

Hitachi Makes a Significant Contribution to the Construction of Secure and Reliable ETC Systems in Japan

Takeshi Horie
Takahiro Saida

Overview: An electronic toll collection (ETC) system collects tolls from vehicles driving on toll roads without making the vehicle stop at a tollbooth. This is accomplished by installing wireless devices in both vehicles and tollbooths to exchange toll-related information by radio. In Japan, deployment of ETC systems is scheduled to begin in 2000, and the plan is to convert major tollbooths on highways throughout the country to ETC over the next three years. Hitachi, Ltd. has been engaged in the research, development, and commercialization of all aspects of ETC systems, beginning with monitoring and radio-communication systems and expanding to on-vehicle devices, tollbooth systems, settlement systems, system security, etc. Through these efforts, Hitachi, Ltd. aims to make a significant contribution to the construction of secure and reliable ETC systems.

INTRODUCTION

As illustrated in Fig. 1, electronic toll collection (ETC) speeds up the collection of tolls by deploying radio frequency devices at toll gates and in the vehicles passing through the gates, so that the toll collection process is automatically handled through the transmission of toll collection data between the roadside and on-board equipment.

Common nationwide standards for ETC equipment were adopted in Japan in 1998. ETC systems became

operational on some of the country's expressways and so on in April 2000, and most of country's toll collection facilities are scheduled to be converted over to ETC systems during the next three years.

The adoption of ETC systems is expected to bring a number of significant advantages. It will

- (1) relieve congestion,
- (2) be more convenient to drivers since they do not have to carry cash,
- (3) streamline toll collection operations,

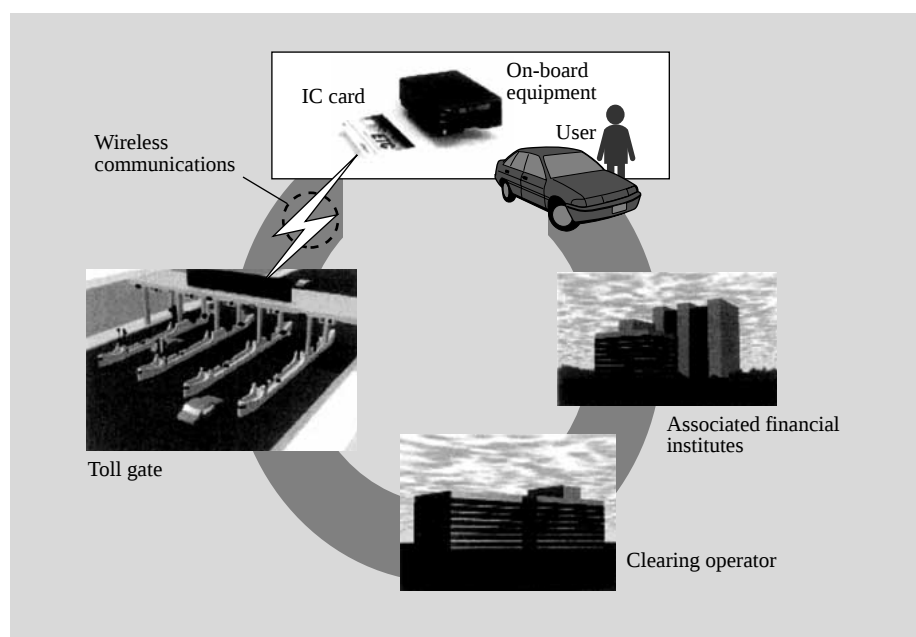


Fig. 1—Overview of the ETC System.

- (4) reduce roadside environmental pollution, and
- (5) enable various and flexible charging systems.

Hitachi, Ltd. has been in the forefront of R&D efforts to realize ETC since the company was involved in joint public-private research in 1995. This paper provides an overview of ETC-related developments in Japan, and highlights some of Hitachi's recent work in this area. We can safely assume that similar approaches will be found in the ETC implementations of other countries around the world.

SYSTEM CONFIGURATION

ETC On-board Equipment

ETC on-board equipment is a radio frequency device mounted in the vehicle that communicates with an in-lane antenna installed at a toll gate. The on-board equipment is used to uniquely identify the vehicle, and therefore is securely installed in such a way that it can not be easily removed from the vehicle.

The on-board equipment is essentially a 'two-piece' system consisting of an IC card and a communications unit. To use the system, a user inserts an IC card containing the user's personal data for toll collection into the on-board equipment. The advantage of this 'two-piece' arrangement is that the data pertaining to the vehicle (type of vehicle) and the data pertaining to the user (charge-related data) can be distinguished and managed separately. This way, optimum charge management and operations systems can be implemented when the system is extended nationwide. For example, this would allow anyone having an IC card whether the driver or a passenger to accept responsibility for the toll and to utilize the ETC system regardless of whether ETC equipment was installed

in the vehicle or not.

As illustrated in Fig. 2, the on-board equipment will be marketed as a dedicated ETC unit retrofitted in older vehicles, or bundled in combination with a navigation system on some lines of new cars offered as a dealer option.

Roadside Systems

As illustrated in Fig. 3, the roadside system is installed on ETC lanes at toll gates and consists of an antenna, an ETC lane control unit, vehicle sensors, a roadside display panel, a barrier, and other elements. We now briefly describe the roadside system processing for ETC lanes assuming a typical implementation where a ticket is issued at the lane's entrance and the toll is paid at the lane's exit.

At the entrance toll gate of an ETC lane, lane entrance data is automatically transmitted from the roadside antenna to on-board equipment. Transmitted data is stored on the IC card inserted to on-board equipment. When the vehicle reaches the exit toll gate, the on-board equipment transmits the entrance data (stored on the IC card), ETC contract data, and data identifying the type of vehicle (stored in the on-board unit itself) to the roadside antenna, and the ETC lane control unit uses this data to calculate the toll. The toll is displayed on the roadside display panel, and also transmitted to the on-board system. The vehicle can then exit the lane as soon as the driver acknowledges the toll charges shown on the roadside display and on the in-car system.

When a vehicle is detected by the in-lane vehicle sensors, the roadside system determines whether the vehicle is ETC-equipped or not (including situations

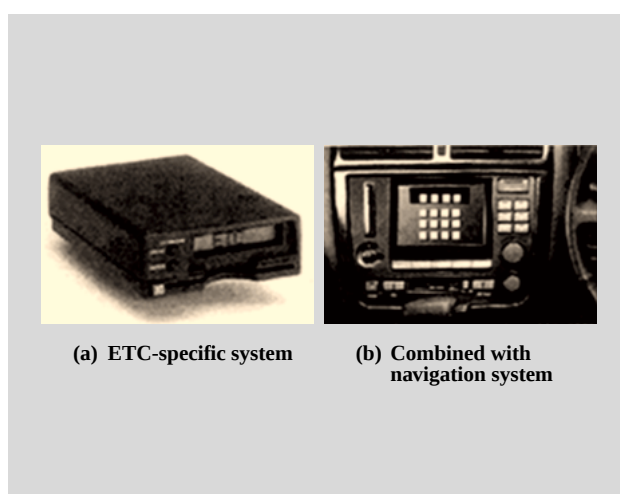


Fig. 2—ETC On-board Equipment.

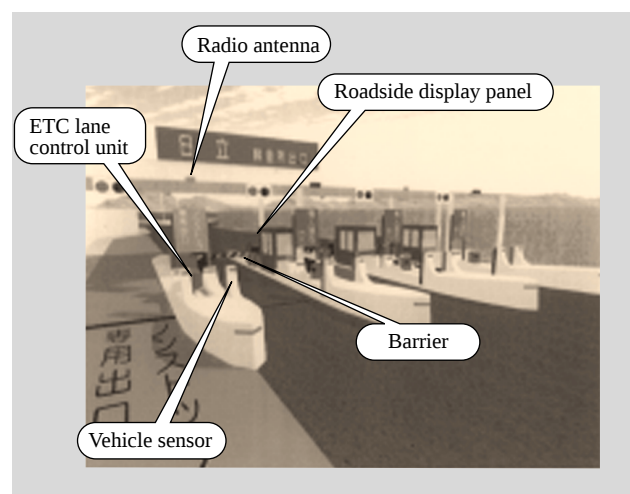


Fig. 3—Overview of ETC Roadside System.

where an IC card is not inserted in the equipment or the on-board equipment is defective) based on whether the antenna is able to communicate with the vehicle. If the vehicle is not ETC equipped, the lane barrier closes and the manual toll collection process takes place.

Communication Between the Roadside System and the Vehicle

At the tollgate, ETC employs dedicated short-range communications (DSRC) to ensure that the large quantity of data involved in toll collection is transmitted quickly and accurately between the roadside antenna and the vehicle.

At the start of the public-private research initiative mentioned to earlier, Hitachi proposed a DSRC standard based on a communications protocol called slotted aloha time-division multiple access (TDMA). Capable of communicating at 1 Mbit/s with multiple vehicles at the same time on the 5.8-GHz frequency band, this scheme was officially adopted by Ministry of Posts and Telecommunications ordinance in September 1997. Note that this scheme is also compliant with ITU recommendations (ITU-R M.1453, May 2000).

The DSRC is known as an active communications scheme. This means that both the roadside antenna and the vehicle equipment can initiate radio transmission, which is advantageous for exchanging large amounts of data with multiple vehicles while at the same time maintaining a high degree of reliability. As a duplex transmission scheme i.e., a method capable of sending and receiving at the same time, DSRC is also highly efficient and should see implementation in wide-ranging applications in the near-term future.

Indeed, efforts are already underway to address issues opening the way to practical deployment of new Intelligent Transportation System (ITS) based services; these include operations management systems for regulating fleets of delivery vehicles, buses, and taxis, and charge/toll settlement systems for parking lots, drive-through facilities, gas stations, car ferries, and so on. The concept of ETC, moreover, can certainly be extended beyond the island type toll collection gates of today to support a free-flowing in-lane toll collection scheme such as illustrated in Fig. 4 which allows vehicles to be charged while they proceed at highway speeds.

Hitachi, Ltd. made a major commitment to ETC research through the deployment of test systems and

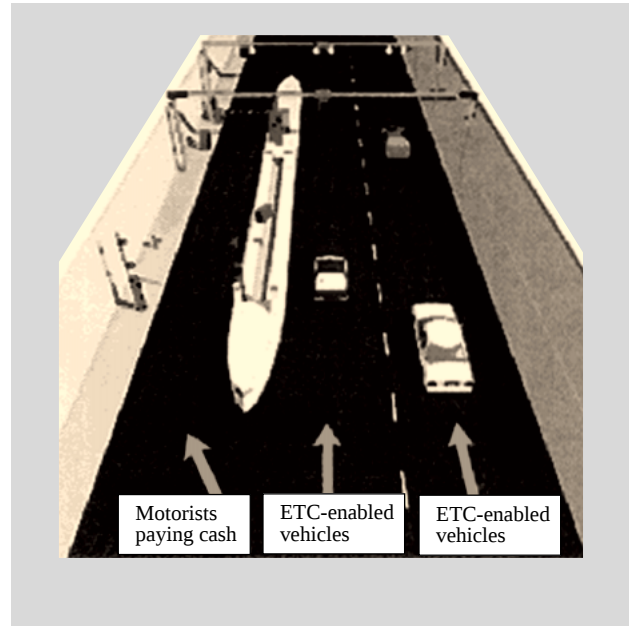


Fig. 4—Free Flow System.

other initiative, and has made significant R&D progress on on-board equipment, toll gate systems, and roadside system-to-vehicle communications systems.

SETTLEMENT PROCESSING

Transaction Settlement Processing System

The toll charge information calculated by the ETC lane control unit is collected by the transaction settlement processing system of each toll facility operator. When an IC card issued by a credit card company is used, detailed information regarding the toll charges is sent from the settlement processing system to the credit card company based on the contractual information stored on the card. At the credit card company, the detailed toll data is processed just like any other credit card transaction, and the toll charges are deducted from the ETC customer's account.

ETC-enabled vehicles are also checked against a negative list at the toll gate and prevented from using the ETC facilities if there is a problem with the IC card or the on-board equipment. This prevents inappropriate use of IC cards and on-board equipment, and also prevents the improper use of cards that have been lost or stolen.

IC Cards

IC cards are issued by toll facility operators and by credit card companies, so contractual information for

the card applicant is stored on the card. When a user inserts his or her IC card in the on-board ETC system in any vehicle then drives through an ETC toll gate, the toll charges are taken out of that person's account in accordance with the contractual information recorded on the card. The IC card can in fact be employed as a record keeping device to maintain a log of toll usage.

In order to provide an IC card like this that can be used for ETC, two factors should be given careful consideration: (1) making the card a multiuse device that can be used for various kinds of purchases, and (2) protecting the card with a high level of security. The first point is important because, if the card can be used for various purposes and can be used as a credit card, this would make ETC much more convenient and would hasten the widespread adoption of ETC. To develop such a card, it would require adding some ETC-specific processing capabilities while maintaining compliance with the credit card industry's Europay, MasterCard, Visa (EMV) standard. The second point is critically important not only to keep the transaction information of different application services separate and concealed from one another but also to prevent transactions from being forged and other fraudulent acts.

SYSTEM SECURITY

Distinctive Features of ETC

Because it involves the clearing of transactions electronically, ETC has the same special security requirements of other electronic charging systems, but in addition, it has a number of distinctive requirements that are unique to ETC. Hitachi, Ltd. conducted a risk analysis of ETC security using an original fault tree analysis (FTA), and analyzed some of the distinctive aspects of ETC system security.

(1) Wireless transmission of toll charge data

In ETC, the data needed to calculate the toll charges (distance traveled on toll facilities, type of vehicle, ID for assessing charges, etc.) is sent over a wireless connection, which is inherently more vulnerable than a wireline connection. In order to address this concern, sufficient countermeasures must be implemented to conceal the radio communications data.

(2) Unattended automatic transactions

Up to now charges on toll road facilities have largely been collected manually by human attendants stationed in toll booths, but unattended automatic in-lane toll collection will become increasingly common

after ETC is introduced. It is generally easier to defraud an unattended charge collection system than a human toll collector, so adequate monitoring, equipment validation (authentication) checks, and other safeguards are critically important.

(3) Driver ownership of on-board equipment

A basic assumption of Japan's ETC system is that users will own and bear the cost of the on-board ETC equipment and IC cards. Since purchasers of ETC equipment will not be subjected to much scrutiny so as to promote faster uptake and acceptance of ETC, the potential for altering or counterfeiting the in-vehicle units and IC cards must be taken into consideration. Here again, strict verification processing (authentication) is called for to ensure the validity of vehicle equipment and cards.

Security Measures

Based on a thorough consideration of the distinctive features outlined above, a range of security measures is being incorporated in Japan's ETC using encryption and other technologies. Another concern, considering that ETC systems are being deployed as public infrastructure, is how to have a large number of companies involved in the manufacturing of ETC roadside and on-board equipment while at the same time disclosing as little information about the system's security measures as possible.

ETC involves a complex system with many elements: the roadside system, on-board equipment, IC cards, the transaction settlement system, financial institutions, and more. Comprehensive system security is being investigated as a way to ensure ETC continues to support a high level of convenience and safety, and sophisticated security technologies providing overarching security protection across the entire system are indispensable. The security technologies that Hitachi, Ltd. has been cultivating over the years is now contributing to the safe and accurate collection of tolls without compromising the privacy of system users.

CONCLUSIONS

This paper has provided a broad overview of Japan's wireless communication-based ETC system for collecting toll charges, related developments, and Hitachi's initiatives in addressing these issues. By alleviating traffic tie-ups at toll gates and relieving drivers from having to fumble for change, ETC has significant advantages for motorists and toll facility operators alike.

Hitachi, Ltd. will continue to commit its R&D resources to the development and deployment of Intelligent Transportation Systems, focusing especially

on technological developments relating to lane-vehicle communications, transaction settlement systems, and security technologies.

ABOUT THE AUTHORS



Takeshi Horie

Joined Hitachi, Ltd. in 1986, and now works at the Public Systems Department of the Systems Engineering Division. He is currently engaged in the development of Intelligent Transport Systems, and can be reached by e-mail at horie@siji.hitachi.co.jp



Takahiro Saida

Joined Hitachi, Ltd. in 1997, and now works at the Public Systems Department of the Systems Engineering Division. He is currently engaged in the development of Intelligent Transport Systems, and can be reached by e-mail at saida@siji.hitachi.co.jp