ISSUES AND RECENT TRENDS IN VEHICLE SAFETY COMMUNICATION SYSTEMS

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This paper surveys the research on the applications of inter-vehicle communications, the issues of the deployment and technology, and the current status of inter-vehicle communications projects in Europe, the United States and Japan. The inter-vehicle communications, defined here as communications between on-board ITS computers, improve road traffic safety and efficiency by expanding the horizon of the drivers and on-board sensors. One of the earliest studies on inter-vehicle communications began in Japan in the early 1980s. The inter-vehicle communications play an essential role in automated platooning and cooperative driving systems developed since the 1990's by enabling vehicles to obtain data that would be difficult or impossible to measure with on-board sensors. During these years, interest in applications for inter-vehicle communications increased in the EU, the US and Japan, resulting in many national vehicle safety communications projects such as CarTALK2000 in the EU and VSCC in the US. The technological issues include protocol and communications media. Experiments employ various kinds of protocols and typically use infrared, micro-wave or millimeter wave media. The situation is ready for standardization. The deployment strategy is another issue. To be feasible, deployment should begin with multiple rather than single services that would work even at a low penetration rate of the communication equipment. In addition, non-technological, legal and institutional issues remained unsolved. Although inter-vehicle communications involve many issues, such applications should be promoted because they will lead to safer and more efficient automobile traffic.

Key Words: ITS (Intelligent Transport Systems), Inter-vehicle communications, AVCSS (Advanced Vehicle Control and Safety Systems), Driver assistance systems, Automated driving systems

1. INTRODUCTION

The Intelligent Transport Systems (ITS) attempt to provide a solution to the twentieth-century's negative legacy of traffic accidents and congestion. Large-scale national ITS projects began in Europe, the US and Japan in the mid-1980s but, compared to those early years, recent ITS efforts have seen a markedly greater focus on safety. The EU's eSafety initiative[1], announced in November 2002, aims to halve the number of annual traffic accident fatalities in the EU by 2010. The United States' ITS Ten-Year Plan[2], announced in January 2002, talks about achieving a 15% reduction in the number of annual traffic fatalities by 2011, while the National Intelligent Vehicle Initiative (NIVI) Meeting in June 2003 announced a goal of reducing the rate of traffic accident fatalities from the then-current 1.51 deaths per 100 million vehicle-miles traveled (VMT) to 1 death per 100 million VMT by 2007. Against this background of ITS activities, vehicle safety communication systems based on inter-vehicle communications have been a topic of great interest around the world in recent years. Taking up this subject, this paper addresses inter-vehicle communications technologies, the history of systems for the applications, and current trends, and some issues for the future.

The term of "inter-vehicle communications" can be also expressed as "vehicle to vehicle communications" or "car to car communications," and "inter-vehicle communications" is used in this paper.

2. ITS AND INTER-VEHICLE COMMUNICATIONS

2.1 The position of inter-vehicle communications within ITS

Under the ITS system architecture of the US and Japan[3], as indicated in Figure 1, ITS communications systems are defined to include four types of communications systems: inter-vehicle (vehicle to vehicle), road-to-vehicle, wide-area wireless and wireline. As this makes evident, the inter-vehicle communications are an important element of the ITS field. By definition, inter-vehicle communications include communications between drivers and between vehicles, but we will define it as communications between on-board computers. Systems introduced in this paper are accordingly those based on the definition.

One characteristic of inter-vehicle communications is that unlike road-to-vehicle communications, where the communications site is determined by the location of road

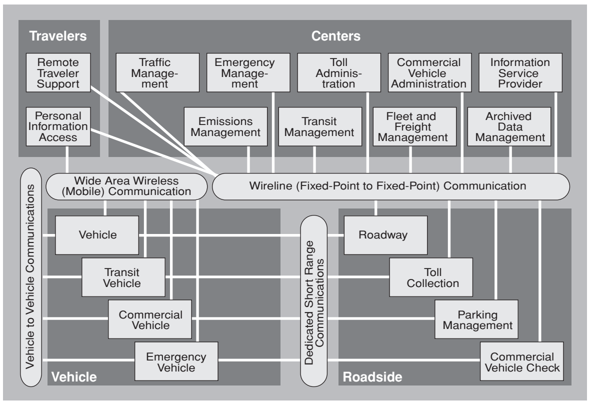

Fig. 1 Communication systems in ITS system architecture

beacons, communications with other vehicles can take place anywhere. Consequently, information and data that would be difficult or impossible to measure from a single vehicle can be collected through inter-vehicle communications. Inter-vehicle communications make it possible to expand the horizon of on-board sensing systems, a characteristic exploited in vehicle safety communication systems.

2.2 The history of research into inter-vehicle communications

Probably the earliest research into inter-vehicle communications was conducted in the early 1980s at the Association of Electronic Technology for Automobile Traffic and Driving (now the Japan Automobile Research Institute). This research treated inter-vehicle communications primarily as traffic and driver information systems incorporated in ATMS/ATIS (Advanced Traffic Management Systems/ Advanced Traveler Information Systems). Efforts have since been made to apply it to driver assistance and automated driving systems incorporated in AVCSS (Advanced Vehicle Control and Safety Systems). From the 1990s through 2000, automated platooning systems such as California's PATH (Partners for Advanced Transit and Highways)[4] and the EU's Chauffeur[5], as well as cooperative driving systems in Japan[6-8], made automated vehicle platooning a reality through the transmission of data, such as each vehicle's acceleration, through the inter-vehicle communications that would be impossible to measure from other vehicles. Recently, as described above, systems for improving automobile traffic safety that use inter-vehicle or road-to-vehicle communications to relay incident or emergency information from a preceding vehicle to succeeding vehicles[9,10] have generated a great deal of interest in Europe, the US and Japan.

3. APPLIED SYSTEMS INCORPORATING INTER-VEHICLE COMMUNICATIONS

Broadly speaking, inter-vehicle communications are applied to traffic and driver information systems within ATMS/ATIS (Advanced Traffic Management Systems/ Advanced Traveler Information Systems) or to driver assistance and automated driving systems within AVCSS (Advanced Vehicle Control and Safety Systems). In general, inter-vehicle communications in ATMS/ATIS applications are ad hoc and sporadic. This is also usually the case with many driver assistance applications in AVCSS. For automated driving systems such as automated platooning inter-vehicle communications must be maintained with a short period. Major research to date and its distinctive characteristics will be introduced below. Note that ATMS, ATIS and AVCSS are technical terms defined by ITS America[11] and represent the mainstream ITS systems.

3.1 ATMS/ATIS applications

Around 2000, a system for incident warnings was developed by the Ohio State University using 220MHz VHF[10], whose range of 1 to 2 kilometers made the inter-vehicle communications possible even where the penetration rate of the communication equipment is low. The researchers were interested in inter-vehicle communications because of the difficulty of preparing infrastructure intelligence to serve such a vast country.

Also around 2000, a German consortium proposed a system for relaying accident and incident information over inter-vehicle communications using the same 800MHz frequency band to that used for car phones[9]. The idea was that sending accident or incident information to succeeding vehicles would prevent multiple-vehicle accidents, particularly on suburban roads under poor visibility conditions. Accidents or incidents would be detected automatically based on the use of hazard lights, vehicle acceleration, airbag deployment or signals from the antilock braking system (ABS) and sent, together with GPS (Global Positioning System) location data from the navigation system, to be sorted out on the receiving end.

3.2 AVCSS applications

In the United State, Demo97, a large-scale demonstration of an automated driving system, was held in San Diego in 1997. The California PATH team[4] participating the Demo had a platoon of 8 passenger vehicles demonstrating automated driving at a speed of 96km/h and a gap distance of 6.3m, as illustrated in Figure 2. This system used inter-vehicle communications in a 900MHz band using off-the-shelf wireless LAN (Local Area Network) equipment to transmit and receive acceleration and deceleration information from preceding vehicles and commands from the lead vehicle. The data transmission rate was 122kbps.

Around 1997, California PATH conducted tests of inter-vehicle communications using infrared. As illustrated in Figure 3, the system employed transmitting and receiving equipment attached to the rear bumper of the preceding vehicle and the front bumper of the succeeding vehicle, and was distinguished by how it varied transmission rate with the bit error rate (BER). It was possible to raise the transmission rate as the BER decreased at shorter distances between the vehicles. This characteristic meets the need for more precise control as vehicles move closer together, which leads to higher transmission rate.

The European ITS project known as PROMETHEUS (PROgraMme for a European Traffic with Highest Efficiency and Unprecedented Safety), which ran from 1987 until 1994, developed an inter-vehicle communications system using 57GHz to achieve cooperative driving among multiple vehicles. Figure 4 shows the communication equipment attached to the vehicles.

Fig. 2 Platooning by California PATH during AHS demo in 1997

Fig. 3 Inter-vehicle communications with infrared by California PATH in 1997

The EU's Chauffer project[5] developed the system for truck platooning shown in Figure 5. The initial system involved inter-vehicle communications of acceleration, deceleration and other data from preceding vehicle to succeeding vehicle, employed a 2.4GHz band, and the communication period was 40msec and the rate was 230kbps. The later version of the system employed a 5.8GHz band.

The Netherlands Organization for Applied Scientific Research (TNO) incorporated inter-vehicle communications using infrared in the MENSOR system developed beginning in 1998. As illustrated in Figure 6, three transmitters attached to the rear bumper of a preceding vehicle communicated with one receiver attached to the front grill of a succeeding vehicle. The goal was to smooth traffic flow and prevent congestion by sending braking information from a preceding vehicle to a succeeding vehicle that would prevent rear-end collisions. The system subsequently developed into the EU's CarTALK2000 project discussed below.

An noted before, Japan was at the leading edge of the inter-vehicle communications research, beginning before either Europe or the US with research conducted by the author and the Association of Electronic Technology for Automobile Traffic and Driving. In the late 1980s, the author and his colleagues employed infrared signals to

Fig. 4 Inter-vehicle communication unit developed during PROMETHEUS project in 1994

Fig. 5 Heavy duty trucks for Chauffeur in 1998

perform inter-vehicle communications between automated guided vehicles for factories, developing vehicles that followed each other based on "soft links[12]." This was one of the earliest systems to apply the inter-vehicle communications to vehicle control.

In 1997 the Association of Electronic Technology for Automobile Traffic and Driving conducted cooperative driving system tests using infrared signals for inter-vehicle communications (Phase I)[6]. Under cooperative driving, the following distance between vehicles was measured by the triangulation between a pair of infrared markers on the roof of the vehicles, one of which functioned as a transmitter. Figure 7 shows four test vehicles, capable of both inter-vehicle communications and of vehicle gap distance measurement, assisting drivers by indicating when to merge.

Later, in 2000, the author and the Association of Electronic Technology for Automobile Traffic and Driving conducted new cooperative driving system tests (Phase II)[7,8]. This cooperative driving system incorporated the inter-vehicle communications among five automated driving vehicles using 5.8GHz DSRC (Dedicated Short Range Communication). As illustrated in Figure 8, the group of automated driving vehicles formed a flexible platoon enabling merging and lane changing. Each vehicle was equipped with D-GPS to measure the present vehicle location, and transmitted the location, speed, direction of the vehicle and the presence of obstacles, if any, through the inter-vehicle communications at a communication period of 20ms.

Research using inter-vehicle communications in driver assistance systems for blind intersections has also been conducted in Japan[13-15]. Sending the vehicle position data by GPS through the inter-vehicle communications enables other drivers to be aware of approaching vehicles that are beyond their field of view. The systems developed by Keio University[13] and by the author and his colleagues[14] employed 5.8GHz DSRC. Figure 9 illustrates the author's system being tested. One thing that must be noted with such systems is that over-reliance on the inter-vehicle communications by drivers of equipped vehicles raised the possibility of creating dangers for non-equipped vehicles.

3.3 Infotainment applications

Efforts have also been made to transmit movie data among vehicles using inter-vehicle communications. The Communication Research Laboratory in Japan conducted research on inter-vehicle communications using 60GHz millimeter waves[16]. Using millimeter waves for line-of-sight communications, experiments shown in Figure 10 were conducted at a relatively short gap distance for high-quality TV picture transmission.

The author and his colleagues conducted experiments in transmitting movie data through inter-vehicle communications using 5.8GHz DSRC. The objectives of this system, shown in Figure 11, were to prevent accidents and congestion by transmitting traffic condition informa-

Fig. 6 Inter-vehicle communications with infrared for CarTALK2000 in 2001

Fig. 8 Cooperative driving with 5 automated vehicles linked by inter-vehicle communications in 2000

Fig. 7 Driver assistance by inter-vehicle communications with infrared in 1997

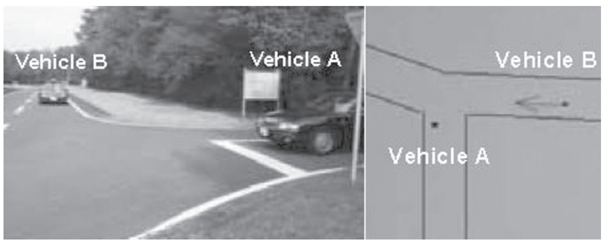

Fig. 9 Collision avoidance at a blind crossing with inter-vehicle communications in 2001

tion in a movie data format from preceding vehicles to succeeding vehicles[17]. Transmission of in-vehicle scenes among partner vehicles allows creation of a "virtual cabin" of the partner vehicle in one's own vehicle, with possibilities for inter-vehicle communication entertainment.

4. TRENDS IN VEHICLE SAFETY COMMUNICATION SYSTEMS IN EUROPE, THE US AND JAPAN

As described in the previous section, research in the applications of inter-vehicle communications to ITS began in the 1990s, but the conspicuous trend in inter-vehicle communications research in Europe, the US and Japan since the start of the twenty-first century has been a focus on safety.

4.1 Trends in Europe

Table 1 lists European (EU) vehicle safety communication projects. ITS in the EU is characterized by a relatively lower emphasis on infrastructure-side intelligence and a correspondingly higher level of interest in inter-vehicle communications. The objectives and characteristics of each project are addressed below.

The joint German-French IVHW (Inter-Vehicle Hazard Warning) project aims to realize the functions listed in Table 2. The frequency band used for the inter-vehicle communications in IVHW is 869.4MHz - 869.65 MHz with a potential range of as much as 1km on urban roads (reliable range of about 500m) and 2km on highways (reliable range of about 1km). The GPS data is included in the communication content and the information is sorted at the receiving end with the localization data.

The German FleetNet project, in which automobile manufacturers, communications companies, universities and research organizations took part, aimed to create a communications platform for inter-vehicle communications. Applications were varied, including cooperative driving assistance, decentralized floating cars and Internet access, and were demonstrated with six small passenger cars. One of the fruits of the project was a communication network routing algorithm based on vehicle position that produced better results than other ad hoc routing algorithms. The NOW (Network on Wheels) project devel-

Fig. 10 TV image transmission over inter-vehicle communications with millimeter wave in 2001

Fig. 11 Movie transmission over inter-vehicle communications with 5.8GHz DSRC in 2004

Table 1 European vehicle safety communication projects

Project	Period	Sponsor Countries	Objectives
IVHW(Inter-Vehicle Hazard Warning)	2000-2002	Germany, France	Hazard Warning
FleetNet	2000-2003	Germany	Communication Platform
CarTALK2000	2001-2004	EU	Cooperative Driving in Practice
INVENT VLA(*Intelligenter Verkehr und Nutzergerechte Technik, Verkehrs Leistungs Assistenz*)	2001-2005	Germany	Traffic Efficiency, Cooperative Driving
WILLWARN(Part of the PReVENT project)	2004-2006	EU	Hazard Warning
NOW(Network on Wheels)	2004-2007	Germany	Demonstration and Standardization
C2C-CC(Car to Car Communication Consortium)	2001-	Consortium of Private Companies	Standardization

Table 2 Functions included in IVHW

Function	Description
Accident and congestion warning	Transmission of accident or congestion information from preceding vehicles, including GPS positioning data.
DTR (Decentralized Traffic Routing)	Each vehicle transmits its own speed, generating a pool of road network traffic information that makes route guidance possible.
Platooning	Convoying of multiple vehicles.
Lane change assistance	Indicates that a vehicle in the neighborhood will change lanes.
Road surface condition monitoring	Preceding vehicles send road surface information such as coefficient of friction to succeeding vehicles.
Transmission of traffic conditions ahead	Transmission of road scene information ahead; the view of the road scene is blocked by other vehicles in front.
Identification of the last vehicle in the congestion	Specify the last vehicle in the congestion through transmissions from it to succeeding vehicles.
Intersection assistance	Prevent collisions through communications among intersecting vehicles.
Merging assistance	Assist vehicles in merging smoothing from the on-ramp to the through traffic lane.

oped from FleetNet.

CarTALK2000 was established within the EU's ADASE2 (Advanced Driver Assistance Systems Europe) ITS project and included the participation of automobile manufacturers, automobile parts manufacturers, communication companies, universities, and research organizations. It incorporated three applications: a warning system that relays information on accidents ahead, break-downs, and congestion; a longitudinal control system; and a cooperative driving assistance system that supports merging and weaving. For CarTALK2000, inter-vehicle communications used mobile, ad hoc multi-hop networks. The reasons to use inter-vehicle communications were defined as:

1) The inapplicability of mobile phones to important, time-critical applications.
2) The need to use high-speed data transmission.
3) The ability to do without infrastructure-side networks.
4) The ability to reduce communication costs.

These characteristics apply not only to CarTALK2000 but commonly apply to many inter-vehicle communications applications.

The German INVENT (*Intelligenter Verkehr und Nutzergerechte Technik*) project, aimed at safe driving assistance and optimizing traffic flow, included both automobile and parts manufacturers. Among its eight subprojects, the VLA (*Verkehrs Leistungs Assistenz*) dealt with safety through communications. The VLA is a key technology for driving assistance systems as it allows drivers to predict traffic conditions and adjust accordingly. VLA inter-vehicle communications envisioned the use of 24GHz UWB (Ultra Wide Band) radar at high speeds (period: 0.01sec) over narrow ranges (50m) to exchange driver intentions and middle-speed (period: 0.1 sec) middle-range (500m) ad hoc networks for transmission of local traffic conditions.

The EU's PReVENT project for improving driving safety included the WILLWARN inter-vehicle communications sub-project. WILLWARN provided dispersed warning information by detecting hazards from vehicles and sharing information among vehicles through an inter-vehicle communications network.

In addition to the projects mentioned above, the C2C-CC (Car-to-Car Communication Consortium) was established by European automobile manufacturers to standardize inter-vehicle communications.

4.2 Trends in the US

The US Department of Transportation in 1998 began the IVI (Intelligent Vehicle Initiative) project with the goal of improving safe driving. As part of this project, IDS (Intersection Decision Support) systems using the communication technologies have been developed in the three states of California, Minnesota and Virginia. The California IDS[18] not only detects straight oncoming vehicles from the ground but also combines GPS data with inter-vehicle and road-to-vehicle communications data for on-board display of other vehicles' locations. Media and protocols used conformed to IEEE802.11a. Figure 12 shows the array of antennas installed on the roof of a test vehicle.

Meanwhile, CAMP (Crash Avoidance Metrics Partnership), a group founded by automobile manufacturers in 1995 in cooperation with the Department of Transportation and standardization organizations, supported the VSCC (Vehicle Safety Communication Consortium) from 2002 to 2004. The VSCC included automobile manufacturers from Europe, the US and Japan and proposed a system applying inter-vehicle and road-to-vehicle communications to active safety. System proposals for the near future include traffic signal violation warning, curve speed warning and emergency electronic brake lights. Middle future proposals include pre-crash sensing (that prepares for unavoidable collisions), cooperative forward collision warning, left-turn assistance (in the US), lane-change warning and stop sign assistance.

The US Department of Transportation also began the VII (Vehicle Infrastructure Integration) program in 2004 in cooperation with state departments of transportation and automobile manufacturers. VII considers applications for inter-vehicle and road-to-vehicle communications to active safety, traffic management and traveler information. Using DSRC for inter-vehicle and road-to-vehicle communications, field operation tests will continue from 2005 through 2009 with a decision on introduction slated in 2010.

4.3 Trends in Japan

In Japan, three of the four ministries involved with ITS are active in inter-vehicle communications. Since 1999, ITS Forum under the Ministry of Internal Affairs and Communications has proposed systems using inter-vehicle communications for ACC (including Stop&Go), cooperative driving, hazard warning, merging and lane-change warning, intersection and curve collision warning, and communications between and within platoons. The media used depends on the applications, with millimeter waves used for line-of-sight communications and microwaves for omni-directional communications. The

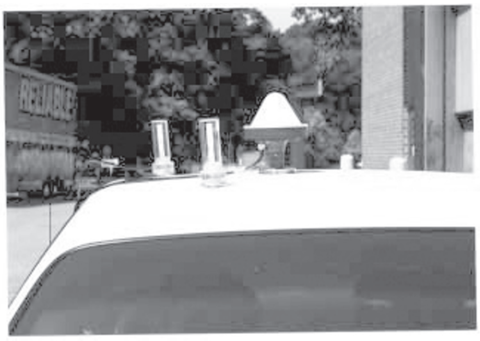

Fig. 12 Antennas for Intersection Decision Support in 2003

Ministry of Land, Infrastructure and Transport, in its active safety-focused ASV (Advanced Safety Vehicle) project, uses communications among heavy duty trucks, passenger cars, and motorcycles to provide notification of motorcycles ahead in blind curves or hidden from view on narrow roads and to assist with right turns (in Japan) by providing notification of motorcycles traveling straight in the opposing lane. The Ministry of Economy, Trade and Industry has also been active in efforts aimed at standardization of inter-vehicle communications.

5. ISSUES FOR INTER-VEHICLE COMMUNICATIONS

As described above, there has been active research and development on the inter-vehicle communications applications to active safety in Europe, the US and Japan. Nevertheless, there remain a number of important issues that need to be resolved.

5.1 Protocols

There are two requirements for ITS inter-vehicle communications protocols. The first is the flexibility to accommodate both the addition of new vehicles to the network and the withdrawal of existing vehicles. The second, particularly when the goal is vehicle control, is real-time data transmission. The importance of these requirements varies by applications. Flexibility is more important in AMTS/ATIS applications. For AVCSS applications, however, it is critical to achieve both flexibility and real-time data transmission. The compatibility is not always easy.

In the cooperative driving Phase II project conducted by the author and his colleagues, flexibility was achieved by using a CSMA (Carrier Sense Multiple Access) technology. Real-time data transmission was achieved by composing a single vehicle control period of five communication periods, using repetitive communication to reduce the packet collision rate. Figure 13 describes the relationship between the number of successful communications within a single vehicle control period and the rate of communication success. The figure shows that when setting the BER below 10^{-3} at least one successful communications are performed within a single vehicle control period, which is equal to five communication periods.

5.2 Media

Many media have been used and tried in experiments to date, including VHF, microwaves, millimeter

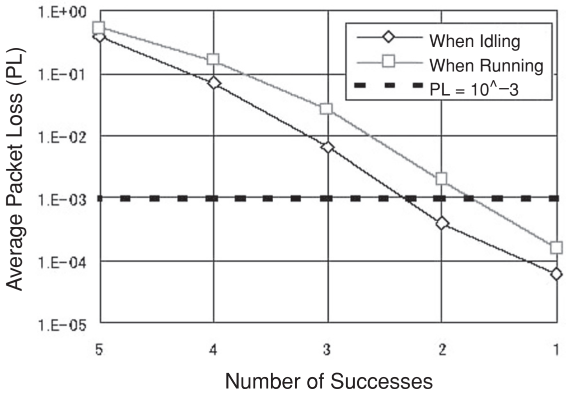

Fig. 13 Relationship between the number of successful data transmission and the rate of packet discard

waves and infrared. The former two are non-directional while the latter two are directional. Many varieties of microwave have been used in experiments, including 800-900MHz, 2.4GHz, wireless LAN, 5.8GHz, and 5.9GHz. The selection of media must match the application.

5.3 Penetration rate

Services using road-to-vehicle communications can begin with even a single vehicle equipped with a communication device as long as the infrastructure-side preparations are in order. Services using inter-vehicle communications, however, unlike road-to-vehicle communications services, require multiple vehicles equipped with communication devices. As previously noted, many services have been proposed that assume high penetration rate of communication equipment or that all vehicles are so equipped. For example, the systems discussed above for preventing accidents at intersections assume that all vehicles are equipped with communication devices. However, given the possibility of equipment failure, loss of power and radio interference, there is no guarantee of communications. Systems that assume all vehicles are equipped are not necessarily realistic. Systems to prevent accidents at intersections may be of assistance to drivers but if drivers become dependent upon them they could create new dangers in situations where unequipped vehicles are present. Such systems have a strong possibility of becoming a “two-bladed sword.” In the intersection collision prevention system mentioned above, a driver relying solely on the system would have no way of knowing of the presence of an unequipped vehicle. In order to confirm conditions are safe, the driver must conduct a visual check and not rely solely on the system, making the system appear meaningless. At the same time, such a system would have a role to play in bad weather or at other times when a visual safety check is difficult, and could contribute to the protection of pedestrians, bicyclists and other vulnerable road users, were they equipped with communication devices to relay proximity information.

The development of inter-vehicle communications systems should begin with services that are effective even in the absence of extensive penetration of communication devices. Such systems should provide advantages to equipped vehicles and, although providing no direct advantages for non-equipped vehicles should avoid creating any disadvantages for them. The author took up a system for relaying incident information from preceding vehicles to succeeding vehicles as a means of avoiding multiple-vehicle accidents and congestion on highways, conducting a simulation to explore the relationship between the penetration rate of communication equipment and distance of data transmission. The results, though varying with traffic density, indicates that the necessary penetration rate of the communication devices would be 10% to 20% in order to be able to relay information back along a single-lane road[19]. Results also suggested a penetration rate of 5% to 10% would be sufficient for a two-lane roadway, and 3% to 7% for a three-lane roadway.

Given a total of 70 million vehicles in Japan, if it were possible to use the 6 million ETC (electronic toll collection) communication units in Japan (as of March 2005) for inter-vehicle communications away from the ETC toll gates, there would be a penetration rate of roughly 9%, meaning an incident transmission system using inter-vehicle communications is already feasible. Because it is already possible to identify the location of one’s own vehicle using car navigation systems, equipment could be switched over from ETC use near ETC toll gates to inter-vehicle communications use at any other locations. Although there are minor differences in the communication system used for ETC in Japan and the inter-vehicle communications system for cooperative driving developed by the author and his colleagues, both use 5.8GHz DSRC and it is not a technical impossibility to add inter-vehicle communications functionality to ETC communication devices.

5.4 Road-to-vehicle communications and inter-vehicle communications

Under the ITS system architecture developed in Japan and the US, road-to-vehicle communications and inter-vehicle communications are defined as separate. The author, however, believes the former to be a subset of the latter because if a vehicle equipped with an inter-vehicle communication device stops along a road side, it engages in road-to-vehicle communications. In other words, road-to-vehicle communications can be seen as a special case of inter-vehicle communications. Regarding the two types of communications in this way rather than in dependent two types makes it easier to develop application scenarios of the inter-vehicle communications like the use of ETC equipment described above.

5.5 Introduction of inter-vehicle communications systems applications

Many ITS systems share a common "chicken-and-egg" problem. Stand-alone systems do not face this problem, of course, but systems incorporating road-to-vehicle or inter-vehicle communications inevitably face the problem of whether infrastructure intelligence or vehicle intelligence comes first, or of who will be first to equip their cars with inter-vehicle communication devices. The key to overcoming this problem is a system that offers not a single purpose or service but multiple purposes and services including safety, infotainment and convenience.

6. CONCLUSION

This paper surveys the research on inter-vehicle communications and some outstanding issues. Much research and development work has been done in recent years but there is still no practical inter-vehicle communications system in operation. The inter-vehicle communications hold the possibility of contributing greatly to automobile traffic active safety by expanding the horizon of both drivers and of on-board sensing systems. Nevertheless, many unresolved issues remain today including technical issues such as standardization, development issues such as application systems, and legal and institutional issues. Finding solutions for these issues and developing systems for the applications of inter-vehicle communications are critical for the realization of safer automobile transportation.

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