SAFE TOLLBOOTH OPERATIONAL GUIDELINE FOR ELECTRONIC TOLL COLLECTION SYSTEM USING VEHICLE SPEED TRAJECTORY ANALYSIS

Yoon-Hyuk Choi
Senior Researcher, Korea Expressway Corporation Research Institute, Korea
yhchoi76@ex.co.kr

Han-Geom Ko
Ph.D. candidate, Ajou University, Korea
hankommi@ajou.ac.kr

Keechoo Choi
Professor, Ajou University, Korea
keechoo@ajou.ac.kr

ABSTRACT

Electronic Toll Collection Systems (ETCS) have begun to be globally introduced in the early 1990s in order to relieve traffic jams at expressway tollgates and are currently operated in approximately 30 countries. However, studies related to safe operation of ETCSs are insufficient. Since ETCS vehicles pass tollgates without any stop while general vehicles stop to pay tolls, speed differences between high speed vehicles and low speed vehicles occur at tollgates. Therefore, when ETCSs are introduced, guidelines for tollgate lane operation are necessary. In this study, we identified the necessity of ETCS operation guidelines through analyses of cases of ETCS operation in various countries and identified the risk of the occurrence of accidents based on speed differences between ETCS vehicles and general vehicles by point through examinations of actual travel speeds of actual vehicles. We also identified that allowing vehicles that entered wrong lanes to change lanes in order to reduce the risk of accidents and preventing accidents resulting from speed differences between ETCS vehicles and general vehicles are important matters to be considered. In particular, we investigated the relationship between speed differences and accident rates to establish traffic operational guideline by point in relation to speed differences.

1. INTRODUCTION

Urban concentration of population, quantitative/qualitative economic growth and increases in domestic-foreign export/import traffic resulted in rapid increases in automobile ownership and as a result, expressways that are main movement paths in urban and rural regions are continuously congested. A problem is that this phenomenon of attaching importance to mobility will continue due to these increases in urbanization and time values and thus congestion in expressway is expected to increase.

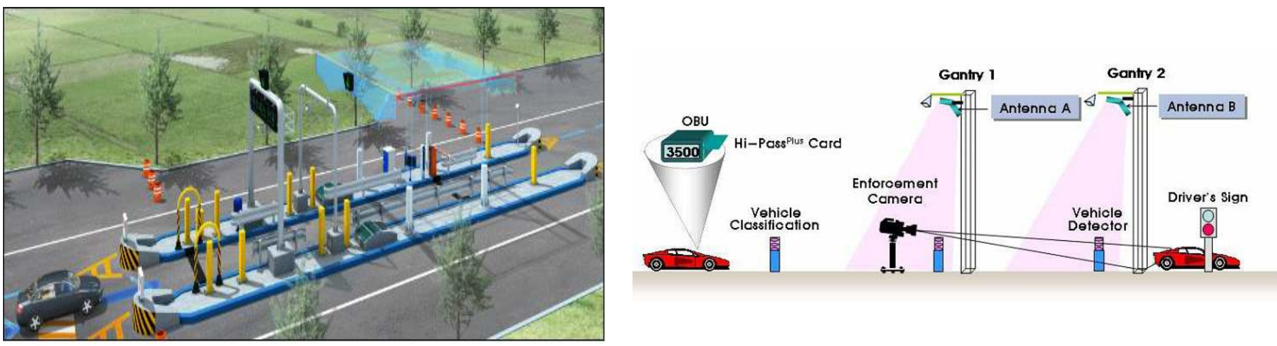
To relieve expressway congestion, measures to increase capacity such as expansion of existing roads and establishment of new roads have been mainly used in the past. Recently, however, ITSs based on information communication technology are rising as a new alternative. Of them, Electronic Toll Collection Systems (ETCS) began from demands for relieving traffic congestion and diversification of the means of payment of tolls at expressway tollgates and now, the electronic toll collection systems have been combined with mobile terminals such as navigations and the iPhone to be changed into essential

systems for convenient expressway services such as the collection and provision of customized traffic information suitable for individuals' characteristics.
Globally, studies related to ETCSs have been conducted since the early 1990s and the systems are now being operated in approximately 30 countries. Although many studies have been conducted in diverse areas such as system configurations, communication methods, communication region setting and violating vehicle checks thus far, studies related to safe operation of ETCSs are insufficient. Although there are no big problems when ETCS tollgates and general tollgates have been separated, if ETCS lanes and general lanes are mixed up at tollgates and only tollbooths are operated separately, guidelines for lane operation will be necessary. Since ETCS vehicles pass tollgates without any stop while general vehicles stop to pay tolls, speed differences between high speed vehicles and low speed vehicles occur at tollgates and the speed differences increase the risk of accidents.
In this study, we plan to identify the necessity of ETCS operation guidelines through analyses of cases of ETCS operation in various countries, identify the risk of the occurrence of accidents based on speed differences between ETCS vehicles and general vehicles by point through examinations of actual travel speeds of actual vehicles and present alternatives to solve the problem.

2. REVIEW OF PREVIOUS STUDIES

2.1. Definition and effect of ETCSs

Hi-pass is a state-of-the-art electronic toll collection system for the payment of tolls in running cars using wireless communication without any stop which has been introduced to prevent the occurrence of traffic jams in expressways resulting from toll collections at tollgates and it is a proprietary brand of the Korea Expressway Corporation for ETCSs which are a major service of Intelligent Transport Systems. In Korea, after the establishment of a pilot ETCS project at open tollgates in the capital area including those in the Seoul Outer Ring Expressway in June 2000, Hi-pass systems are in operation at all tollgates in expressways throughout the country as of December 2010. With efforts to activate Hi-pass systems, 5.2 million Hi-pass terminals have been supplied to date and the current rate of utilization is 52.1% which means that a half of expressway users are using Hi-pass systems.
ETCS facilities are divided into antennas, car type classifying units, controllers, driver displayers and violating vehicle imaging systems as shown in <Figure 1>.



<Figure 1> Facilities of ETCS in Korea

Effects expected from the introduction of ETCSs include the realization of three 'NOs' at tollgates that are no-cash, no-stop and no-person aimed to relieve traffic jams at tollgates and reduce environmental pollution (CO_2) in order to form comfortable running

environments, reduce labor costs and administration expenses and reduce costs to establish more lanes at tollgates.
Since the introduction of ETCSs in 2000, the Korea Expressway Corporation has identified the following effects through field surveys at tollgates.

ㅁ Effects of ETCSs
- Tollgates' processing capacities have increased by approximately four times: (based on open tollgates)
  · Cash (450 vehicles/h), electronic cards (600 vehicles/h), Hi-pass (1,800 vehicles/h)
- Environmental pollution has decreased by 20%
  · One ETCS has the same effect as planting a tree

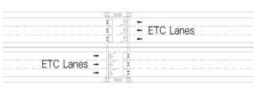
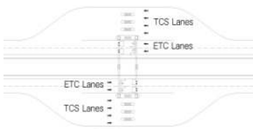
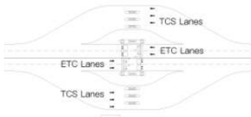
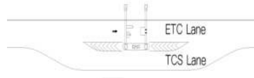
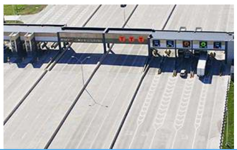
2.2. Examinations of cases of ETCS operation

2.2.1 Tollgate operating methods

Tollgate operating methods are largely divided into four forms. They are a complete ETCS method where ETCS lanes and general lanes are not separated, a proximal ETCS lane and general lane separation method, a detour separation method and a mixed use method.
First, the complete ETCS method has no toll island and does not distinguish between ETCS vehicles and general vehicles but applies a settlement method by perceiving license plates. This method is advantageous in that it requires the smallest tollgate sites as there are no tollbooths or islands. However, it is disadvantageous in that costs to configure the system are high and toll assessment is difficult and thus this system is applied only to some roads for special purposes. Currently, this system is being operated in Canada (407ETR), Australia (e-TAG), Israel (Highway 6), Singapore (ERP) and the USA (FasTrak, E-Z Pass, Pike Pass).
The proximal separation method is a method to separate ETCS vehicles and general vehicles in the proximity of tollgates and this method is advantageous in that it increases safety by inducing traffic stream separation. However, since this method requires lager sites compared to general tollgates in order to physically separate lanes, this method cannot be immediately applied to existing tollgates. Currently, this method is primarily used in major countries including the USA.
The detour separation method is a method to make general vehicles make a detour before tollgates for ETCS vehicles to separate general vehicles from ETCS vehicles and this method is advantageous in that the risk of accidents resulting from speed differences is low because traffic streams are completely separated. However, this method is disadvantageous in that tollgate sites required are the largest because general tollgates and ETCS tollgates are separately operated. This method is primarily used in Japan (ETC), Italy (TELEPASS) and the USA.
Finally, the mixed use method is a method to separate ETCS vehicles and general vehicles only at tollbooths without separating them by lane and this method is advantageous in that it can be immediately applied to existing tollgates in case ETCSs are operated and that it requires small tollgate sites. However, this method is disadvantageous in that there are risks of accidents resulting from speed differences between ETCS vehicles and general vehicles since tollgate sites are commonly used. This method is applied in most countries including Korea (Hi-pass), Japan, France and the USA.
In conclusion, it has been identified that tollgate operating methods to separate ETCS vehicles and TCS vehicles after the vehicles enter tollgate square areas are applied in most case although separating methods (proximal or detour separations) are different by country depending on conditions. The complete ETCS lane method (Multi Lane method) is applied to some loads for special purposes. Therefore, in case ETCSs are to be newly operated in existing tollgates, studies of operational guidelines are necessary in order to

smoothly process general vehicles and ETCS vehicles smoothly without additionally expanding tollgate sites. This method will be advantageous in that economic effects will be increased through fast introduction of ETCSs and it will be very effective for stepwise tollgate operating plans based on increases in ETCS vehicles.

<Table 1> Cases of ETCS operation

Division	Complete ETCS method	Proximal ETCS lane and general lane separation method	Detour ETCS lane and general lane separation method	ETCS lane and general lane mixed use method
Summary	A form where there is no toll island	Separate ETC and TCS traffics in the proximity	Separate ETC and TCS traffics by detour	Mixed application of ETC and TCS traffics
Schematic diagram				
Case of operation				
Applying countries	Canada (407ETR), Australia (e-TAG), Israel (Highway 6), Singapore (ERP) and the USA (FasTrak, E-Z Pass, Pike Pass) etc	The USA etc	Japan (ETC), Italy (TELEPASS) and the USA etc	Most countries including Korea (Hi-pass), Japan, France and the USA
Characteristics	• Tollgates are not necessary • Applied to some roads for special purposes • License plate perception and settlement methods are used in most cases	• Moderate tollgate site areas • Safety is increased as traffic stream separation is induced • Generally, this method can be applied to entire roads	• Largest tollgate site areas • Safety is increased as traffic stream separation is induced • Generally, this method can be applied to entire roads	• Smallest tollgate site areas • Can be immediately applied to existing tollgates • Use both ETC and TCS to process mixed vehicles

2.2.2 *Other lane operational guidelines*

Guidelines for tollgate square area access rates, ETCS lane arrangements and installation locations and lane painting are diverse depending on traffic conditions in individual countries. Tollgate square areas in Korea and in the USA are relatively large and those in other countries are relatively small. Guidelines for ETCS lane arrangement and installation locations have been established in Korea and Japan. As for guidelines for ETCS lane painting, ETCS lanes and general lanes are painted differently in Korea and Italy but not in other countries.

<Table 2> Tollgate Square Area Access Rate

Division	Square Area Access Rate
Korea	• Main line tollgates: 1/10 or lower, interchange tollgates: 1/5 or lower • Minimum access length: 340~360m • Entry area: The largest one among calculated values of the minimum non-passing sight distance, the deceleration lane length and the lane changing length is applied • Exit area: The largest one among calculated values of the acceleration lane length, the length of the shock wave of traffic streams and the lane changing length is applied
Japan	• 1/3~1/7 or lower
The USA	• 1/10 or lower
Italy	• 1/3~1/4 or lower
Spain	• 1/4~1/5 or lower
Argentina	• 1/5 or lower

<Table 3> Standards for Lane Installation Locations and Arrangements

Division	Korea	Japan
Standards for lane installation locations and arrangements	• Basic: Center lane in principle - If the minimum distance for access terminal before and after tollgates has not been secured, changes in the installation locations and arrangements should be reviewed considering traffics by direction • The locations may be adjusted considering tollgate environments and the characteristics of traffic • Lane distribution method - Basic principle: Equal distribution of traffics by tollgate entry · exit vehicle lane - Equal distribution except for HI-Pass lanes and lanes dedicated to buses $\frac{N}{n} = A$	• Main line tollgates - Install two lanes each on the left and right side • IC tollgates - When there are joining and separation . Central area that connect the ends of the nodes of the joining and separation areas - When there is no joining or separation . Install at the right lane

<Table 4> Standards for Lane Marking

Division	Content
Korea	• Hi-pass and general lanes are painted differently - Hi-pass-blue, general lane-white - Lanes are painted even in tollgate square areas

Japan	• Lanes are not differently painted (To identify by painting in lanes) - ETCS: blue • Lanes in tollgate square areas are not painted
The USA	• Lanes are not differently painted • Vehicles are induced to respective tollgates based on their main line lanes - Divided from 1 lane → 2 lanes - Combined from 2 lanes → 1 lane
Germany	• Lanes in tollgate square areas are not painted
Italy	• ETCS and general lanes are differently painted (Yellow-Telepass, white-general lanes, blue-Card)

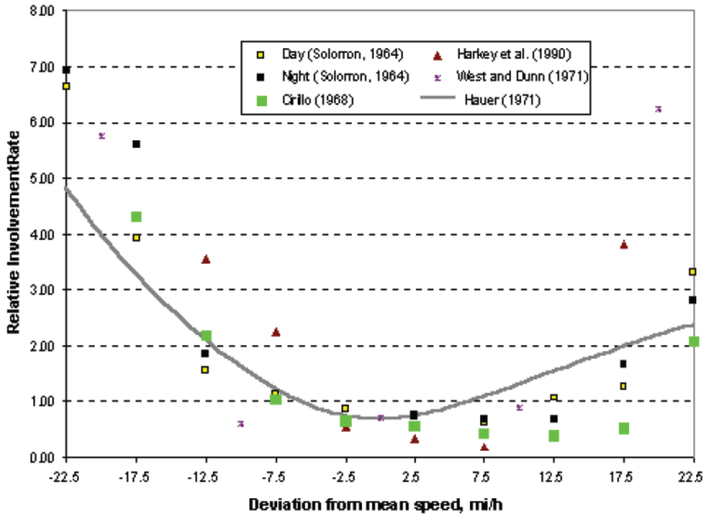
As such, individual countries are operating ETCSs diversely depending on their cultural characteristics and traffic environments. A problem is, however, that tollgates are operated without comprehensive consideration about the running characteristics of ETCS vehicles and general vehicles. In particular, as mentioned above, if ETCS lanes and general lanes are combined, guidelines for lane operation will be indispensable for safety. Furthermore, even in other cases, separate regulations over entry/exit access distances before and after tollgates are indispensable because the travel speeds of ETCS vehicles and those of general vehicles are different from each other and the guidelines considering this fact are necessary.

2.3. Review of previous studies

Some studies have been conducted in relation to ETCS operation guidelines. Choi et. al. (2007) presented appropriate distances for the installation of sight induction rods as safety facilities for ETCSs. In his study, he presented guidelines to prevent accidents resulting from differences in relative speeds between general vehicles and ETCS vehicles, but, the guidelines have limitations since the values were based on designed speeds instead of actual survey data. Besides, since expressway tollgates are sections where differences in travel speeds between ETCS vehicles and general vehicles increase first and then decrease, that is, deviations in the travel speeds of traffic streams increase and the risk of traffic accidents increases due to diverse travel speeds, we reviewed related literature.

Solomon (1964) extensively examined the relationship between speeds and accident rates and showed that the relationship between vehicle speeds and accident rates was in a U shape where accident rates were the lowest when vehicle speeds were close to the mean travel speed of vehicles and accident rates were high when surveyed vehicle speeds were higher or lower than the mean travel speed thereby indicating that the incidence rates of traffic accidents did not necessarily increase along with travel speeds. Through accident records, he evaluated the speeds of vehicles in individual accidents as being higher or the same as the speed distribution ranges measured in states similar to those when the accidents occurred. Cirill (1968) also analyzed the relationship between traffic accidents and travel speed during daytime and reconfirmed the curve in the form of U as with the results of the study by Solomon.

However, the Traffic and Communication Department of Ontario, Canada (1974) pointed out that speeds were not an essential prerequisite of the occurrence of accidents but were an important factor to determine the seriousness of accidents. Lave (1985) published the results of a study indicating that death rates were not statistically significantly related with speeds but were closely related with speed differences and concluded that, therefore, to reduce death rates, speed limits that could reduce speed deviations should be set up.



<Figure 2> Cumulative Ratios of the Seriousness of Accidents relative to Collision Speeds

Besides, Garber and Gadiraju (1998) gathered various kinds of road data including two-lane roads and expressways in rural regions and expressways in urban regions to present the relationship between speed distribution and traffic accidents. As shown in the Figure 2, they indicated that traffic accidents increased along with speed distribution. They also published the results of the study indicating that although traffic accidents do not necessarily increase along with mean speeds, accident rates increase along with speed distribution to reconfirm that rather than speeds per se, the degrees of vehicle speed distribution were closely related with the incidence rates of accidents.

3. ESTABLISHMENT OF STUDY METHODOLOGY

In this study, we plan to identify difference in the characteristics of running between general vehicles and ETCS vehicles through surveys of the travel speeds of general vehicles and ETCS vehicles at actual tollgates, analyze the risk of occurrence of accidents relative to relative speed deviations and present a method to set and apply different traffic operation guidelines based on speed differences as a method to solve related problems. To this end, we divided tollgates into entry areas and exit areas and grasped the spatial characteristics of each of the areas to establish traffic operation guidelines based on the characteristics.

4. FIELD SURVEY

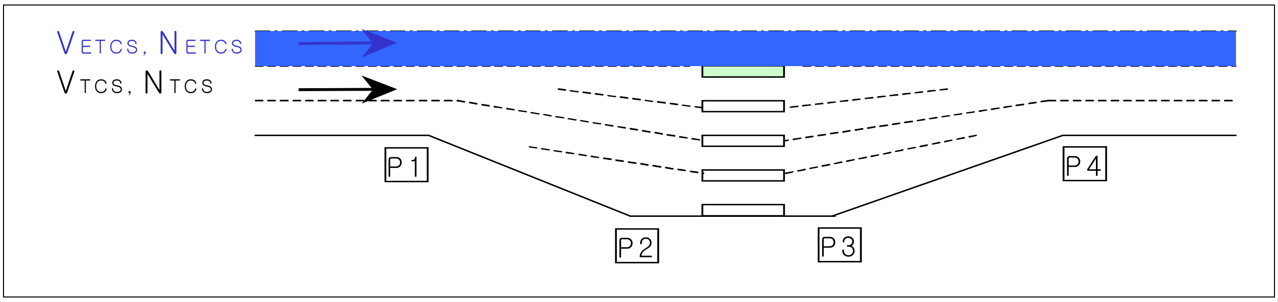
4.1. Overview of the survey

We conducted field surveys of six expressway tollgates during a period of November 2007~March 2008. The subject points were three main line tollgates and three Interchange tollgates selected among representative points where many vehicles use tollgates including ETCS vehicles.

<Table 5> Overview of the Field Survey

Date of survey		2007. 11.	2007. 12.	2008. 3.
Survey subject	Main line Tollgates	Cheonggye	East Seoul	Seoul
	IC Tollgates	East Suwon	Cheongwon, Balan	-

In the surveys, travel speeds by point in tollgate square areas and the number of times of lane changing were surveyed. Each survey point was divided into four points including a square area entry point, an island entry point, an island exit point and a square area exit point (P1, P2, P3, P4).



<Figure 3> Tollgate Square Area Survey Points

4.2. Survey Results

For travel speeds and the numbers of times of lane changing, the cumulative distribution of travel speeds and the numbers of times of lane changing of individual survey points were calculated and values corresponding to 85% were selected as representative values of the relevant points. This is to apply safety rates higher than those of actual mean speeds in order to prevent accidents for the same reason as that of using 85% speeds when setting speed limits.

4.2.1 Travel speeds

Travel speeds were analyzed and the results indicated that speed differences between ETCS vehicles and general vehicles were the largest. Points where speed differences were the largest were shown to be island exit points where speed differences of at least 20km/h were shown followed by island entry points, square area entry points and square area exit points in order of precedence. Of tollgate types, main line tollgates showed larger speed differences than Interchange tollgates.

<Table 6> Result of Travel Speeds (V_{85}) Analysis

(unit : km/h)

Division	Main line Tollgates			Interchange Tollgates			Note
	ETCS Lane	General Lane	Speed Differences	ETCS Lane	General Lane	Speed Differences	
P1	97.6	81.8	15.8	67.4	58.8	8.6	Entry point
P2	74.1	56.5	17.6	53.2	40.2	13	
P3	69.0	47.3	21.7	50.1	31.3	18.8	Exit point
P4	78.3	70.7	7.6	61.5	57.1	4.4	

4.2.2 Number of times of lane changing

The numbers of times of lane changing were analyzed and based on the results, it was identified that, in the case of main line tollgates, the mean number of times of changing from a general lane to an ETCS lane was 5 and the mean number of times of changing from a ETCS lane to a general lane was 2. In the case of Interchange tollgates, the numbers of times were identified to be 3 and 2 respectively.

<Table 7> Result of Number of Times of Lane Changing (N_{85}) Analysis

(unit : times)

Division	General Lane → ETCS Lane	ETCS lane → General Lane
Main Line Tollgates	5	2
Interchange Tollgates	3	2

4.2.3 Analysis of the accelerations and decelerations of actually running vehicles

Using actually surveyed travel speeds by point, we estimated the accelerations and decelerations of actual vehicles at tollgates. Since ETCS vehicles run without stopping at tollgates and thus their accelerations and decelerations are smaller than general vehicles, we limited the subjects of the estimation to general vehicles. We divided each field survey point into four sections to conduct the analysis.

$$a\ (\text{or } d) = \frac{|(v_2)^2 - (v_1)^2|}{L}$$

where, a : acceleration (kph/sec)
d : deceleration (kph/sec)
L : acceleration/deceleration distance (m)
V1: travel speed in the entry area of the section
V2: travel speed in the exit area of the section

The results of the analysis showed lower decelerations than the mean deceleration in the entry area beginning at P1 and ending at P2. From P2 to the island, that is, until the vehicles stopped at the island entry point to pay tolls, the results showed higher decelerations than the mean deceleration. This means that general vehicles show a tollgate entry area running pattern of not generally decelerating from tollgate square area entry points to island entry points and rapidly decelerating from island entry points that are close to islands.

Unlike entry areas, the results showed higher accelerations than the mean acceleration. The results showed much higher accelerations than the mean acceleration from islands to P3 and slightly higher accelerations than the mean acceleration from P3 to P4. Thus, in tollgate exit areas, the vehicles generally showed a running pattern of rapidly accelerating until they reached island exit points and relatively decreasing accelerations from there to square area exit points.

This driving pattern means that accelerations/decelerations made from island entry points to exit points including islands are very large and that if lanes are not appropriately operated, the risk of traffic accidents will become large. In particular, since almost two times of general accelerations are made in sections from islands to island exit points, it is seems like that special measures will be necessary in relation to this.

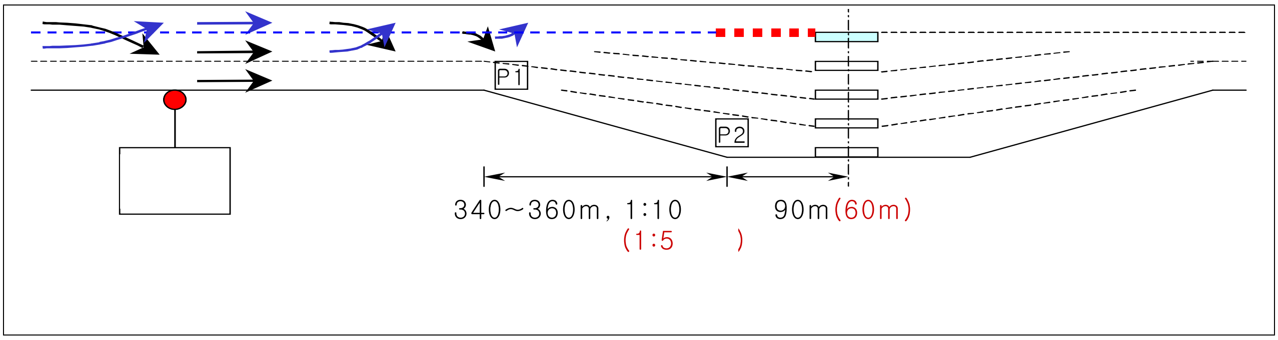
<Table 8> Comparison of Measured Deceleration/Acceleration and Mean Deceleration/Acceleration

(unit : kph/sec)

Division	P1～P2	P2～Island	Island～P3	P3～P4
Measured Deceleration/Acceleration (a)	2.69	9.85	10.36	2.13
Mean Deceleration/Acceleration (b)	5.0	7.5	5.5	1.4
Difference (a-b)	-2.31	2.35	4.86	0.73

4.3. Speed Trajectory Analysis

4.3.1 Entrance side



<Figure 4> Speed Trajectory Analysis : Entrance Side

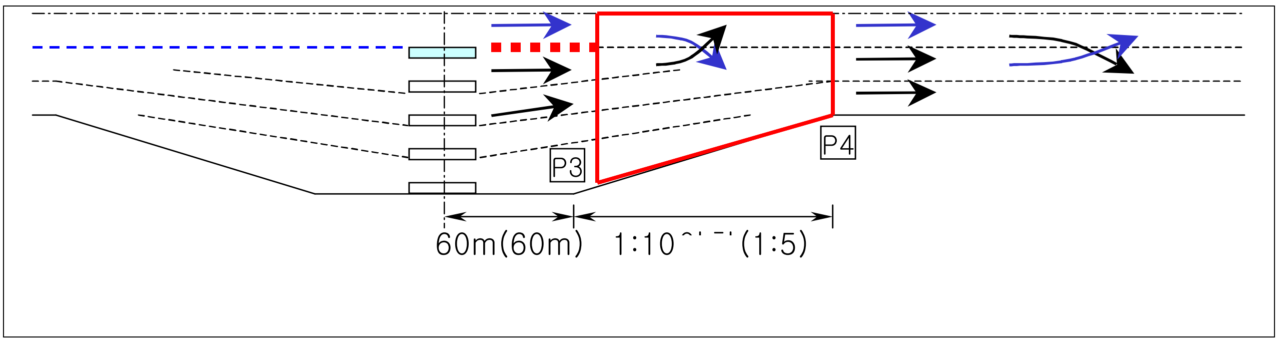
(1) Main Line Tollgates

Vehicle separation and joining were smooth from the point 2km before the square area to the square area entry point (P1) as vehicles were induced from before the area (blue dotted line). However, speed differences between ETCS vehicles and general vehicles were large (17.6km/h) from the square area entry point (P1) to the island entry point (P2) and thus accidents might occur during lane changing. Since ETCS vehicles' travel speeds did not decrease very much (97.6→74.1km/h) while general vehicles' travel speeds decreased greatly (81.8→56.5km/h), it was indicated that, if some vehicles would enter wrong lanes and change their lanes from ETCS to general lanes or from general lanes to ETCS lanes, accidents might occur.

(2) Interchange Tollgates

From the square area entry point (P1) to the island entry point (P2), there were speed differences between ETCS vehicles and general vehicles (13.0km/h) although the differences were not big. These differences were made because ETCS vehicles' travel speeds did not decrease greatly (67.4→53.2km/h) while general vehicles' travel speeds decreased greatly (58.8→40.2km/h). However, it was indicated that, since the speeds were low, the risk of accidents was relatively low.

4.3.2 Exit side



<Figure 5> Speed Trajectory Analysis: Exit Side

(1) Main Line Tollgates

The section from the island to the island exit point (P3) is a running section for ETCS vehicles (69.0km/h) and an acceleration section for general vehicles (0→47.3km/h) and thus speed differences are large. Therefore, it seems like that active restrictions on lane changing using physical facilities are necessary. The section from the island exit point (P3) to the square area exit point (P4) is where separation and joining resulting from lane changing occur and thus speed differences between ETCS vehicles and general vehicles are large (18.4km/h). Therefore, accidents may occur due to lane changing and thus related countermeasures are necessary.

(2) Interchange Tollgates

Though relatively smaller than main line tollgates, speed differences are large from islands and island exit points (P3) in the same tendency and thus active restrictions on lane changing using physical facilities are necessary. The section from the island exit point (P3) to the square area exit point (P4) was also shown to require countermeasures against lane changing.

4.3.3 Integration of the results of analysis of travel speeds

It was indicated that, at the entry side, it is important to allow vehicles that entered wrong lanes to change lanes to reduce the risk of accidents and, at the exit side, it is important to prevent accidents resulting from speed differences between ETCS vehicles and general vehicles.

5. ESTABLISHMENT OF TRAFFIC OPERATIONAL GUIDELINES

When ETCS systems have been installed at tollgates, traffic operational guidelines are indispensable in order to physically distinguish between high speed vehicles and low speed vehicles and enhance drivers' visibility. The purposes are largely divided into two and one of them is to provide appropriate distances necessary for lane changing when general vehicles and ETCS vehicles enter wrong lanes. The other purpose is to prevent the risk of traffic accidents resulting from deviations in relative speeds.

5.1. Distance necessary for lane changing to be made when vehicles entered wrong lanes

One of major considerations necessary when establishing operation guidelines for entry areas is allowing vehicles entered wrong lanes to change their lanes. The results of field surveys indicated that in the case of main line tollgates, ETCS vehicles changed lanes two times and general vehicles five times and thus the appropriate distance for lane changing by vehicles that entered wrong lanes is calculated as follow applying the results of the field surveys.

$$L_1\ (\text{or}\ L_2) = \frac{1}{3.6} \times v \times t \times N$$

where,
- L1 : distance necessary for lane changing by ETCS vehicles that entered wrong lanes (m)
- L2 : distance necessary for lane changing by general vehicles that entered wrong lanes (m)
- v : travel speed at point P1 (km/h)
- t : travel time necessary for lane changing 3.6sec. in case the lane width is 3.6m
- N : number of changed lanes

The results of the calculation indicated that, in the case of main line tollgates, approximately 400m is necessary for general vehicles that entered wrong lanes and approximately 200m is necessary for ETCS vehicles that entered wrong lanes and in the case of Interchange tollgates, 180m and 140m are necessary respectively.

<Table 9> Lane Changing Distance considering Vehicles' Entries into Wrong Lanes

Division		v	t	N	L	Note
Main Line Tollgates	Lane changing distance considering ETCS vehicles' entries into wrong lanes	81.8km/h	3.6sec	5	409m	General lane→ ETCS lane
	Lane changing distance considering general vehicles' entries into wrong lanes	97.6km/h	3.6sec	2	195.2m	ETCS lane →General lane
Interchange Tollgates	Lane changing distance considering ETCS vehicles' entries into wrong lanes	58.8km/h	3.6sec	3	176.4m	General lane→ ETCS lane
	Lane changing distance considering general vehicles' entries into wrong lanes	67.4km/h	3.6sec	2	134.8m	ETCS lane→ General lane

5.2. Review of the probability of occurrence of accidents in relation to relative speed deviations

5.2.1 Guidelines for lane operation based on the probability of occurrence of accidents relative to speed differences

According to Garber and Gadiraju (1998) who studied the risk of traffic accidents relative to speed differences, the relationship between vehicles' speed differences and the incidence rates of accidents is roughly summarized as follows. This means that when travel speed differences are within ±4 km/h, the probability of occurrence of accidents is low, when travel speed differences are within ±12 km/h, the probability of occurrence of accidents is moderate and when travel speed differences are within ±20 km/h, the probability of occurrence of accidents is high.

<Table 10> The Probability of Occurrence of Accidents relative to Speed Differences

Speed Differences	Unit Conversion (km/h)	Incidence of Accidents	Division
± 2.5 mil/h	± 4 km/h	1.2	The probability of occurrence of accidents is low
± 7.5 mil/h	± 12 km/h	1.6	The probability of occurrence of accidents is moderate
± 12.7 mil/h	± 20 km/h	2.8	The probability of occurrence of accidents is high

The speed difference at which the incidence rate of accidents is doubled obtained by inverse operation using the results of the study by Garber and Gadiraju (1998) is approximately 17km/h. Therefore, sections where speed differences are larger than 17km/h are considered to require physical lane separation between ETCS vehicles and general vehicles and sections where speed differences are smaller than 17km/h are considered to require lane separation through lane painting.
That is, standards for lane operation based on the incidence rates of accidents relative to speed differences are as follows.

- Sections where relative speed differences are 17km/h or larger: physical lane separation using tubular markers etc.
- Sections where relative speed differences are smaller than 17km/h: lane separation through lane painting etc.

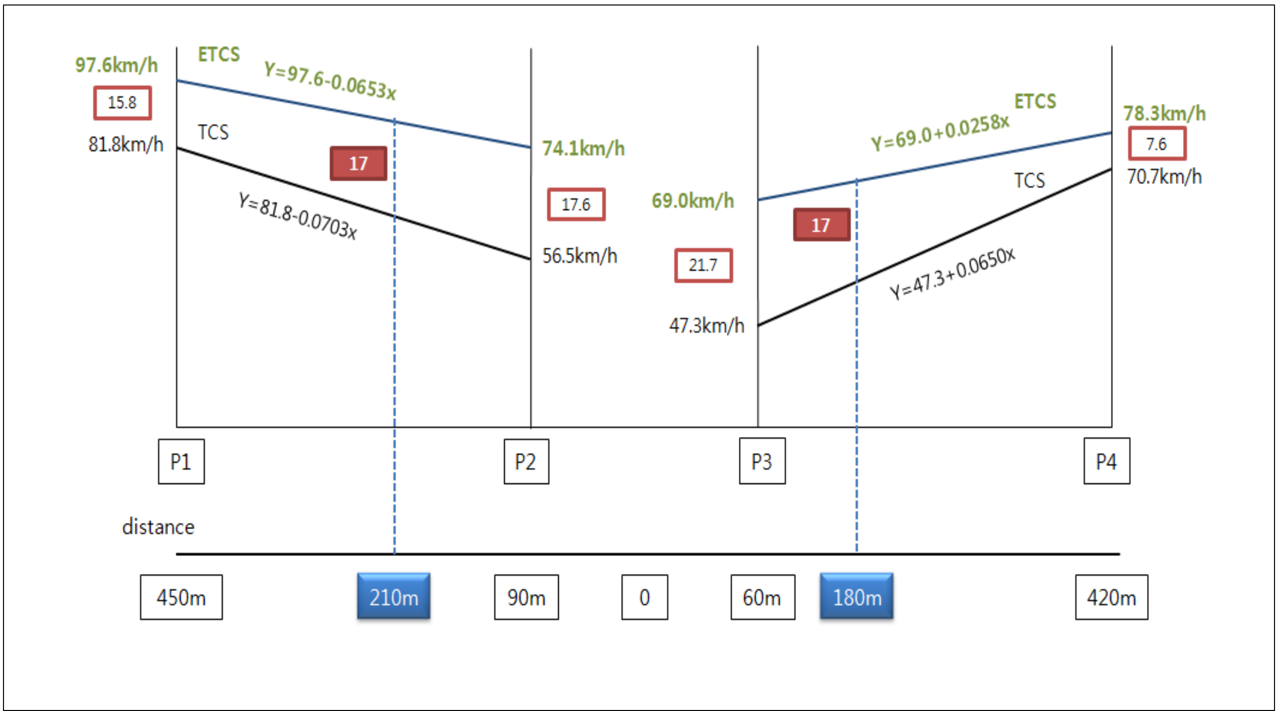
5.2.2 Process to calculate guidelines for lane operation based on the incidence rates of accidents relative to speed differences

Guideline distances for lane operation considering relative speed differences and the incidence rates of accidents are calculated through the following processes.

1. Surveys and calculation of travel speeds by point
2. Calculation of ETCS and general vehicles' travel speed change curves by section
3. Determine the point at which the relative speed difference is 17km/h

5.2.3 Example of guidelines for main line tollgate lane operation

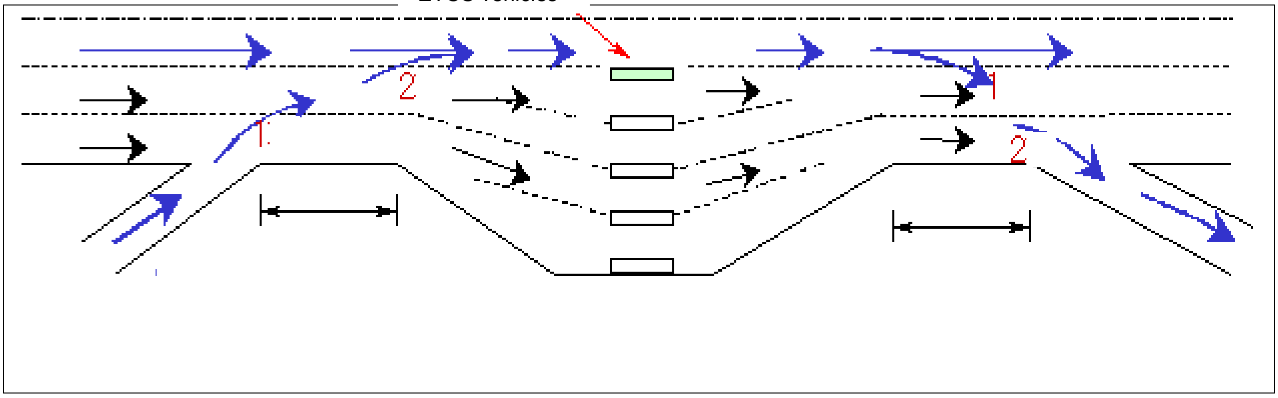
When the guideline distances for main line tollgate lane operation was calculated through the above processes, the distances obtained were approximately 210m from the island in the entry area and 180m in the exit area. Therefore, if these distances are applied, it is considered appropriate for preventing accidents to distinguish ETCS lanes and general lanes from each other for 210m and 180m using tubular markers etc and paint remaining sections with solid lines and dotted lines.



<Figure 6> Calculation based on Main Line Tollgate Lane Operation

5.3. Analysis of distances of access terminals between tollgates and entry/exit facilities

If an exit area exists immediately after passing a tollgate, an appropriate distance for lane changing will be necessary so that ETCS vehicles can safety arrive at exit lanes. This is because, when ETCS lanes have been installed in a tollgate square area, although the points and number of lanes installed may vary with the geometric structure of the tollgate, exit traffic, passing traffic, the ratio of trucks, the ratio of ETCS installation and future increases in the ratio, ETCS vehicles should be able to smoothly move in any event. The distance of the access terminal to the entry/exit area should not be shorter than the distance for ETCS vehicles to safely exit. Therefore, the distances of access terminals between tollgates and entry/exit areas can be obtained by obtaining the distance for ETCS vehicles to safety enter/exit.



<Figure 7> Analysis of Distances of Access Terminals between Tollgates and Entry/Exit Facilities

For a vehicle to change one lane without any trouble, it requires around one second per 1m in its lateral direction. If this converted into a time necessary for one lane, it will become approximately 3~4 seconds. In particular, in the case of expressways where the lane width is 3.6m, the time necessary for one lane becomes approximately 3.6secend. Based on this result, the distance of each access terminal from a tollgate to an entry/exit area is obtained as follows.

$$L = \frac{1}{3.6} \times v \times t \times N$$

where, L : distance necessary for lane changing (m)
v : travel speed (km/h)
t : travel time (sec.), 3.6 second in case the lane width is 3.6m
N : number of changed lanes

<Table 11> Distances necessary for Lane Changing by Travel speed and by the Number of Changed Lanes

Travel speed / Number of Lanes	30km/h	50km/h	60km/h	80km/h	100km/h
1	30m	50m	60m	80m	100m
2	60m	100m	120m	160m	200m
3	90m	150m	180m	240m	300m

Note) The lane width was assumed to be 3.6m

6. CONCLUSION AND FUTURE STUDIES

Despite that ETCSs are operated in approximately 30 countries throughout the world; studies related to safe operation of ETCSs are insufficient. In this study, we tried to identify the necessity of tollgate lane operation guidelines through analyses of cases of ETCS operation in various countries, identify the risk of the occurrence of accidents based on speed differences between ETCS vehicles and general vehicles by point through examinations of actual travel speeds of actual vehicles and present a method to set

different traffic operation guidelines based on speed differences as a method to solve the problem.
Through surveys of actual travel speeds, we identified different speed differences by point and identified the risk of accidents and discovered that it is important to allow lane changing by vehicles that entered wrong lanes depending on the geometric structural characteristics of tollgates in order to reduce the risk of accidents and to prevent accidents resulting from speed differences between ETCS vehicles and general vehicles. We reflected these when we established traffic operation guidelines and in particular, we established the relationship between speed differences and accident rates to establish traffic operation guidelines by point relative to speed differences, established related processes and applied the processes to actual sites to present lane operation guidelines as examples.
The results based on vehicle travel speeds indicated that the entry area should be approximately 210m and the exit area should be approximately 180m from the island. If these distances are applied, it is considered appropriate for preventing accidents to distinguish ETCS lanes and general lanes from each other for 210m and 180m using tubular markers etc and paint remaining sections with solid lines and dotted lines. In addition, we presented guidelines for calculating the distances of access terminals from tollgates to entry/exit areas based on distances for ETCS vehicles to safely enter/exit from the road.
In future, additional studies are necessary in order to identify the characteristics of accidents at tollgates in relation to relative speed differences centering on actual accident cases at tollgates and apply the results in establishing ETCS operational guidelines. In the situation where global interest in low carbon green growth is increasing, the ETCS safety guidelines presented in this study will contribute to the reduction of traffic jams resulting from accidents and traffic congestion and enable safer and faster ETCS operation.

REFERENCES

1. Ministry of Transport and Communications (1974), Speed and Accidents: A preliminary Report, Canada
2. Nillson G. (1984), Speed, Accident Rates and personal Injury Consequences for Different Road Types, VTI Report 277
3. Charles A. Lave (1985), Speeding, Coordination, and the 55 mph Limit, The American Economic Review
4. Nicholas J. Garber and Ravi Gadiraju (1989), Factors Affecting Speed Variance and its Influence on Accidents, TRR 1213
5. The Korea Expressway Corporation (1992), Guideline of Road Design
6. The Ministry of Land, Transport and Marine Affairs (2000), Explanation of and guidelines for the rules regarding the guidelines for the structures and facilities of roads, Korea
7. The Korea Expressway Corporation (2001), Road design practice handbook (interchanges and auxiliary facilities)
8. The Ministry of Land, Transport and Marine Affairs (2002), Guidelines for road safety facility installation and management (Section of sight induction facilities), Korea
9. Federal Highway Administration (2003), Manual on Uniform Traffic Control Device
10. Cheol-Wung Do (2004), Principles of traffic engineering
11. Han-Seon C., et al. (2005), Calculation of 2004 traffic congestion costs and analysis of the trend, the Korea Transport Institute
12. Yoon-Hyuk Choi, Keechoo Choi, and Han-Geom Ko (2007), DEVELOPMENT OF SAFETY STANDARD FOR HI-PASS: FOCUSING THE TUBULAR MARKERS, The 14th world congress on Intelligent Transport Congress, Beijing