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A Study on Characteristics of Toll Nonpayment Associated with Expressway High-Pass

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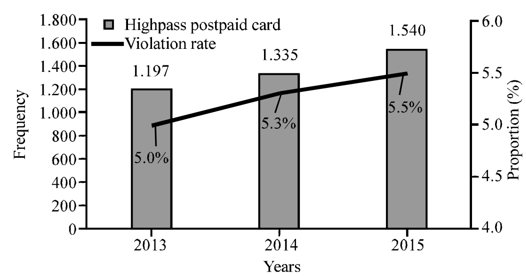
Abstract: The expressway toll violation and non-payment has been increasing with the wide use of highpass system. Thus, the present study analyzed the data published in 2015 to characterize the toll non-payment trend associated with the highpass system. The sample analyzed here included the vehicles that used expressways without paying tolls in 2015. The 7,755,042 vehicles failed to pay tolls in 2015. For the analysis, Excel and statistics S/W package SPSS 19 were used. This finding suggests that the toll nonpayment is attributable to communication errors between devices from different manufacturers, traffic volumes and vehicle types. To adopt the smart tolling system, a nonstop multi-lane free-flow ETCS where vehicles fitted with highpass terminals pay tolls automatically as they do now while those without such terminals have their license plates recognized by some video devices for automatic tolling, the information collected by the existing highpass lane controllers need be specified further, so that, devices causing problems can be determined with ease. In addition, some remote-control features need be employed for an efficient maintenance approach.

Key words: Expressway, highpass system, toll violation, characteristics of toll nonpayment, smart tolling system, efficient maintenance approach

INTRODUCTION

Since, December 2007 when the expressway highpass system was first installed across the country, the toll payment on the convenient and fast highpass lanes has increased every year. Specifically, the use of highpass lanes increased by 28.7% in 2015 compared with 2013, whereas the toll violation associated with highpass cards surged by 41.5%, outpacing the penetration rate of the cards. Highpass cards are sub-divided into prepaid and post-paid ones. As in Fig. 1, the toll violation associated with post-paid highpass cards increased by 5.5 and 5.0% in 2015 and 2013, respectively given the traffic volume.

The toll nonpayment associated with highpass cards accounted for 98% minimum of all toll violations in 2015. As in Fig. 2, the toll nonpayment grew every year, i.e., 0.14% p ('12) → 0.06% p ('13) → 0.07% p ('14) → 0.13 p ('15).



Variables	2013	2014	2015
High postpaid card	1.197	1.335	1.540
Number of violation	59.8	70.9	84.6
Violation rate (%)	5.0	5.3	5.5

Fig. 1: Highpass postpaid card violation trend (Unit: thous./day, %)

Literature review

Theoretical background: The highpass system refers to Korea's unattended ETCS (Electronic Toll Collection System) on expressways, comprised of vehicle classification system, vehicle violation shooting equipment, antenna, drive controller, breaker, drivers indicators and vehicle detection device as shown in Fig. 3.

The highpass ETC system is an IR-RF integrated system with the DSRC communication method applied based on the characteristics of each toll booth. The toll collection system is sub-divided into open and close systems and the lanes into highpass-only and hybrid lanes where both highpass cards and TCS (Toll Collection System) are available.

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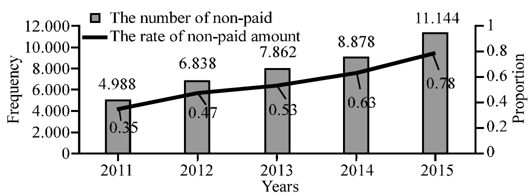
The entire highpass system consists of the headquarters server, toll booth, lane equipment and vehicle-mounted device. The vehicle-mounted device consists of a highpass terminal (OBU, On Board Unit) and an electronic card which communicate with the highpass lane equipment for toll settlement. The lane equipment involves the vehicle classification system, vehicle detection device, wireless communication unit, vehicle violation shooting equipment, breaker system unit and driver indicator, LED board, signal lamp and integrated lane controller that controls the tolling process by communicating with the foregoing components via. the interface.

Kim (2012) classified the toll collection procedure of the highpass system largely into the wake-up, downlink, transaction, detection and out zones as shown in Fig. 4. In the wake-up zone, the vehicle-mounted terminal starts upon receiving the wake-up signal. The electronic card in the terminal generates the signature value 1. In the downlink zone, the terminal includes the signature value 1 generated by the electronic card and the BST (Beacon Service Table) value received from the antenna controller in the VST information. In the transaction zone, the antenna controller puts the signature value 1 in the lane controller's Purchase Secure Application Module (PSAM), verifies it and generates the signature value 2. At the same time, the antenna controller uses the terminal's entry information to calculate the toll and checks the black list. When the antenna controller requests the terminal for the calculated toll, the electronic card verifies the signature value 2, pays the toll and generates the signature value 3 which is in turn verified by the lane controller's PSAM. Then, the antenna controller requests the terminal and electronic card to record the exit (present) information. In the vehicle detection zone, the vehicle violation shooting equipment determines the violation status of the vehicle and decides whether to capture its license plate or not. At the same time, the terminal switches to the buzzer and sleep mode and the electronic card records the exit information. In the out zone, the final result is summarized and transmitted to the toll booth computer, followed by the notification that the toll collection process for the vehicle is completed.

Lee and Kim (2013) studied the existing method which is based on the Level of Service (LOS) concept proposed by Hugh as a measure to guarantee a certain speed of driving to the user in designing the high pass car and it can be regarded as a design method of the concept which does not guarantee smooth communication when viewed



Variabels		2011	2012	2013	2014	2015
Traffics (aggregate)		1.257.433	1.274.403	1.301.631	1.335.833	1.396.745
Non-paid	Number (rate)	4.988 (0.40%)	6.838 (0.54%)	7.862 (0.60%)	8.878 (0.67%)	11.144 (0.80%)
	Amount (rate)	49.854 (0.35%)	14.091 (0.47%)	16.404 (0.53%)	20.011 (0.63%)	26.179 (0.78)
Acceptance	Number	4.810	6.518	7.417	8.217	8.772
	Amount (rate)	9.399 (96.4%)	13.237 (95.3%)	15.362 (94.3%)	18.517 (92.6%)	22.042 (84.2%)

Fig. 2: Non-payment trends (Unit: thous.\mil)

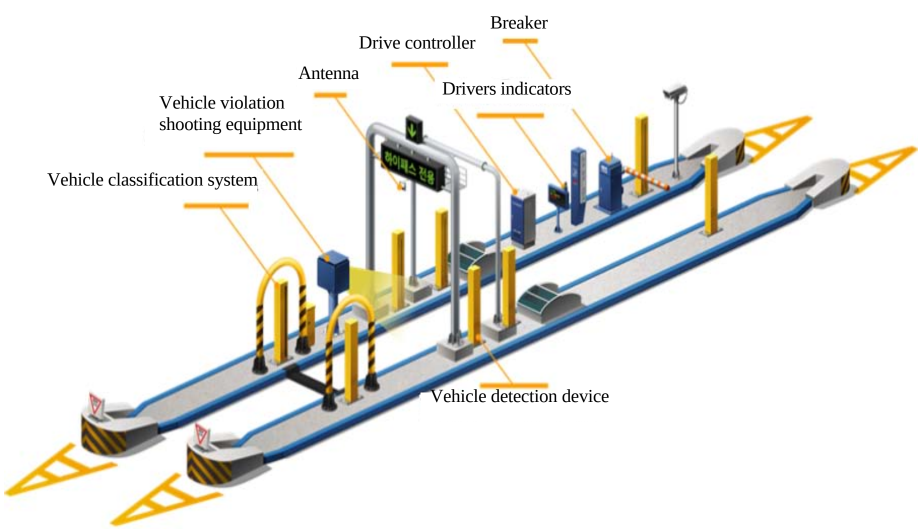


Fig. 3: Highpass system schematic diagram

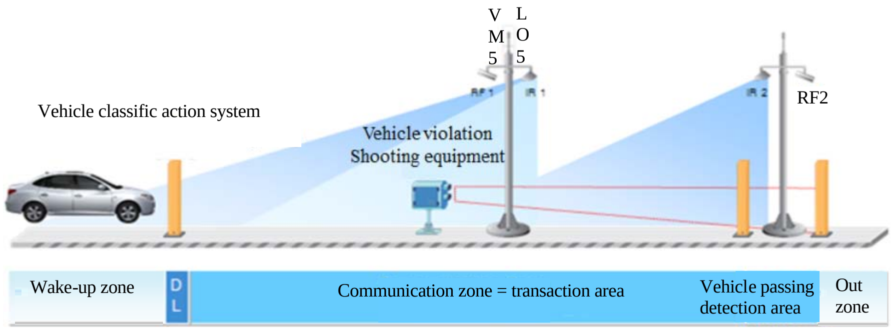


Fig. 4: Highpass toll collection process

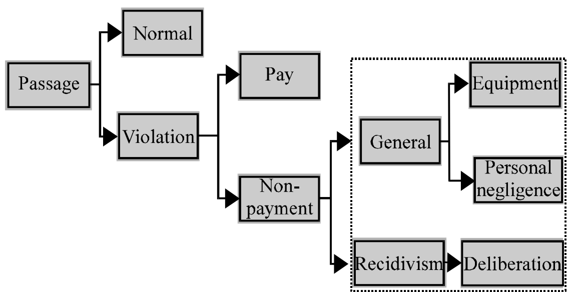


Fig. 5: Research model

from the user side. In addition, Kim (2012) pointed out that the high-pass circuit breaker installed in the high-pass in the problems and improvement plan of the highway high-pass operation was originally intended to prevent traffic accidents due to mis. The speed limit for the system was only cost.

Lee and Jeon (2009) estimated the travel time of the highway by combining the travel time of the links based on the TCS data base. Rim *at el.* (2009) collected the trajectory data of the individual vehicle through the vehicle terminal in the ubiquitous environment and calculated the representative travel time and presented the method to the driver and analyzed it through simulation. Park *et al.* (2009) proposed a methodology for collecting traffic trajectories of individual vehicles using VISSIM, a micro-traffic simulator and calculating segment information using the running data of individual vehicles located within the influence zone of RSE.

Research model: As in Fig. 5, vehicles are classified into normal and violation types. The violation vehicles are sub-classified into pay and nonpayment vehicles. The nonpayment is sub-classified into general (equipment error and personal negligence) and deliberation. Hence, the present study characterized the non-payment vehicles among other toll violators:

- Question 1: at which IC does the toll nonpayment occur most frequently?
- Question 2: what time of day does the toll nonpayment occur most frequently?
- Question 3: what types of vehicles are most frequently associated with the toll nonpayment?
- Question 4: which combination of lane equipment and terminal (OBU) is most frequently associated with the toll nonpayment?

MATERIALS AND METHODS

The sample analyzed here included the vehicles that used expressways without paying tolls in 2015. 7,755,042 vehicles failed to pay tolls in 2015. For the analysis, Eexcel and statistics S/W package SPSS 19 were used. The number of violations outlined in Table 1 implies that the devices became outdated over time, since, the adoption of the highpass lanes in each region which was regarded as a control variable and not considered in the analysis.

RESULTS AND DISCUSSION

Empirical analysis and verification: First, Table 1 and 2 shows the number of toll nonpayment at each IC (interchange) in 2015. Guri IC had the highest frequency of toll nonpayment followed by Kimpo and Incheon in the order named. In other words, vehicles failed to pay tolls mostly in the capital region.

Therefore, regarding the hypothesis 1 (at which IC does the toll nonpayment occur most frequently), the toll nonpayment occurred mainly at Ics in the capital region.

Next, as for the analysis of the time of day when the toll nonpayment occurred most frequently, the curvilinear regression analysis found the coefficient of determination $R^2 = 0.904$. Also, the p was 0.973, 0.002 and 0.000 based on the linear (time), quadratic (time 2**) and cubic (time 3**) regression equations, respectively, indicating the cubic regression equation proved to be a fit model as Table 3-5 and Fig. 6. Regarding the hypothesis 2 (What time of day does the toll nonpayment occur most frequently?), the toll

Table 1: Number of toll nonpayment by the year of highpass opening

Year of opening	The number of non-payment
2005	1082055
2006	830188
2007	2516003
2008	715834
2009	538210
2010	412354
2011	296178
2012	445509
2013	218295
2014	452925
2015	247491
Total	7,755.042

Table 2: Toll nonpayment by IC

IC	Frequency	Proportion
Guri	566235	0.072746
Kimpo	529320	0.068004
Incheon	400691	0.051478
Siheung	397601	0.051081
ChungGye	366308	0.047061
Sungnam	362817	0.046612
Seoul	273882	0.035187
Seoseoul	252123	0.032391
Pangyo	237823	0.030554
Namincheon	187359	0.024071
Dongseoul	167577	0.021529
Gunja	126039	0.016193
Singal	110237	0.014163
Dongsuwon	96737	0.012428
Hanam	85886	0.011034
Daedong	81425	0.010461
Seoansan	81222	0.010435

Table 3: Regression result on time and the number of non-payment model summary

R	R^2	Adj. R^2	Estimated SE
0.951	0.904	0.890	54390.671

Independent variable: time

Table 4: ANOVA

Model	Sum of square	df	Avg. square	F-values	p-values
Regression model	5.579E11	3	1.860E11	62.857	0.000[a]
Residual	5.917E10	20	2.958E9		
Total	6.170E11	23			

Independent variable: time

Table 5: Coefficient

Variables	Non standardized coefficient (B)	Standardized coefficient (β)	SE	t-values	p-values
Time	-498.053	-0.022	14728.218	-0.034	0.9730
Time 2**	5333.536	5.483	1506.758	3.540	0.002
Time 3**	-223.996	-5.116	43.020	-5.207	0.000
Constant	80103.867		38284.295	2.092	0.049

**Significant values

nonpayment gradually increased during the morning rush hour and reached a peak during the evening rush hour (i.e., at 5 pm).

The Korea Expressway Corporation classified the vehicles using expressways into five types, i.e., the 1st-class (2 axles with the tire width of 279.4 mm or less), the 2nd-class (2 axles with the tire width of over 279.4 mm and the tread width of 1800 mm or less), the 3rd-class (the tire width of over 279.4 mm and the tread width of over 1800 mm), the 4th-class (3 axles) and the 5th-class vehicles (more than 4 axles). The toll nonpayment per vehicle type was analyzed as Table 6.

Table 6: Toll nonpayment per vehicle type

Types	Car.freq.	Car.prop.
1	7389517	0.949401
2	127865	0.016428
3	164825	0.021177
4	11951	0.001535
5	11409	0.001466

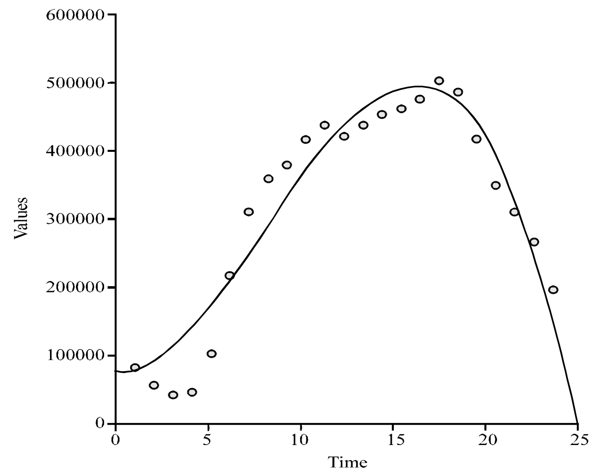


Fig. 6: Results of non-payment

Thus, as for the hypothesis 3 (What types of vehicles are most frequently associated with the toll nonpayment?), the 2-axle vehicles with the tire width of 279.4 mm or less (the 1st class vehicles) accounted for 94.9% of all toll non-payments, surpassing all the other types of vehicles.

Finally, the frequency of toll nonpayment was analyzed in terms of the lane equipment and vehicle terminals (OBU). The highpass system is comprised of the CCU centrally controlling the lanes, the IR (Infrared Ray) antenna and the RF(Radio Frequency) antenna which communicate with the personal highpass terminals (OBU) to collect tolls. At present, the CCUs, IR antennas and RF antennas installed on expressways nationwide are manufactured by 6 companies each. The personal terminals are manufactured by more than 140 companies. Thus, the combination of the highpass system components and the personal terminals was analyzed to determine the highest frequency of toll nonpayment. As a result, the combination of the CCU from STraffic, the IR antenna from STraffic and the RF antenna from Seotong and the terminal from Mpion led to the highest frequency of toll nonpayment as in Table 7.

Table 7: Toll nonpayment per highpass system component manufacturer

CCU	IR-ANTNA	RF-ANTNA	OBU	Non-payment
Straffic	Straffic	Seotong	Mpion	493709
Seotong	Straffic	Seotong	Mpion	372546
DB	DB	DB	Mpion	347776
Posco	AITS	Seotong	Mpion	242202
DB	AITS	Seotong	Mpion	225266
Posco	Posco	Posco	Mpion	206266
LS	LS	LS	Mpion	199520
Straffic	Straffic	Seotong	Mobis	182532
iTronics	iTronics	iTronics	Mpion	180867
DB	AITS	DB	Mpion	165026
DB	DB	Seotong	Mpion	134662
Seotong	Straffic	Seotong	Mobis	134084
Posco	AITS	Highgain	Mpion	128852
DB	DB	DB	Mobis	124110
Straffic	Straffic	Seotong	SDSystem	102844
Straffic	Straffic	Seotong	AITS	100479

Hence, regarding the hypothesis 4 (Which combination of lane equipment and terminal (OBU) is most frequently associated with the toll nonpayment?), the CCU from STraffic, the IR antenna from STraffic, the RF antenna from Seotong and the terminal from Mpion were associated with the toll nonpayment most frequently. That is, the combination of STraffic, STraffic, Seotong and Mpion was most prone to the toll nonpayment.

CONCLUSION

As Siva *et al.* (2015) pointed out the efficiency, despite the increasing use of the convenient and fast expressway highpass system, chronic traffic congestion takes place once vehicles pass the toll booths whilst the cases of toll nonpayment are increasing at the same time. Thus, the present study analyzed the characteristics of expressway toll nonpayment in 2015 with a view to improving the efficiency of the highpass system. The analysis highlighted that the 1st-class vehicles failed to pay tolls most frequently at ICs in the capital region during the evening rush hour. Also, the combination of lane equipment and terminal manufactured by STraffic, STraffic, Seotong and Mpion led to the most frequent toll nonpayment. This finding suggests that the toll nonpayment is attributable to communication errors between devices from different manufacturers, traffic volumes and vehicle types. To adopt the smart tolling system, a nonstop multi-lane free-flow ETCS where vehicles fitted with highpass terminals pay tolls automatically as they do now while those without such terminals have their license plates recognized by some video devices for automatic tolling, the information collected by the existing highpass lane controllers need be specified further, so that, devices causing problems can be determined with ease. In addition, some remote-control features need be employed for an efficient maintenance approach.

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