Traffic Management System toward Connected and Automated Vehicles Era

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Traffic accidents and congestion problems have been reduced by the efforts of public and private sectors. Sumitomo Electric Industries, Ltd., a leading supplier of intelligent transport systems, has contributed to the development and installation of wide area traffic management systems. For more safety, infrastructure-vehicle cooperative driving safety support systems using sensing and wireless communication technologies are expected to be one of the best solutions to traffic problems particularly near intersections. To meet these needs in the era of connected and automated vehicles, we have been researching and developing new technologies utilizing artificial intelligence and simulations. This paper reports on our previous and future efforts for advanced traffic management systems.

Keywords: traffic control, driving safety support systems, sensing technology, connected vehicles, automated driving

1. Introduction

The rapid development of motorization in Japan significantly has contributed to the country's economic growth and improvement of living standards, but at the same time it was, of course, a factor in the increasing number of traffic accidents, rising road congestion, and air pollution. Such negative effects on society have now become even more obvious. To address such aspects, Sumitomo Electric Industries, Ltd. commenced R&D of intelligent transport systems (ITS) as early as the late 1960s, developing traffic control systems for the Traffic Control Center of the Tokyo Metropolitan Police Department, to contribute to the improvement of road safety and traffic congestion. Also, in emerging countries, where motorization is expanding at an explosive pace, traffic accidents and congestion are becoming a serious problem, just as they were in Japan. Utilizing Sumitomo Electric's expertise in traffic control technology, which we have cultivated in Japan, we are also working on introducing our traffic control systems to countries in Southeast Asia and other regions. The important point here, however, is adopting the technologies and knowhow of each country into the system in order to suit the country's specific traffic conditions, rather than simply applying Japanese specifications universally.

Although the number of road accident fatalities in Japan has been declining thanks to efforts such as those described above, still quite a number of fatal traffic accidents are reported and more than half of them occur near intersections, and more than half of these victims are elderly citizens. Countermeasures for these two issues are indispensable for better road safety, and joint efforts by the government and the private sector are being keenly undertaken to introduce and spread a cooperative safe driving support system. In such a system, the technology to sense vehicles and pedestrians in blind spot that cannot be sensed by on-board sensors, combined with wireless communication technology, functions as an important component. Sumitomo Electric has been actively developing and commercializing such technologies.

Further, we have been making continuous efforts in order to respond to new types of demands in the era of connected and automated vehicles through new technology development backed up by our wide-ranging business record. Development areas include traffic control systems integrated with artificial intelligence (AI) and simulation technologies, and refinement of traffic signal communication products that help smooth transport operations.

This paper reports on the record of Sumitomo Electric's contribution to traffic systems to date and future prospects for our technologies.

2. Traffic Control

2-1 Trends of traffic accidents in Japan and national countermeasures

As motorization progressed in Japan, the number of traffic accidents suddenly increased from the 1950s (referred to in Japan as the "First Traffic War") and the number of road accident fatalities exceeded 16,000/year around 1970. The government published the Fundamental Traffic Safety Program (five year plan) in fiscal 1971, and accordingly a variety of traffic measures were established, together with the Traffic Control Center. As a result, the number of road accident fatalities was halved over the following 10 years. However, fatalities rose again due to the continuous increase in vehicle ownership, eventually exceeding 10,000 again in 1988 (so-called "Second Traffic War"). At the same time, traffic congestion and environmental pollution grew into a social problem, which prompted five ministries and agencies to create the Comprehensive Plan for Intelligent Transport Systems (Long-Term Vision) in 1996, setting shared R&D targets across nine development areas under a joint effort by government, academia, and industry. The introduction of ITS has reduced the number of traffic road fatalities, yet the rate of decrease is slowing down and the percentage of elderly (aged 65 or older) among fatalities is still about 55%. Such issues to be addressed are present even today.

2-2 History of traffic control and Sumitomo Electric's contribution

The first contribution by Sumitomo Electric to traffic control was in the field trials on the Koshu Road, jointly carried out by Sumitomo Electric and the University of Tokyo, and other organizations, in 1968, to operate traffic signals remotely from a central controller. In 1970, together with other corporations and organizations, the Company received an order to develop a wide-area traffic control system that would cover Tokyo. Since that time, we have been playing a leading role in the development of traffic signal control in Japan. In 1995—for the first time in Japan—Sumitomo Electric developed an adaptive signal control system(1) that optimizes the green (GO) time based on the current traffic conditions, which was collected by multiple vehicle detectors. The traffic signal control method used in this system (known as "MODERATO control") was later adopted as the standard system in Japan by the National Police Agency. Sumitomo Electric showcased a demonstration of Japan's first decentralized autonomous (profile control) system exclusively developed by us, in the ITS World Congress held in Aichi Prefecture in 2004. This control method has been steadily adopted by prefectural police departments across Japan. In this way, Sumitomo Electric has constantly developed the technology to advance traffic signal control to address public demand for smoother traffic flow.

On the other hand, the recent worsening of the finance of local governments in Japan has caused a serious deterioration in the traffic infrastructure, primarily due to aging. Along with this requirement for infrastructure replacement, traffic signal control systems need to be updated with more resilient traffic control systems, including lower installation and maintenance costs. Following such changing social demands, Sumitomo Electric has been taking the initiative in developing and commercializing a new traffic signal control system that utilizes "probe data," which is vehicle trajectories gathered from connected vehicles, instead of data gathered from conventional fixed vehicle detectors. The number of connected vehicles is now rising quickly due to the advancement of information and communication technology (ICT). Sumitomo Electric further aims to streamline traffic flows using a cooperative traffic control system, in which traffic signal data is exchanged between vehicles and roadside units, so that the vehicles automatically change their driving behavior according to the anticipated traffic signal ahead.

2-3 Traffic control measures utilizing probe data

To realize a safer, smoother, and more comfortable road traffic environment, Sumitomo Electric has been gathering and analyzing past traffic conditions utilizing the probe data accumulated by car manufacturers and other organizations in the private sector.

The Company conducted a two-year survey from 2014 in Okayama Prefecture, aiming to reduce traffic congestion. This survey assessed the utilization of probe data in creating traffic smoothing measures, and resulted in the creation of traffic accident prevention measures with the prospect of immediate effect, together with medium- to long-term traffic congestion reduction measures. Analyzing the speed information in the probe data enabled us to identify areas where traffic speeds are frequently decreased and pinpoint regular congestion hot spots. We further studied these congestion-prone areas to gain more detailed information, such as the branching ratio at an intersection and the average number of stops by vehicles in the area. This detailed analysis helped us understand congestion in areas outside the coverage of the traffic control system and congestion in specific traffic directions that could only be captured by fixed detectors in the past. We also conducted a trajectory analysis, which clarified residential roads used as shortcuts to avoid traffic congestion on the primary routes. Based on these analysis results, we established a basic policy to (1) review traffic signal control parameters, (2) extend traffic control coverage areas, and (3) advance data collection mechanisms, in order to refine our congestion-easing program.

2-4 Exporting traffic control systems to emerging countries

Southeast Asian countries import traffic control systems from other countries; however, such systems are sometimes eventually abandoned due to difficulties in system maintenance, as system specifications are not tailored to suit the traffic conditions specific to that particular country (e.g. Thailand has significant volumes of traffic merging to and from side roads), and the technical and operational knowhow concerning the system are not passed on or cannot be passed on to local administrators. Therefore, it is important to deliver the system in a format tailored to the traffic conditions in the target country, as well as in a format that can be easily maintained by local administrators. The following section introduces Sumitomo Electric's recent projects in Thailand and Cambodia.

In Thailand, Sumitomo Electric commenced technical exchanges with a local corporation in 2014 to fuse the traffic signal control methods adopted by the two companies. This resulted in the creation of a new traffic signal control method that would specifically suit Thailand's traffic conditions. The new method was programmed into the system and installed in traffic signals by the local corporation, in order to enable continuous maintenance by the Thai team. Utilizing this new traffic signal control system, a field trial to improve traffic flows was conducted at five consecutive intersections in Bangkok as a part of the 2015–16 Japan International Cooperation Agency (JICA) project. The trial demonstrated the possibility of economic effects worth approx. 50 million JPY per year as an estimate of human cost reduction from decreased waiting time at traffic signals. This collaborative project is ongoing, aiming at a system extension to establish a new traffic control center in Thailand.

In Cambodia, we received an order for the development of a traffic control system that would manage 115 intersections in Phnom Penh under official development assistance (ODA) grant aid by the Japanese government and the system is now being installed. This is a large scale project that covers installation of a traffic control center, monitoring cameras, optical fiber networks, traffic signals, and vehicle detectors. Completion of the system is keenly awaited, with great expectations for reducing Phnom Penh's traffic accidents and congestion, which are growing into serious problems as the number of vehicles in the city rapidly rises.

Photo 1. Traffic improvement in Phnom Penh

3. Cooperative Driving Support Systems (V2X)

3-1 Background of system installation and situations in different countries

On March 11, 2016, the Japanese government compiled the 10th Fundamental Traffic Safety Program, which states that Japan aims to (1) have the world's safest road traffic by reducing the number of road accident fatalities (deaths within 24 hours of an accident) to 2,500 or less by 2020 and (2) reduce the number of road accident injuries and fatalities to 500,000 or less by 2020. The current number of road accident fatalities is 3,694 (2017) and further efforts are required to meet the project's target. The Driving Safety Support Systems (DSSS) based on coordinated road transport are a part of such efforts, and system development and installation are in process under the collaboration between the government and the private sector. In the US, there were about 35,000 fatal motor vehicle accidents in 2016. According to a study by the National Highway Traffic Safety Administration (NHTSA) in the US, 94% of vehicle crashes were caused by human error. For this reason, the introduction of connected vehicles and automated driving is being accelerated in the country and field trials of connected vehicles are being carried out across more than 30 cities. Trials to realize cooperative ITS based on connected vehicles and automated driving have also started in Europe towards eliminating road accident deaths and reducing traffic congestion.

3-2 Driving Safety Support Systems

Despite the recent declining trend in the number of road accident injuries and fatalities in Japan, the actual figure still remains high at more than 580,000 per year. When focusing on the number of deaths, 55% of those killed were aged 65 or higher, and the major causes of accidents were delays or errors in recognition, judgment, or operation. This suggests that the urgent establishment of accident prevention measures targeted at elderly drivers is necessary. As a means to reduce damage in the event of a road accident, independent safety support systems (using on-board sensors) have been proactively developed by car manufacturers, such as a collision mitigating brake system and lane-keeping assistance system. However, road accidents cannot be prevented solely with such independent safety support systems because many accidents are caused by factors that cannot be detected directly by the vehicle itself. This is the reason why expectations for cooperative driving safety support systems are rising so that factors of accident that cannot be visible from a single vehicle can be detected through wireless interactive communications among multiple vehicles and roadside detectors.

Against this background, the National Police Agency has been engaged in R&D and the practical application of a cooperative DSSS to assist drivers' recognition and judgment concerning road conditions. UTMS Society of Japan is the organization that manages infrastructural field operation tests (FOTs) of ITS and ITS standardization. Sumitomo Electric has been involved in the society's R&D and FOTs to develop and test key DSSS components, including a 700-MHz band ITS wireless roadside unit, a sensor that detects a vehicle's position and speed, a sensor to detect pedestrians at a crossing, and a traffic signal controller that can output predicted traffic lights state. Sumitomo Electric also participated as a board member of the ITS Connect Promotion Consortium from its foundation in October 2014, towards establishing ITS wireless security specifications, interconnectivity validation methods, and their related operational methods. This participation has also involved playing a role in building the framework for ITS operations under the collaboration between the government (which is responsible for infrastructure building and management) and the private sector (which actively promotes vehicle usage). As a result of such efforts, the Right Turn Collision Prevention Support System, the Post-Right Turn Predestination Collision Prevention Support System, and the Traffic Signal Oversight Prevention System were put into practical use in 2015. These services are accessible from commercial vehicles, in 81 intersections across eight prefectures as of the end of March 2018. We are currently working on refining DSSS and planning infrastructures for assisting automated driving utilizing the key components described above, including the ITS wireless roadside unit.

3-3 Sensing technology

A vehicle detector used in a DSSS needs to have a wide detection area and highly accurate distance and speed detection performance in order to precisely estimate the time that the vehicle will arrive at the intersection. Based on a substantial record of sales of our image detectors designed for traffic control use, Sumitomo Electric has now launched an image-based vehicle detector for DSSS. A pedestrian detector, on the other hand, must be able to detect pedestrians, who do not emit any light themselves, in a reliable manner all the time. To achieve this, Sumitomo Electric has newly developed a millimeter wave radar pedestrian detector, which is unaffected by weather conditions and light levels. A millimeter wave radar is a detector that measures the distance to and direction of a target object by casting a radio wave at the target and then receiving the reflection wave returned from it. Sumitomo Electric's millimeter wave radar pedestrian detector secures a wider detection area by using advanced antenna design technology, a capability that provides flexibility in the detector's installation location. We have also developed an algorithm optimized exclusively for roadside usage, to achieve highly accurate detection, including a function to estimate pedestrian movement based on an analysis of the reflection wave features. We are now developing a millimeter wave radar to detect vehicles utilizing the knowhow we have gained from our development of the roadside pedestrian detector.

4. Next Generation Traffic

4-1 AI traffic control

Conventional traffic control systems usually calculate the traffic condition based on data from vehicle detectors installed on the roadside, and then control traffic signal operations and provide traffic information based on the calculation results. However, the maintenance costs for such roadside vehicle detectors have grown into a serious burden for local governments due to increasing financial constraints. To reduce the number of vehicle detectors, we are currently conducting research on calculating the road condition from probe vehicle trajectories at the same level of accuracy as when using roadside detectors, through using AI to learn about the correlation between probe vehicle data and the data from roadside vehicle detectors. This is a trial both of the latest probe vehicle trajectory technologies and AI machine learning, which have become more commercially available recently.

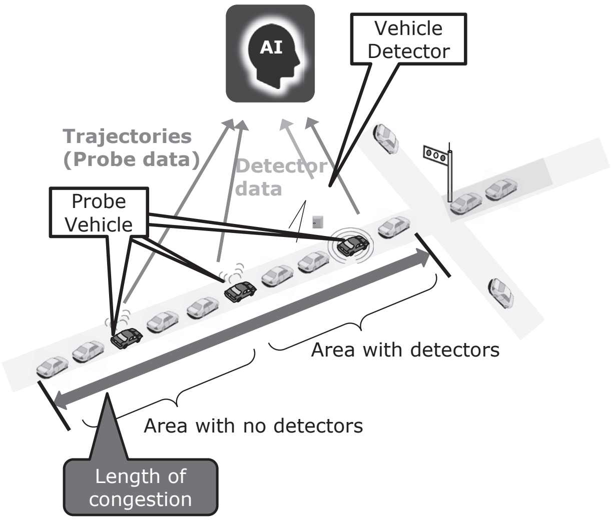

Fig. 1. AI traffic control

4-2 Wide-area traffic simulation technology

A traffic simulator is one of the most effective support tools for testing various traffic measures and assessing their effects, such as for new road building plans, diversion route guiding plans used in the event of an accident or road works, and preparations for a major event or natural disaster. However, it has been difficult to run simulations that can reproduce the actual measurement of traffic volume, congestion, and travel time, when the simulation area becomes large like the entire Tokyo metropolis. Also, simplification of simulator operations is important as traffic administrators need to be able to compare the effects and traffic influences from different traffic control choices in various traffic scenarios when assessing potential traffic measures.

To address these issues, we developed a technology to improve simulation accuracy by automatic adjustment and simplify operations through utilizing the data managed by the traffic control system. This technology was incorporated into the SOUND Traffic Simulator (developed by the Institute of Industrial Science, the University of Tokyo) and was put into operation in the Traffic Control Center of the Metropolitan Police Department in April 2011.(2) Figure 2 shows an example of a simulation of the congestion that occurred during the Great East Japan Earthquake in March 2011. The horizontal axis shows the time and the vertical axis shows the length of congestion within the 23 wards in Tokyo. The three lines in the graph are an actual measurement on March 4, 2011 (one week before the earthquake), an actual measurement of March 11 (on the day of the earthquake), and a simulation result for March 11. The Traffic Simulator managed to reproduce a generally accurate simulation of changes in the length of congestion based on the input parameters, such as the closure of the Metropolitan Expressway, increase in transport demand, and decrease in the intersection function efficiency. The simulator also has additional functions to execute a post-event analysis to identify the effective traffic measures in a certain situation by adding extra parameters, such as to calibrate the traffic demand.

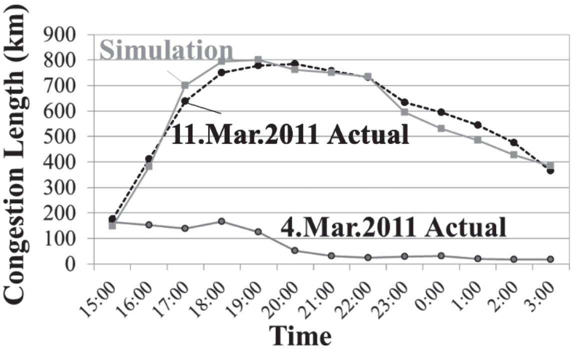

Fig. 2. Traffic simulation sample (Source: ITS World Congress 2012)

The wide-area traffic simulator is now an indispensable tool for designing and identifying effective traffic measures in the metropolitan area as a part of disaster prevention measures and in preparatory measures for major forthcoming events in Tokyo, such as the Tokyo Olympics and the Paralympics in 2020.

4-3 Efforts for automated driving

Automated driving are expected to control starting, stopping, and speed by recognizing the traffic light ahead through a vehicle-mounted camera. However, the recognition may not be sufficiently accurate in a backlit situation, or the inability to recognize the signal setting may be caused when hidden by a large vehicle in front of the camera. Also, depending on the traveling speed of the vehicle, a situation may arise where the vehicle cannot stop safely without crossing the stop line by the ending time of the amber signal during a signal changing cycle (known as "the dilemma zone"). In such a situation, an automated vehicle may run through a red light or cause an intersection collision. Or, the vehicle may activate an emergency stop, causing passenger injuries or a collision with vehicles behind. To prevent this kind of scenario, the vehicle can be designed to reduce speed and stop once whenever it approaches an intersection equipped with traffic signal (signalized intersection). However, this may reduce the commercial value or social acceptability of self-driving vehicles. Therefore, as a solution to these issues, it is indispensable for safe automated driving to continuously provide the vehicle with the information of the current traffic light and the time until changing through wireless communication. Continuous provision of traffic signal information enables support for smooth continuing travel or for a stop at a signalized intersection.

To realize this continuous data provision, vehicle-to-infrastructure (V2I) communication and vehicle-to-network (V2N) communication can be used. V2I communication is used to transmit data to a vehicle from a wireless roadside unit installed at an intersection. The 700 MHz band is allocated to this type of communication in Japan, while the 5.9 GHz band is used in the US and Europe. V2N communication uses the 4G (LTE) mobile telephone network and will make use of 5G in the future.

On the other hand, traffic signals have two control types. One is the central control type in which a traffic signal is connected to a Traffic Control Center and the traffic signal light duration in seconds is determined each time depending on traffic conditions. The other is the local control type where traffic signal cycle duration is predetermined according to the day of the week and the time of the day. Further, both of these types may adopt traffic-actuated control, whereby the cycle can be altered according to demand, such as by using a vehicle detector or by a pedestrian pushing a button.

For signalized intersections of the central control type or the traffic-actuated control type where the traffic signal cycle frequently changes, V2I communications would be suitable for automated driving so that the latest data can be submitted directly from the wireless roadside unit in real time. On the other hand, V2N communications would be more beneficial for a signalized intersection of the local control type without traffic-actuated control, as it may reduce its installation costs than V2I communications by delivering predetermined traffic signal cycle data for each intersection from a designated data center. A combination of V2I and V2N communications according to the intersection type will certainly help to accelerate the expansion of the infrastructure required for automated driving.

One of technical issues is to prevent erroneous data provision. If the data transmission latency is widely variable, a vehicle must make a judgment of whether to stop or continue driving taking account of such variability. Also, traffic signal controllers have a function to switch themselves to a maintenance mode if the controller fails or communications with the Traffic Control Center are interrupted, therefore it is necessary to change the traffic signal information immediately into a maintenance mode for both V2I and V2N communications. Working together with car manufacturers, Sumitomo Electric has been actively involved in the development of V2I and V2N communication systems that are suitable for automated driving including solutions for such technical problems.

5. Conclusion

Sumitomo Electric's traffic control technologies are playing a major part in Japan's traffic control systems that are now evolving into comprehensive systems that connect roads, vehicles, human beings, and society. Sumitomo Electric continues to contribute to the formation of future traffic systems through the united power of the entire group by flexibly adapting to changes in the transportation environment under our unchanging business vision of "Realization of a safe, secure and comfortable society."

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