Comprehensive Analysis of the Factors Affected to Traffic Volume and Time Series Change of Smart ICs

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Abstract: The policies for shifting traffic from ordinary roads to expressways have been implemented for reducing of congestion in Japan. It is effective to promote the use of expressway by shortening interval of ICs by setting Smart ICs. It is important to analyze the effectiveness of Smart ICs in order to establish the design criteria related to the size and position of Smart IC. In this paper, the analysis focuses on the following themes using traffic data of 33 Smart ICs for several years; (1) Timeline change of usage of Smart ICs (2) The impact of the development in the surrounding area and the improvements of the Smart ICs such as into 24 hours and into full-fledged access. (3) Extraction of influencing factors such as distance from city, population of affected area, (4) Synergistic effect with discount charge for promoting the use of the expressways.

Keywords: Smart IC, ETC, NITAS, Induced use, Converted use

1. INTRODUCTION

More than sixty per cent of all expressway development plans in Japan have been completed. Amid calls for urgently needed expressway construction in undeveloped areas, other calls are also increasing, demanding more emphasis on such policy issues as improving the environment, enhancing safety, promoting regional revitalization, and building more efficient logistical networks, by efficiently using, or enhancing, the functions of existing expressway networks (Road Bureau, Ministry of Land, Infrastructure and Transport, 2005).

One of the bottlenecks for increased expressway usage in Japan is the distance between interchanges (ICs). The average distance between Japanese ICs is roughly 10 km, almost double the roughly 5-km distance in major western countries.

Smart Interchanges (Smart ICs) have been installed in some locations to address these problems. Smart ICs are interchanges where vehicles can get on and off an expressway by way of a main express lanes, service area (SA), parking area (PA), or bus stop, associated with the given expressway. As Smart ICs are only available to vehicles equipped with the Electronic Toll Collection system (ETC), toll booths can be simplified because they require no personnel for toll collection, making Smart ICs less expensive to install than conventional ICs. Smart ICs were launched, as a pilot project, in fiscal year 2004, and the Implementation Guidelines for SA- or PA-based Smart ICs were formulated in 2005. As of January 2015, in Japan, Smart ICs had been officially installed at 63 locations.

Selecting highly effective and efficient locations for Smart IC installations is important for promoting their widespread use. To this purpose, it is necessary to study past and current Smart IC usage, as part of an evaluation, using a nationally consistent method, of the effectiveness of prior Smart IC installations.

For the above-described reasons, the purpose of this study is to find simple methods for estimating the effectiveness of installing Smart ICs. To this end, this study:

(1) Investigates the transition to Smart IC usage, and the division of traffic between Smart ICs and other traffic options, such as adjacent ICs.

(2) Identifies factors that could influence the traffic volume of Smart IC.

(3) Examines potential toll policies, such as toll-discounts and toll-free, and their impact on Smart IC usage.

2. PREVIOUS RESEARCH ON OPTIMAL IC LOCATIONS, AND THE SIGNIFICANCE OF PRESENT STUDY

An earlier study on optimal IC locations by Ohara, Ieda, and Hayashi (2001) suggested, based on simulations they conducted in Iwate Prefecture, that installing additional ICs very close to major cities is effective in increasing expressway usage because the rate of such usage increases in conjunction with trip length. Providing toll discounts on such additional ICs also tends to increase IC expressway usage. Ieda (2001) also found ways of identifying factors that could influence the optimal intervals between expressway ICs, by creating a formula for calculating such optimal intervals and the proper division of roles for expressways and ordinary roads, with an eye to improving mobility within extensive living areas. The identification of potential factors influencing optimal IC intervals was also supported by the creation of a formula for calculating the cost-benefit ratio of ICs in terms of the promotion of broad regional exchange. A study by Takahashi and Nishino, et al. (2002) suggested, using examples from Germany and Okinawa, the promotion of expressway use for short trips by shortening IC intervals.

A study by Miyagawa (2006) defined the areas accessible to the nearest ICs, and the areas from which people can reach destinations within a certain period of time, as "indices of effectiveness". After creating a formula for calculating these areas, Miyagawa evaluated changes in the indices as a result of reducing IC intervals. Evaluating IC intervals in terms of travel-time based areas demonstrated that Smart ICs are effective in areas with longer IC intervals, and ordinary roads where the driving speed tends to be slower. A study by Ohashi et al.(2005) estimated IC-traffic volumes based on the population and amount of industrial shipments within an IC's area of influence, after first calculating IC influence areas using a mathematical model based on minimal total costs. A study by Hamaya,Tsukada and Sakai (2006) extracted, from revealed preference (RP) data, factors that could affect the traffic volume of Smart IC.

Smart ICs have some limitations, including the following: (1) All Smart ICs are available only to ETC users; (2) the majority of Smart ICs are connected with an SA or PA, and with trunk roads still less ; and (3) the number of roads with access to Smart ICs is smaller than the number with access to conventional ICs. On the other hand, using the National Integrated Transport Analysis System (NITAS), which is described below, this study was able to identify areas where required travel time could be reduced by the installation of a Smart IC, based on road network status, and travel speed during congestion which drawn from link-road based road traffic census data. This study also estimates the traffic volume of Smart IC, using the ETC popularity rate by Prefecture, in addition to the populations of areas where the required travel time can be reduced. Furthermore, this study estimates the potential benefits of installing Smart ICs, based on estimated traffic volumes.

3. HISTORY OF INTRODUCE OF SMART ICs

3.1 Transition from their implementation up to the present

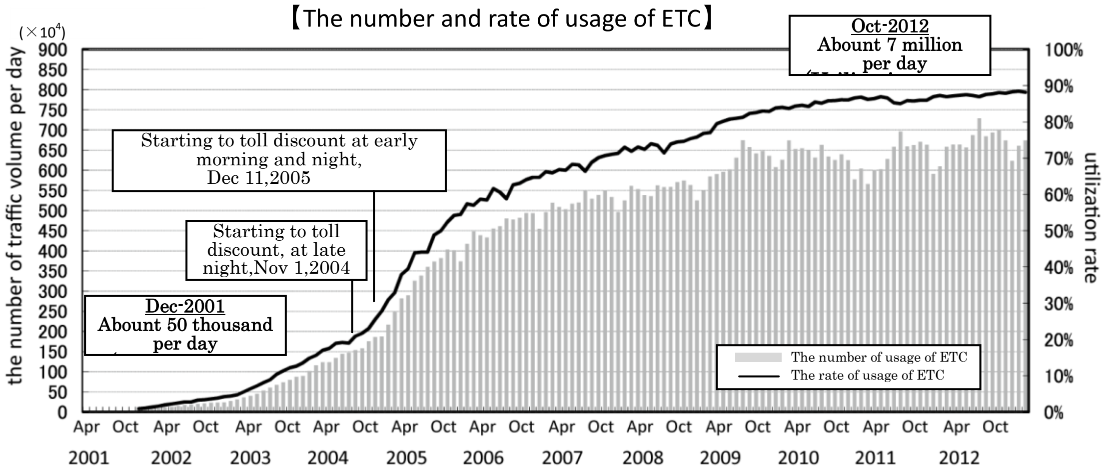


Figure 1. The number and rate of usage of ETC (Road Bureau, MLIT(2013))

Because of the limited car equipped ETC, it is conceivable that ETC popularity rate will affect the traffic volume Smart IC. The increase in the number available to ensure ETC from the start, as shown in Figure 1, growth in the past few years, but there is a trend of leveling off, the traffic volume using ETC has reached about 7 million per day in the country as of October 2014, utilization rate has reached 88% in days.

It is conceivable that as a reason for the increased utilization of ETC, it can pass through non-stop at the gate charge, you can take advantage of toll discount at late night, morning and evening, and that the Smart IC is available, the convenience is improved. On the other hand, the price of the ETC OBE is 10 000 yen or less, as shown in Figure 2, it can also act to promote the use of price 10 years has been greatly reduced to 1 / 4-1 / 3 from launch is clear that you are.

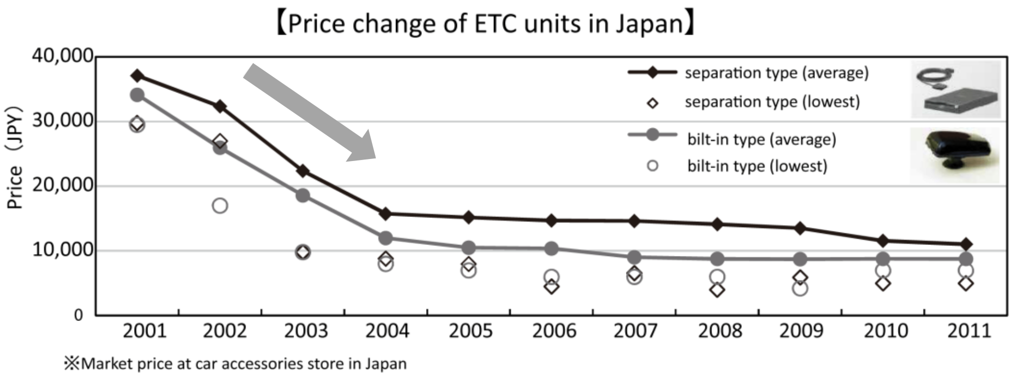


Figure 2. Price change of ETC units in Japan (Road Bureau, MLIT (2013))

3.2 Types of Smart ICs -direct connection with an SA or PA and direct connection with main express lanes-

Smart ICs can be classified into two types: those connecting directly to an SA or PA, and those connecting directly to main express lanes. Many of the Smart ICs currently installed have a direct connection with an SA or PA. This type of Smart IC provides IC features by installing a simple ETC system at an SA or PA that offers rest facilities to drivers, and by providing access to adjacent ordinary roads. This type of Smart IC is less costly to install and requires no new land acquisition. However, depending on the location of its associated SA or PA, and the characteristics of its access roads, this kind of Smart IC often has poor access to adjacent major cities, does not provide full –fledged access, and cannot accommodate large-size vehicles.

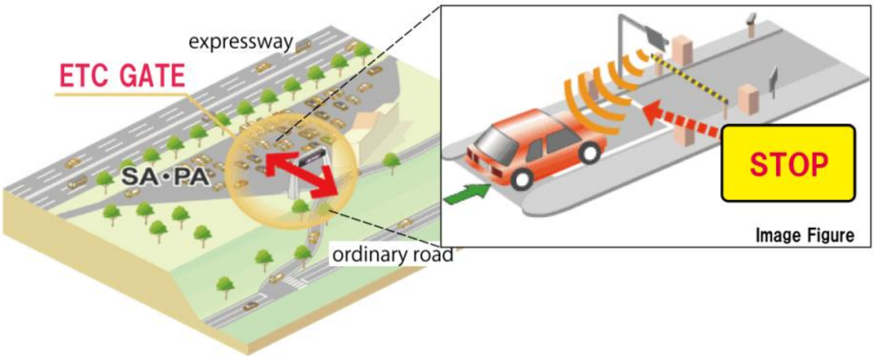


Figure 3. SA/PA connecting type Smart IC

A Smart IC with a direct connection to main express lanes offers features similar to a conventional IC because of the convenience afforded by its direct connection to trunk roads. However, the installation of such Smart ICs involves new land acquisition, traffic restrictions during the necessary construction work on main express lanes, traffic controls on connected trunk roads, and relatively high construction costs.

Nevertheless, the construction cost of a Smart IC is typically estimated at approximately 2 billion yen, while the construction cost of a conventional IC is estimated at 3.5 billion yen. On the other hand, maintenance cost of Smart IC is 0.7 billion yen /year, while that of conventional IC is 0.9 billion yen /year. (Road Bureau, MLIT 2012)

4. DATA USED IN THIS STUDY

4.1 Types and sources of data

This study uses data from 33 Smart IC locations which has been collected the traffic data during several years installed after 2004 as a pilot project. Smart ICs in this study are 32 SA/PA connecting type and one main lane connecting type. See Table 1 for data, including the traffic volume of Smart IC and its adjacent ICs, traffic volume of the main expressway and ordinary roads.

Table 1. Data sources for this analysis

Type of Data related to Smart IC	**Data sources**
Average of traffic volume per day in Smart IC (Monthly average)	Monthly report for Statics expressway from "Expressways and Automobiles" issued by Express Highways Research Foundation in Japan
Average of traffic volume per day in adjacent ICs (Monthly average)	
Traffic volume of expressway in each section	
Traffic data of ordinary roads around section	Road traffic cencus in 2005 and 2010
Population in identifying areas where required travel time can be reduced using NITAS	Calculated by section 4.2

4.2 Identifying areas where required travel time can be reduced using NITAS

4.2.1 About the "National Integrated Transport Analysis System (NITAS)"

In furtherance of its desire to create a comprehensive traffic system combining hardware and software, the Ministry of Land, Infrastructure and Transport (MLIT) developed the "National Integrated Transport Analysis System (NITAS)", which can quantitatively analyze and evaluate the effectiveness of prospective traffic systems, and the current status of actual systems. Within a given zone in Japan (e.g., a municipality, a 1-km mesh, a 10-km mesh), NITAS considers various factors, such as minimum time required, minimum cost, and minimum distance, with respect to all modes of transportation which are cars, trains, airplanes, ships, and combinations of these modes, to identify possible routes, times, and required costs. NITAS can also perform diversified analysis and evaluation using statistical data relevant to any given zone, including data from the national census, and industrial and commercial statistics. Furthermore, NITAS can analyze the effectiveness of traffic infrastructure development, in terms of such measures as reduction in required travel time, by incorporating yet-to-be developed, future traffic networks in its analysis.

To facilitate the identification of more practical routes that are shorter and/or require less travel time, NITAS in "Road" mode incorporates both the Japan Digital Road Map Database for the current road network, and the latest Road Traffic Census, which provides road traffic data for each link road, such as its length and travel speed during congestion.

4.2.2 Model for identifying areas where the required travel time can be reduced

In this study, we define the "areas where the required travel time can be reduced" as areas where the minimum travel time required to reach a destination can be reduced by installing new Smart IC. We were able to identify such areas using NITAS, with the traffic mode set to "Road", the road type set to "Only ordinary roads", the search condition set to "minimum generalized costs", and the road speed to set to "Travel speed during congestion".

The "areas where the required travel time can be reduced" were determined according to the following method. As a precondition, we only used an Origin-Destination (OD) where the shortest current route was by way of expressways before considering future installations of new Smart IC; any OD where the shortest route was by way of ordinary roads before considering future installations of new Smart IC was excluded. We also assumed that drivers select routes that require the least travel time, and that the typical expressway travel speed was significantly higher than that of ordinary roads. A given 1-km mesh was used as a major traffic connection zone. The minimum travel time required to reach a Smart IC from that zone, by way of ordinary roads, was defined as t_{si}; the minimum travel time required to reach IC-A (an IC on an inbound lane selected from among all ICs adjacent to the Smart IC) from that zone, by way of ordinary roads, was defined as t_{ai}; and the minimum travel time required to reach IC-B (an IC on an outbound lane from among all ICs adjacent to the Smart IC) from that zone, by way of ordinary roads, was defined as t_{bi}. The time required to reach IC-A from the Smart IC, by way of expressways, was defined as t_{sa}; and the time required to reach IC-B from the Smart IC, by way of expressways, was defined as t_{sb}.

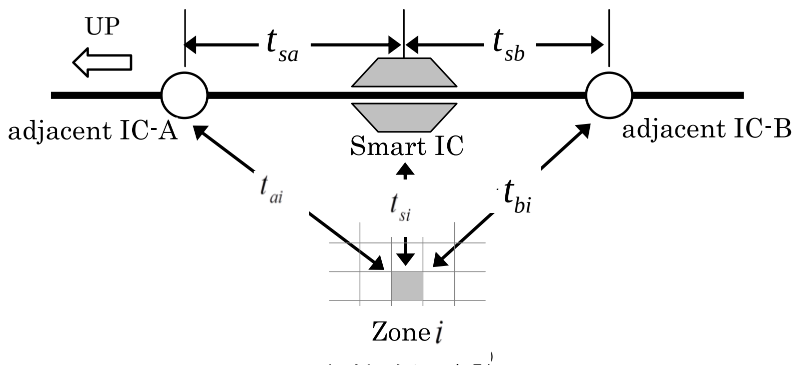


Figure 4. Identifying areas where required travel time can be reduced using NITAS

Routes whose minimum required travel time can be affected by the significantly higher travel speeds of expressways compared with ordinary roads are limited to ODs where the routes with the minimum required travel time before considering the installation of new Smart IC pass through nearest adjacent ICs (IC-A or IC-B). Where expressways are to be used, the difference, in terms of time required, between the routes that pass through Smart IC and the routes that use nearest adjacent ICs, will equal the difference in time required to reach nearest adjacent ICs on the current lanes, as both routes are identical for the sections that run outside the nearest adjacent ICs. Therefore, the conditions under which routes using Smart ICs can be the routes with the minimum travel time may be expressed by the following inequality:

(1) Inbound lane

$$t_{ai} > t_{si} + t_{sa} \ , t_{bi} + t_{sb} + t_{sa} > t_{si} + t_{sa} \tag{1a}$$

(2) Outbound lane

$$t_{bi} > t_{si} + t_{sb} \ , t_{ai} + t_{sa} + t_{sb} > t_{si} + t_{sb} \tag{1b}$$

Where,

t_{si} : Minimum travel time required to reach the Smart IC from Zone i (Ordinary roads)

t_{ai} : Minimum travel time required to reach IC-A from Zone i (Ordinary roads)

t_{bi} : Minimum travel time required to reach IC-B from Zone i (Ordinary roads)

t_{sa} : Time required to reach IC-A from the Smart IC (Expressways)

t_{sb} : Time required to reach IC-B from the Smart IC (Expressways)

Time calculations were made for each given zone (1-km mesh), and areas represented by meshes satisfying (1a) were considered to be inbound areas where the required travel time can be reduced; while areas represented by meshes satisfying (1b) were considered to be outbound areas where the required travel time can be reduced. By combining the inbound and outbound areas, areas where the required travel time can be reduced by the installation of a new Smart IC were obtained. Additionally, as drivers are unlikely to access ICs which take longer than a certain amount of time to reach, meshes were limited to those for which 30 minutes or less were required to reach ICs from Smart ICs.

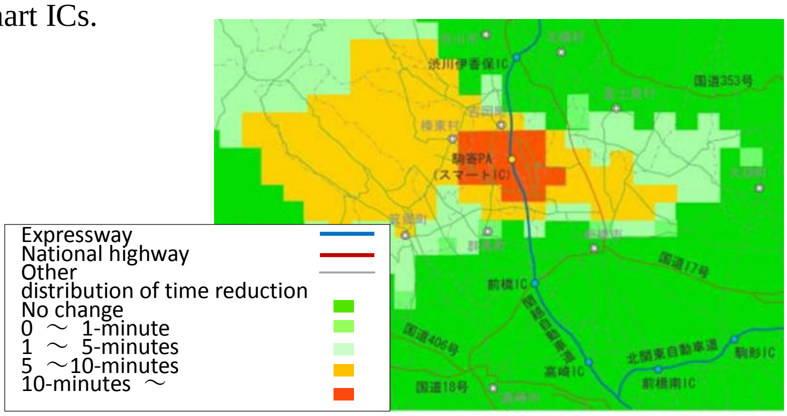


Figure 5. An example of distribution of time reduction by NITAS

5. T

5.1 Transition of traffic volumes

The traffic volume of Smart ICs tends to rise as their number of years in service increases. Timeline changes in traffic volumes clearly show the influence of the relevant expressway networks developed after the start of Smart IC services, as well as the influence of toll-free pilot projects so on. In Sagae and Arai, each Smart IC’s share of the combined traffic volume of the Smart IC and its adjacent ICs increased from 25% to 30%. In other regions, each Smart IC’s share of the combined traffic volume of the Smart IC and its adjacent ICs is typically between 5% to 15%.

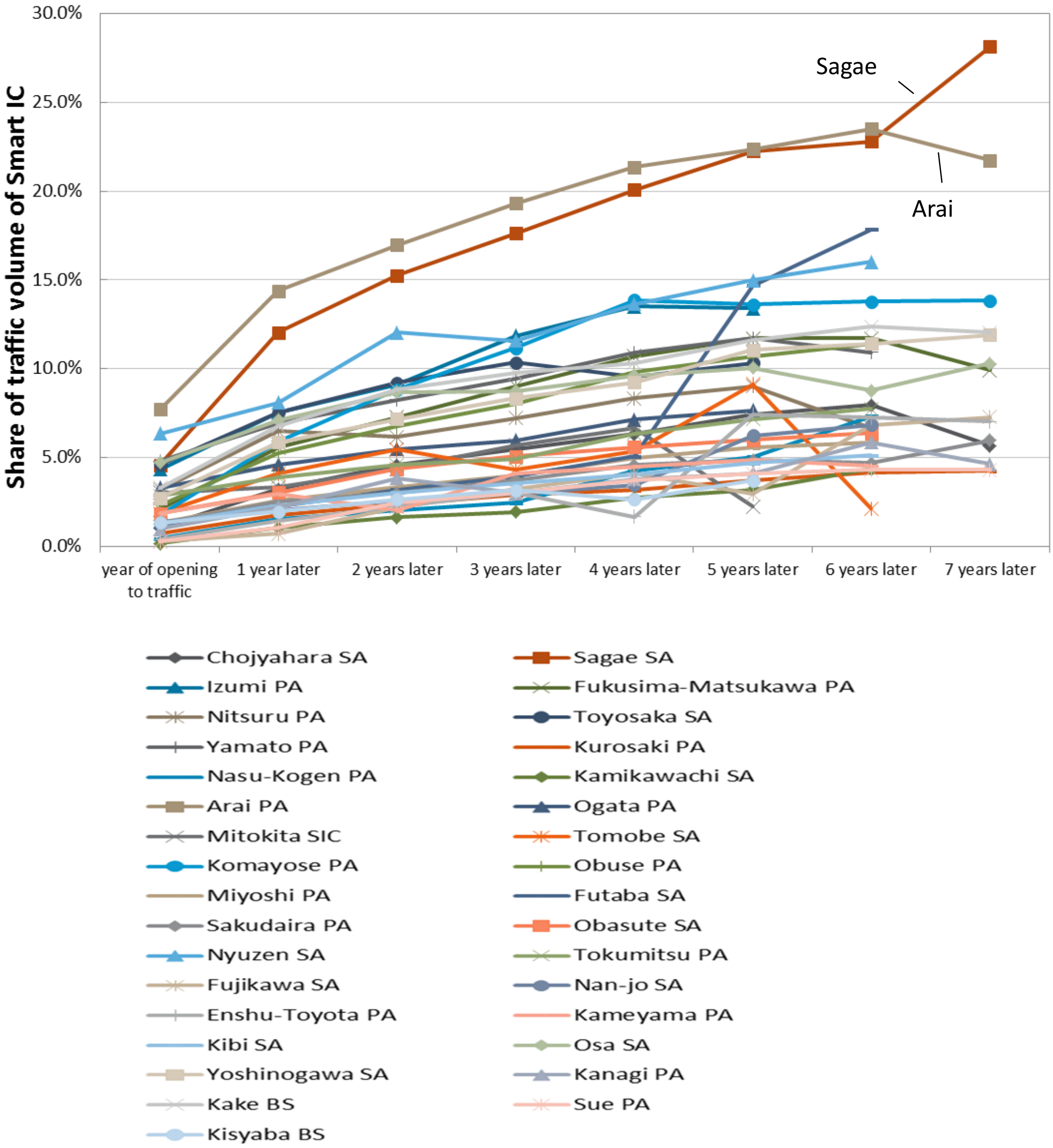


Figure 6. Timeline change of share of traffic volume of each Smart IC

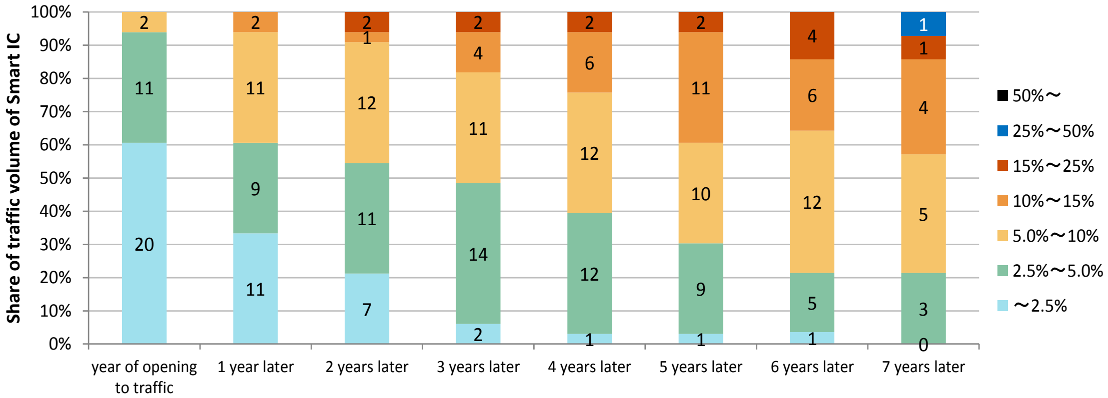


Figure 7. Timeline change of share of traffic volume of Smart ICs
(Classification by share value)

We describe the impact of the toll-free pilot projects in detail below. In terms of regional trends, Smart ICs show the same seasonal cycles as existing adjacent ICs in the same regional areas. We found that traffic volume at each Smart IC in Nasu Highland (Tochigi Prefecture), Arai (Niigata Prefecture) and Sakudaira (Nagano Prefecture) increases significantly during the early-May holiday season, the summer and autumn tourism seasons, and the winter skiing season.

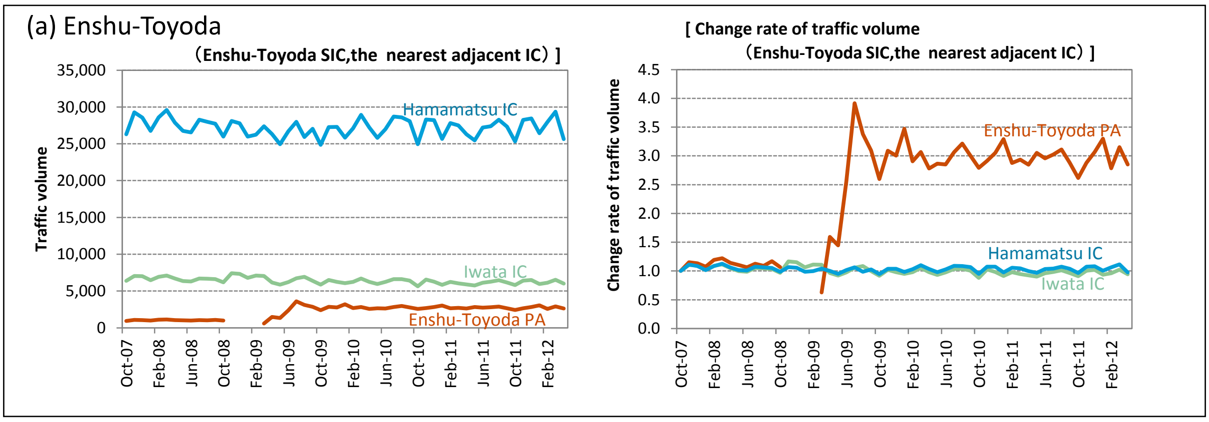
A nationwide increase in the traffic volume of Smart IC can be attributed to the above-mentioned enhancements of Smart IC features, increased convenience as a result of access road development, increased ETC popularity, toll charging policy, and increased recognition of Smart ICs.

5.2 Change in Smart ICs' share of traffic volume due to improvement

Table 2 shows the volume change in some smart ICs which were implemented the improvements such as full-fledged access, support for large-size vehicles, and extended service hours. Across the country, the traffic volume of Smart IC has been increasing at many Smart IC locations as a result of nearby development, and/or enhancement of the Smart IC's features, including conversion to a full-fledged access IC, support for large-size vehicles, and extended service hours. For example, the traffic volume at the Enshu-Toyoda Smart IC in Shizuoka Prefecture is increasing rapidly because it was converted to a full-fledged IC in April 2009, and is directly connected to a nearby large-scale shopping facility. So, the rate of increase was indicated around 300%. The Futaba Smart IC in Yamanashi Prefecture also increased the traffic volume of Smart IC because it was converted to a full-fledged IC in November 2009, as well as having been renovated to accommodate large-size vehicles. The increasing rate of traffic volume of Smart IC in Futaba IC was significant large as about 400% even though there is no change in the adjacent ICs. These evidences of increase of Smart ICs due to improvement indicate that it is very important to facilitate sift of traffic from ordinary roads to expressways through Smart ICs by above mentioned improvement.

Table 2. Examples of Change of traffic volume influenced by improvement

Smart IC	Prefecture	Expressway	Type of Improvement	Change of Traffic Volume in Smart IC
Kami-kawauchi	Tochigi	Tohoku	Full acccess、 Improvement of Acess roads	1000→1200
Futaba	Yamanashi	Chuo	Full Access Large-size Vehicle	1000→4000
Fujikawa	Shizuoka	Tomei	Full Access Connection with “Michi-Station”	3000→4000
Nan-jo	Fukui	Hokuriku	Addition of access ETC Large-size Vehicle	300→500
Enshu-Toyota	Shizuoka	Tomei	Full Access Lage-size Vehicle Connect with shopping center	1000→3000



(b) Futaba

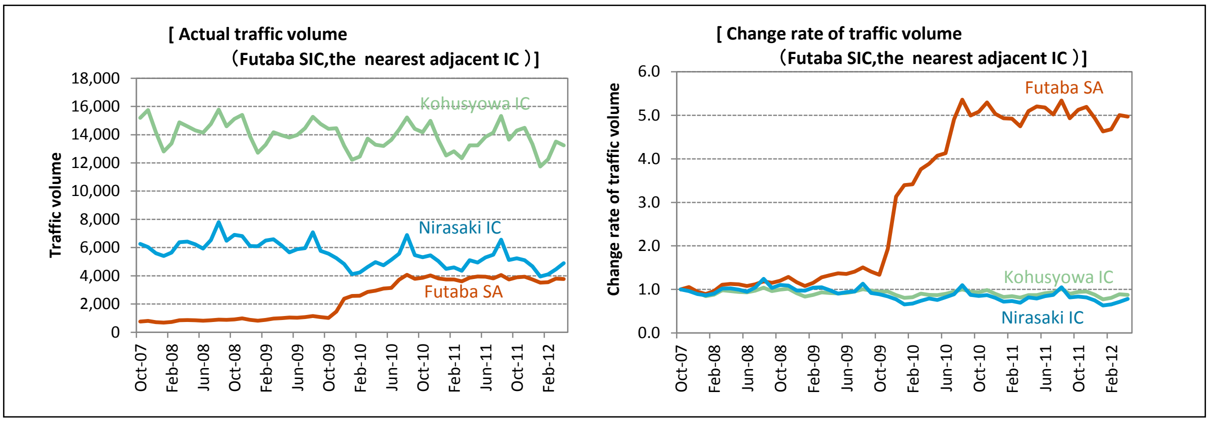


Figure 8. Change of traffic volume in Enshu-Toyoda IC and Futaba IC by Improvement (Left : Actual traffic volume, Right: Change rate of traffic volume)

6. EVALUATION OF “INDUCES USE” AND “CONVERTED USE” TRAFFIC VOLUMES

6.1 Definition of “induced use” and “converted use”

There are two principal Smart IC usage patterns as shown in Figure 9. The first pattern is known as “induced use”, and refers to a traffic pattern in which drivers who have not used expressways thus far, begin to use them. The second pattern is known as “converted use”, and refers to a traffic pattern in which drivers who have long been using expressways, change the ICs they use.

The “induced use” pattern can result in such benefits as reduced congestions on ordinary roads, an improved environment along ordinary roads near expressways due to increased expressway usage and a corresponding decrease in ordinary road usage, improved traffic safety resulting from the revival of community roads, and regional revitalization resulting from increased mobility. The “induced use” pattern also helps increase the revenues of companies operating expressways. The “converted use” pattern is similarly beneficial, promoting smooth traffic flow as drivers’ use of new additional ICs helps traffic, which used to be overly concentrated at specific ICs, become more appropriately dispersed. This pattern is especially effective when ICs adjacent to or in the vicinity of Smart ICs are congested.

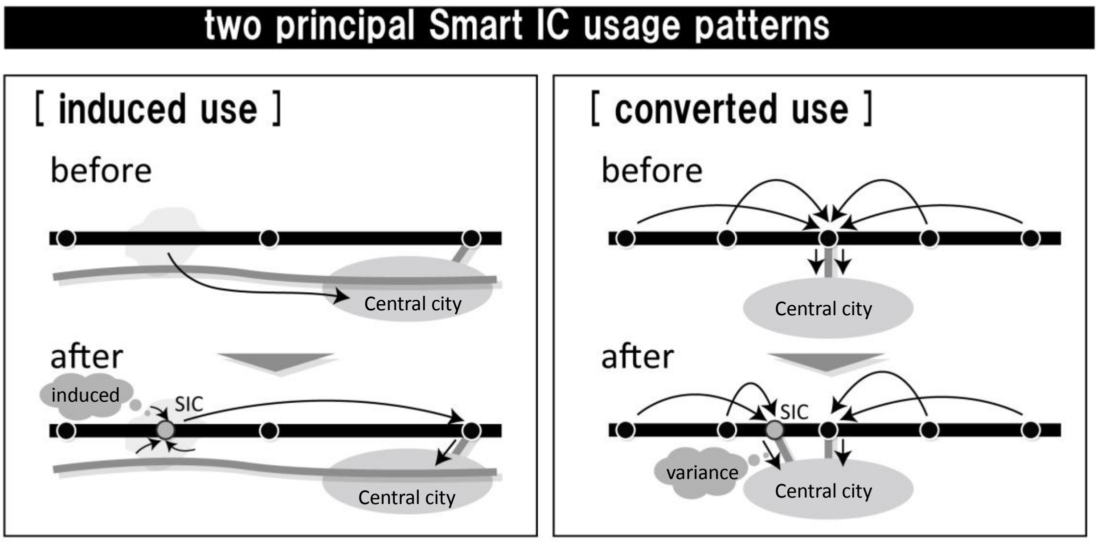


Figure 9. Image of Induced use and Converted use of Smart IC

6.2 Methods for calculating the number of “induced use” and “converted use” pattern vehicles

Formulas (2) and (3) can be used to calculate the number of “induced use” Q_{induce} and “converted use” $Q_{convert}$ pattern vehicles, respectively.

The number of “induced use” pattern vehicles

$$Q_{induce} = Q'_S - Q_S \times \frac{Q'_A}{Q_A} \tag{2}$$

Where,

Q_{induce}: The number of “induced use” pattern vehicles

Q_S: :The number of vehicles using adjacent before Smart IC installations

Q'_S: :The total number of vehicles using installed Smart ICs and adjacent ICs

Q_A: :The number of vehicles on all routes*, before Smart IC installations

Q'_A: :The number of vehicles on all routes* with Smart ICs, after Smart IC installations

*Except for sections between Smart ICs and their respective adjacent ICs

*The number of vehicles using Smart ICs is used as the maximum cap value, on the assumption that vehicles induced by Smart IC installations are sure to use the Smart ICs.

$$Q_{convert} = Q_{SIC} - Q_{induce} \tag{3}$$

Where;

Q_{induce} :The number of “induced use” pattern vehicles

$Q_{convert}$:The number of “converted use” pattern vehicles

Q_{SIC} :The number of vehicles using Smart ICs

6.3 The results of calculation of Induced use and Converted use

Figure 9 shows a result of induced use and converted use in each Smart IC by above equation (2) and (3). From the figure 9, Smart ICs of induced use trend to be when the newly developed a large shopping centers and industrial parks, such as Enshu-Toyota IC and Komayose IC so on. On the other hands, Smart ICs of converted use trend to be when it is close to the metropolitan area where the road network is developed such as Miyoshi IC and Kameyama IC so on. In the case of Smart ICs of full-fledged access or service for large-size vehicle, it trend to be the type of convert use.

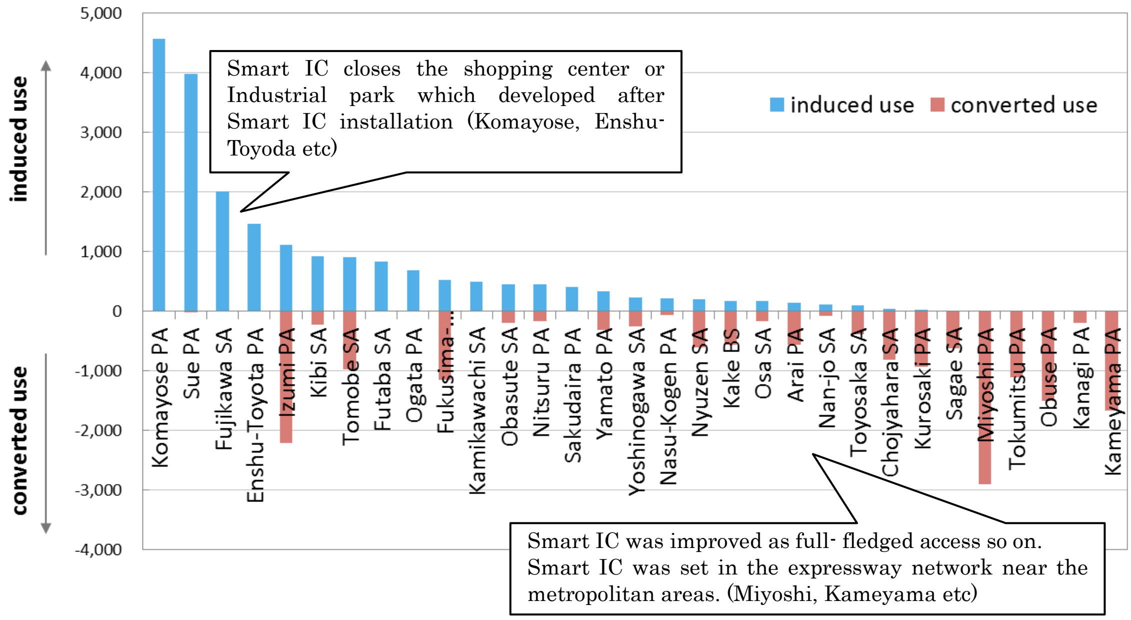


Figure 10. The volume of Induced use and Converted use in each Smart IC

7. ANALYSIS OF FACTORS INFLUENCING THE TRAFFIC VOLUME OF SMART ICs

7.1 Evaluation standard for the traffic volume

To make comprehensive understanding of the determinants of the traffic volume at Smaı IC, we carried out regression analysis by taking the directly-measured traffic data from the monthly report for statistics of expressway on Monthly Expressways and Auto ıobiles.

There are some factors related to the traffic volume of Smart IC such as the traffic volume of adjacent ICs, the distance from Smart IC to the center of nearest city, the distance of access from the ordinary road to Smart IC, population of time reduction by NATAS, the popularity rate of ETC in each Prefecture, time in service, vehicle type in service etc. In this paper, based on the results of the checking the correlation between traffic volume of Smart ICs and some related parameters as shown Figure 11, we selected initially the five parameters for regression analysis which were the traffic volume of adjacent ICs, the population of time reduction by NITAS, the distance from nearest ordinary road to expressways, the average speed of nearest ordinary road and time in service with an initial,. The time in service is dummy variable.

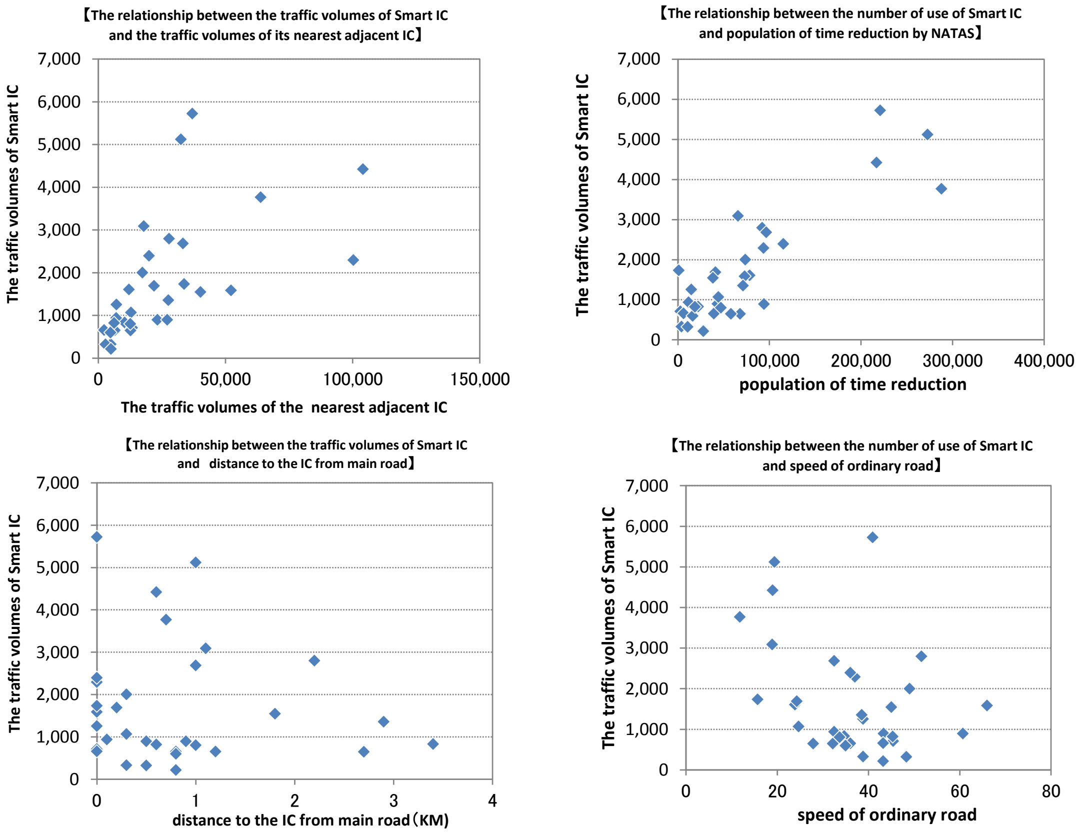


Figure 11. The relationships between the traffic volumes of Smart IC and related factors

7.2 Results of multiple regression analysis

The result is summarized in Table 3. The goodness of fit is almost satisfying because the coefficient of multiple correlations is 0.892 and the adjusted R-squared takes high value as 0.796. Therefore we use this estimation results for the following discussion on each independent variable. And the correlation function is as shown in Formula 4.

Table 3. Results of multiple regression analysis

independent variables	Parameter	standard error	t score	P score
an intercept	344.644	613.404	0.562	0.579
X1(the traffic volume of adjacent ICs)	0.004	0.006	0.614	0.544
X2(the distance of access from the ordinary road to Smart IC)	-87.905	138.133	-0.636	0.530
X3(population of time reduction by NATAS)	0.014	0.002	6.487	5.933E-07
X4(speed of ordinary road)	-6.945	10.482	-0.663	0.513
X5(time in service)	387.168	278.001	1.393	0.175
multiple coefficient	0.892			
multiple coefficient of determination R^2	0.796			
adjusted multiple coefficient of determination R^2	0.758			

$$y=0.004x_1-87.905x_2+0.014x_3-6.945x_4+387.168x_5+344.644 \quad (4)$$

Where,

y : the traffic volume of Smart IC
x_1 : the traffic volume of adjacent ICs
x_2 : the distance of access from the ordinary road to Smart IC
x_3 : population of time reduction by NATAS
x_4 : speed of ordinary road
x_5 : time in service

The traffic volumes of adjacent ICs, population of time reduction and time in service have positive impact on traffic volume of Smart IC. Evaluating from t-value and p-value, particularly, the result shows population of time reduction by NITAS is significantly positive. On the other hands, the distance of access from the ordinary road to Smart IC and speed of ordinary road have negative impact on traffic volume of Smart IC.

8. SYNERGY BETWEEN TOLL CHARGING POLICY AND SMART ICS

A toll-free pilot project was conducted at some sections in nationwide for a period of one year, from June 2010 to June 2011. Four Smart ICs were related to this pilot project. Four Smart ICs are Sagae, Toyosaka, Kanagi and Kishaba. Table 4 shows the traffic volume in a timeline manner before, implementing and after the pilot project for each Smart IC, its nearest adjacent ICs, and the main express lanes of the expressway to which the given Smart IC is connected. Figures 12(a), (b), (c), (d) show the relative values of changes in the traffic volume (the percentage difference between Max and Min values).The relative value of traffic volume of four Smart ICs increased sharply after the toll-free pilot project started, and then declined after the pilot project ended. Looking at the relative values from before and after the toll-free pilot project, we can see that the value for the Kanagi Smart IC returned to its pre-pilot project levels following the pilot project; however, significant post-pilot project increases in relative values were observed for the Sagae, Toyosaka, and Kishaba Smart ICs. We found the increasing point on March 11, 2011 At Sagae Smart IC, located in the Tohoku region were heavily influenced by the Great East Japan Earthquake.

Table 4. Traffic volume of SIC, its nearest adjacent ICs and the main lanes in toll-free project

	Smart IC			The nearest adjacent ICs			Main lanes		
	Before	Imple	After	Before	Imple	After	Before	Imple	After
Sagae	800	2547	1,156	1,549	4,900	2,172	55,971	108,003	68,145
Toyosaka	633	1,844	892	2,875	8,542	3,811	30,755	88,595	45,521
Kanagi	236	927	292	2,742	7,721	2,952	8,606	20,088	9,472
Kishaba	1,139	1,673	1,532	17,531	30,079	19,367	163,650	266,861	180,839

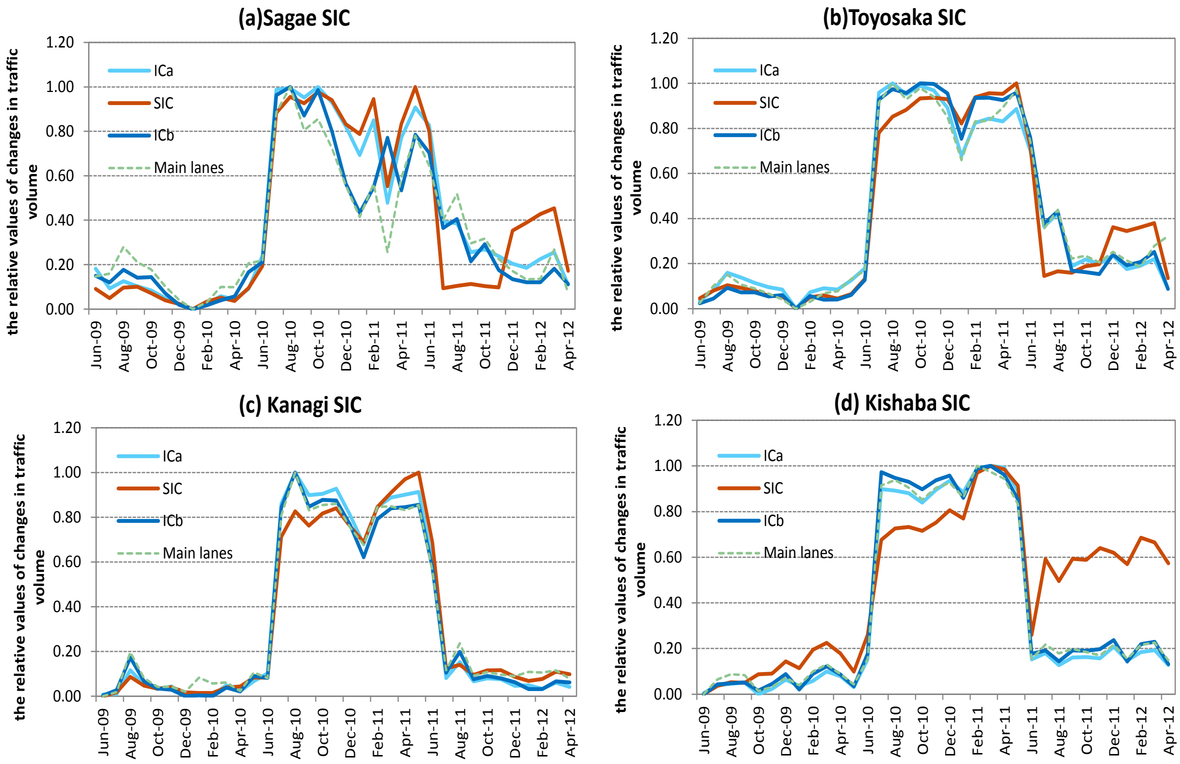


Figure 12. The relative values of changes in traffic volume (the percentage difference between Max and Min values) for each Smart IC, its nearest adjacent ICs

At the Kishaba Smart IC, in particular, the change in relative value was larger than the change in traffic volume of the adjacent ICs. We assume this is because of (a) increased recognition, as a result of the toll-free pilot project, of expressway benefits, including reduced travel time; (b) increased recognition of Smart IC convenience; and (c) the lingering influence of the pilot project, even after it had ended. Figure 13 shows the relationship between change of traffic volume in main lanes and change of traffic volume of Smart ICs and adjacent ICs comparing with before and implementing the pilot project. In this figure, we found that there are the differences comparing with four Smart ICs. At Kishaba and Toyosaka, both change rate of Smart ICs and adjacent ICs are almost equal to that of main lanes. At Sagae, both change rate of Smart IC and adjacent Smart ICs are larger than that of main lanes. However, at Kanagi Smart IC, the change rate of traffic volume of Smart IC is significant larger than those of adjacent ICs and traffic volumes of main lanes.

From the above results, we found following aspects;

(1) The traffic volume of Smart IC has the effect of increasing that to change in conjunction with the expressway toll,

(2) It is effective to increase the elasticity of traffic volume with respect to the change of toll with Smart IC.
(3) It is possible to increase the proportion of expressway use because drivers understood the convenience of discount and highways by using Smart IC.

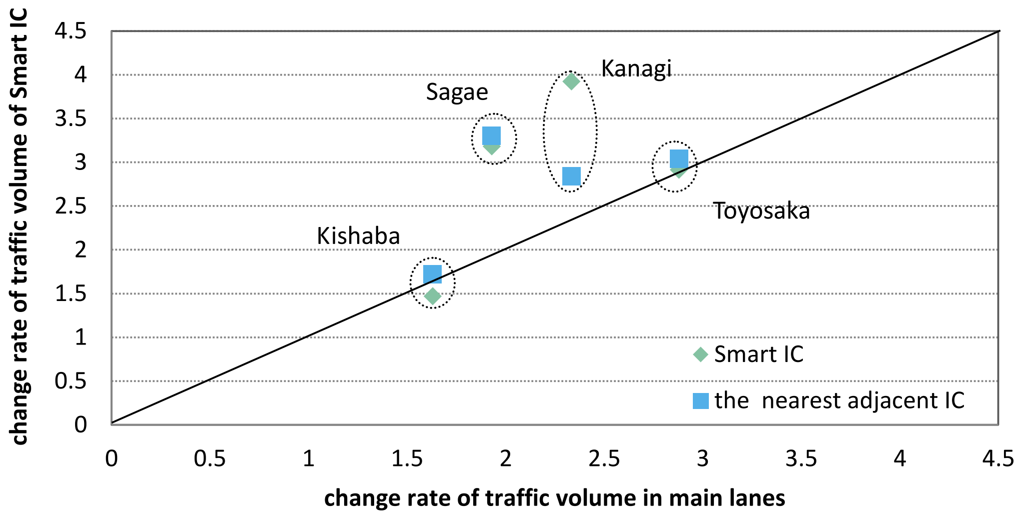


Figure 13. The relationship between change rate of traffic volume in main lanes and change rate of traffic volume of Smart IC

9. CONCLUSIONS

This paper reported the comprehensive analysis of the factors affected to the traffic volume and the time series change of Smart ICs. We have some results from the comprehensive analysis as follows

(1) The traffic volume of Smart ICs is increasing year by year after opening.
(2) The traffic volume of Smart ICs is rapid increasing due to the development in the surrounding area such as industrial park and shopping center and the improvements of the Smart ICs such as into 24 hours, into full-fledged access and service for large-size vehicle.
(3)By the separation of usage of Smart IC such as “induced use” and “convert use”, we found “induced use” occurred in the development area such as industrial park or some area development so on, “converted use” occurred near the metropolitan areas where developed expressway networks densely.
(4) From the results of extraction and multiple regression analysis of influencing factors for the traffic volume of Smart IC, we found that population of affected area by

NAITAS are positive strongly.
(5) We found synergistic effect with discount charge and Smart ICs for promoting the use of the expressways through free-charge pilot projects.

Though we used 33 Smart ICs data in this analysis, there are already 63 Smart ICs which have been installed in Japan as of 2013. We would like to try regression analysis for the differences between type of ICs such as SA/PA type and direct connecting type using recent data of all Smart IC.

And we would like to check and apply the proposed design criteria for the actual Smart ICs as many as possible.

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