Information Conference*, SAE, 1991, pp. 269–277.
5. S. Tsugawa et al. *Info-Mobility: A Concept for Advanced Automotive Functions Towards the 21st Century*. Paper 910112, SAE, 1991.
6. H. Endo. Japanese Patent 61-6349 (in Japanese). 1986.
7. M. Sakata et al. Laser Radar Rear-End Collision Warning System for Heavy-Duty Trucks. *Proc., ATA International Symposium on Future Automotive Microelectronics*, 1988.
8. T. Hirose. Position Prediction of Automobiles—White Line Detection (in Japanese). *Proc., 28th SICE Annual Conference*, Vol. 1, 1989, pp. 23–24.
9. Y. Ohshima et al. Control System for Automatic Automobile Driving. *Proc., IFAC Tokyo Symposium on Systems Engineering for Control System Design*, 1965, pp. 347–357.
10. S. Tsugawa et al. An Automobile with Artificial Intelligence. *Proc., 6th International Joint Conference on Artificial Intelligence*, 1979, pp. 893–895.
11. S. Tsugawa et al. An Intelligent Vehicle with Obstacle Detection and Navigation Functions. *Proc., IECON '84*, 1984, pp. 303–308.
12. M. Taniguchi et al. The Development of Autonomously Controlled Vehicle, PVS. *Proc., 1991 Vehicle Navigation and Information Conference*, 1991, pp. 1137–1141.
13. M. Aoki et al. An Inter-Vehicle Communication Technology and Its Applications. *Proc., 22nd ISATA*, Vol. 1, 1990, pp. 127–134.
14. S. Tsugawa et al. Vehicle Following System Using Vehicle-to-Vehicle Communication—Its Concept, Control Algorithm, and Communication System. *Proc., ASME/ISCIE USA-Japan Symposium on Flexible Automation*, 1988, pp. 621–628.
15. T. Yatabe et al. Control of Autonomous Vehicles with Vehicle-to-Vehicle Communication. Presented at IFAC/IFIP/IFORS Conference on Control, Computer and Communication in Transportation, 1989.
16. S. Tsugawa et al. Velocity Control for Vehicle Following Through Vehicle-Vehicle Communication. *Proc., 22nd ISATA*, Vol. 1, 1990, pp. 343–350.
17. Association of Electronic Technology for Automobile Traffic and Driving. *Report of Studies on the Super Smart Vehicle System in FY 1990* (in Japanese). March 1991.
18. Association of Electronic Technology for Automobile Traffic and Driving. *Report of Studies on the Super Smart Vehicle System in FY 1991* (in Japanese). March 1991.
19. Japan Industrial Technology Association. *Research and Development of the Comprehensive Automobile Traffic Control System*. Agency of Industrial Science and Technology, Ministry of International Trade and Industry, Japan, 1979.

Publication of this paper sponsored by Task Force on Advanced Vehicle and Highway Technologies.