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Effectiveness of the Peripheral Transverse Line as Speed-Reduction Treatment on Korean Expressway Ramps

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ABSTRACT

PURPOSES : Since expressways in South Korea are toll roads, many trumpet type interchanges exist, resulting in the installation of loop ramps very frequently. While the travel speed of the main lane is designed to be 100-110 km/h, the structure of a loop ramp is different and is designed for a minimum speed of 40 km/h. In fact, most of the actual travel speeds measured on the ramp exceed the designated speed, which has been a major problem in traffic safety. In this research, a type of pavement marking speed-reduction treatment called the "Peripheral Transverse Line" is installed on expressway loop ramps in order to study the change of driving speeds after the installation.

METHODS : To verify statistically the change, this speed-reduction treatment has been installed on the Chungju interchange and the Yeoju junction. The driving speeds before the installation were compared with driving speeds both one month and five monthsafter the installation.

RESULTS : As a result, the reductions of the average driving speeds after the treatment were statistically significant. More specifically, the average driving speeds of the Chungju interchange were reduced by 7.1-7.7 % for its tangent road section, and the speeds decreased by 8.5-9.5 % for its curve section. Similarly, in the Yeoju junction, an average speed reduction of 2.9-4.8 % for its tangent section was measured, along with 3.9% long-term speed reduction for its curve section.

CONCLUSIONS : Since the pavement marking speed-reduction treatment has been partially proven to be effective from this research, we expect to expand this treatment and re-confirm the effect from a long-term perspective in the future.

Keywords
traffic safety, peripheral transverse line, speed-reduction method, independent t-test

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1. INTRODUCTION

According to the statistics from the Korea Expressway Corporation, a total of 2,368 traffic accidents were reported in the year 2010, and 551 cases (23.3%) were due to speeding. Among the total of 1,336 traffic-related casualties, 269 (20.1%) were due to speeding, a considerably serious issue. By taking a look at the statistics of loop ramps in this study, 105 accidents (41.7%) out of 252 cases were caused by speeding.

Since expressways in South Korea are toll roads, many trumpet type interchanges can be found, resulting in the frequent installations of loop-type ramps. Since the actual driving speeds are higher than the designated speed, several accidents tend to be concentrated on loop ramps.

There are three main types of speed-reduction treatments: physical countermeasures (hump, grooving, and anti-skid surfacing), traffic control devices (speed-renforcement cameras, speed limit signs, and traffic control signs), and recent pavement markings for speed-reduction (virtual speed humps, zigzag lines, and other pavement markings)

In South Korea, physical traffic control treatments, including grooving and speed cameras, have been widely used. However, visual speed-reduction treatments have been limitedly applied due to its uncertain effect of reducing speeds. Therefore, in this study, a pavement marking system for speed-reduction treatment is applied on a highway to experiment and verify the effect for the first time in South Korea.

Pavement markings are utilized in order to make drivers believe that their driving speeds are higher than the speeds they are actually going. First, to apply and evaluate a proper type of pavement marking in this research, literature regarding the visual speed-reduction treatment had been consulted. Then, the Peripheral Transverse Line was selected as a representative pavement marking speed-reduction treatment. It was installed on two expressway ramps to evaluate the change of driving speeds before and after the installation.

To select proper installation locations, various types of points were widely examined. These included such places as accident-prone sections, rapid plane-curvature changed regions, and intersection exits. After deliberation, the Chungju interchange and the Yeoju junction from the Jungbu expressway were selected to apply the Peripheral Transverse Line (Herringbone Pattern) according to the "Guide of Pavement Marking Speed-Reduction Treatments."

To analyze how the treatment influences the average driving speeds, a number of traffic and speed data (2009. 11-12, 1 minute interval for 24 hours) was collected at the corresponding locations. After both one month and five months from the installation of the countermeasure, the same types of data on identical locations was collected for comparisons.

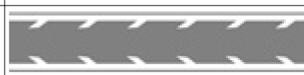
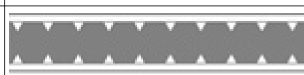
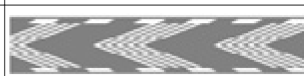
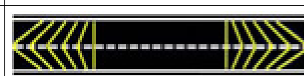
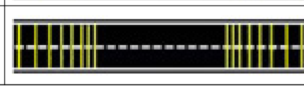
2. PRE-STUDY ON PAVEMENT MARKING SPEED-REDUCTION TREATMENT

2.1. Pavement Marking Speed-Reduction Treatment

The "Pavement Marking Speed-Reduction Treatment" is a countermeasure based only on visual effects. It persuades drivers to reduce their driving speeds in a safe and easy way by psychologically pressuring them.

Such a countermeasure is highly effective to drivers who are newly accustomed to the treatment, but it becomes less effective as drivers familiarize themselves with the treatment as time goes on. However, the treatment is advantageous since the speeds can be reduced simply through pavement markings with its low maintenance cost.

Table 1. International Pavement Marking Speed-Reduction Treatment Usage Status (Noh, et al. 2010)

Category	Type	Nations
Peripheral Transverse Line(I)		USA, AUS, JPN
Peripheral Transverse Line(II)		USA
Dragon's Teeth		GBR
Chevron Markings		JPN, USA, GBR
Wundt Narrowing Illusion		GER
Transverse Line		GBR, USA

The pavement marking speed-reduction treatments commonly used in rapid curves, expressway interchange exits, and highway work zones are categorized into two types. One treatment makes drivers believe that their driving speed is faster than their actual driving speed. The other treatment type makes the width of the lane appear to be narrower than it actually is in order to make the driving speed reduced.

Griffin attempted to measure the effectiveness of pavement marking speed-reduction treatment. He reported that it was a cost-effective method, and stated that the Chevron Marking and the Peripheral Transverse Line (I) can reduce traffic accidents by approximately 25-50% and 5%, respectively (Griffin and Reinhardt, 1995).

With regard to the Peripheral Transverse Line (I) installed in highway ramps, Katz carried out in-depth research in Syracuse. His study showed that the actual speed reduction of 9.5 mph immediately after an installation was measured, and a 4 mph speed reduction was maintained 4 months after the installation (Katz, 2004). The effectiveness was proven again in Gates' research. The Peripheral Transverse Line (I) reduced driving speeds by 0.05-5.03 mph (with an incidence of 0.64 mph increment) immediately after the installion. Driving speeds decreased by 3.74 mph (with an incidence of 5.37 mph increment) six months after the installation (Gates, Qin, and Noyce, 2005).

Additonally, according to the Noh's simulation result of five different pavement markings, it was found that the Peripheral Transverse Line (II) was the most effective method, with a reduced speed of 14.3 km/h (Noh et al., 2010). It is common to find research showing that pavement markings are effective in reducing driving speeds and traffic accidents.

2.2. Driving Speeds around Exit Ramps

The graph in Figure 1 represents the number of traffic accidents that occurred in expressways and ramps in South Korea. It shows that the total number of accidents tends to decrease while the accidents on ramps consistently increase.

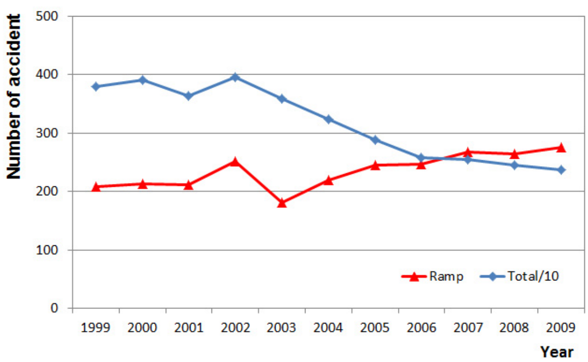


Fig. 1 A Trend of Expressway Traffic Accidents

The speed limit of the ramps can be as low as 40 km/h, while the speed limit of the main lane of an expressway ranges from 100-110 km/h. A big speed difference exists between the main lane and ramp.

In addition, the significant difference between the designated speeds and the actually measured speeds are proven. The results of the differences are summarized in Table 2. According to the table, an extremely minor percentage of drivers actually obey the speed limit on ramps, and the risks of having traffic accidents are almost always present due to the unregulated high driving speeds.

Especially true regarding loop ramps, the probability of a car derailment is very high if the driver approaches the ramp entrance with a main lane's driving speed. The disaster would be caused due to the extreme designated speed differences. To resolve such an issue, physical speed-reduction methods, such as anti-skid surfacing and grooving, had been used and expanded upon widely. However, these treatments require high installation costs and they also cause complaints from drivers because the surfaces are not completely even to the ground. This is why visual based speed-reduction treatments have been gaining attention recently.

Table 2. Designed vs. Measured Speed of Loop Ramps

Location	Designed Speed(km/h)	Measured Data	
		Tangent (km/h)	Curve (km/h)
Chungju Interchange	50.0	Average: 76.9 Violation: 99.2%	Average: 52.2 Violation: 88.3%
Yeoju Junction	40.0	Average: 74.9 Violation: 99.8%	Average: 55.6 Violation: 96.9%

3. THE EFFECT OF PAVEMENT MARKING SPEED REDUCTION TREATMENT

3.1. Installation

To analyze the effect of the pavement marking speed-reduction treatment, each loop ramp on the Chungju interchange and the Yeoju junction is chosen to install the Peripheral Transverse Line. Since no standards for domestic pavement marking speed-reduction treatments have been made yet, the treatment is only applied within a 100-meter range, from the beginning of a curve to the end of a curve as an experiment. Also, when determining an installation location, it is recommended to consider road geometries so the targeted driving speed can be maintained.

Table 3 summarizes the installed pavement marking speed-reduction treatment. The type of installation is referenced in a previous Peripheral Transverse Line (II) study (Noh, et al., 2010), where it was already partially proven to be effective.

The corresponding marking has been installed on an expressway for the first time. To determine whether there is a change, measurements of the traffic speeds are taken at one-minute intervals and collected 24 hours before the installation, as well as one month and five months after the installation. The data is collected by using portable equipment on the lane to measure the traffic volume and driving speeds with one minute intervals.

Chungju Interchange
(Slope: -4.6%, Radius: 80m, Design Speed: 50km/h)

Yeoju Junction
(Slope: -2.0%, Radius: 70m, Design Speed: 40km/h)

Fig. 2 Pavement Marking Speed-Reduction Treatment Installation Sites

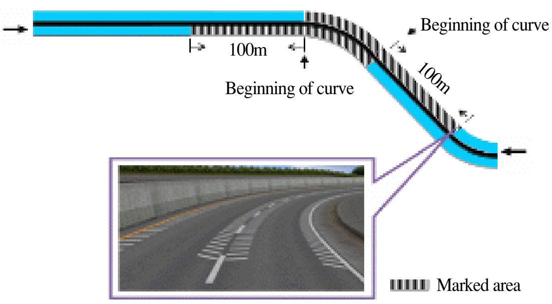


Fig. 3. Experimental Installation of the Marking

Table 3. Summary of Installation

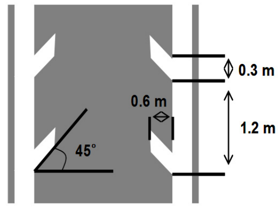
Type	Chungju Interchange	Yeoju Junction
Install	2009.12.4.-5	2009.11.25.-26
Design	 Length: 400m (Tangent 100m, Curve 300m) Pavement marking: Width 0.3m, Tilt 45˚, Pitch 1.2m	
Result	 Before	 After

Table 4. Driving Speed Data Collection Status

(unit: number of data)

Type	Chungju Interchange			Yeoju Junction		
	Dates	Tangent	Curve	Dates	Tangent	Curve
Total Number of Data [1]		3,072	3,054		2,011	1,851
Before Installation (Analysis 1)	'09.11.09-10	1,065	1,044	'09.11.17-18	649	571
1 month later (Analysis 2)	'10.01.13-14	964	961	'10.01.13-14	633	592
5 months later (Analysis 3)	'10.05.12-13	1,043	1,049	'10.05.12-13	729	688

3.2. Driving Speed Comparisons Before & After Installation

The average driving speeds in the two locations are summarized in the Table 5. The average driving speeds on the ramp's tangent section is compared before and after the installation. On the Chungju interchange, the average speed reduction after one month is 7.1 km/h, and the average speed reduction after five months is 6.4 km/h. On the Yeoju junction, average speeds are reduced by 2.2 km/h and 3.7 km/h after one month and five months, respectively.

The average driving speeds on the curve section are also

1) The number of samples which are collected from a tangent should be theoretically identical to that of a curve in a specific site. However they are usually not same in real world because of the driver's typical driving behaviors in curve section and the detector's unique mechanical errors.

compared before and after the installation. On the Chungju interchange, average speeds decrease by 4.3 km/h and 3.9 km/h after one month and five months, respectively. However, on the Yeoju junction, an increased speed of 5.1 km/h is observed one month after the installation, along with a 2.0 km/h reduced speed five months after the installation.

The increased average speed on the curve section in Yeoju one month after the installation seems contradictory to the objective of the treatment. At the same time, this result initiates further research on the treatment in three aspects: removing outliers from the collected speed data, collecting more data from the site, and considering additional test sites to reach more general conclusion.

What's more, when the driving speeds of a ramp's tangent and curve sections are compared, both Chungju interchange and Yeoju junction are measured to have decreased speed differences after the installation. Such phenomena can be considered positive from the safety perspective, since the speed variation is decreased when the drivers are passing through the ramps.

The 85th percentiles of the driving speeds and the changes made during certain time periods are also summarized in Table 5. Similar results to the results in average speed reductions are shown. However, the speed reductions by time (before and after the installation) are smaller than the average speed reductions. With the 85th percentile speed, we can reason that the motorists already familiar with the site didn't reduce their travel speed. On the contrary, the speed reductions by geometry (between tangent and curve) are always larger than the average speed reductions. This result partially explains that the motorists familiar with the site experience relatively large speed changes between the tangent and the curve.

Table 5. Speed Comparisons Before & After Installation

Location	Type	Average Speed (km/h)			85th Percentile Speed (km/h)		
		Tangent (D)	Curve (E)	Difference (E-D)	Tangent (D)	Curve (E)	Difference (E-D)
Chungju Interchange	Before Installation (A)	74.9	55.6	-19.4	83.7	61.2	-22.5
	1 month later (B)	67.9	51.3	-16.6	77.3	58.0	-19.3
	5 months later (C)	68.6	51.7	-16.9	80.4	58.7	-21.7
	B-A	-7.1	-4.3		-6.4	-3.2	
	C-A	-6.3	-3.9		-3.3	-2.5	
Yeoju Junction	Before Installation (A)	76.9	52.2	-24.7	88.5	61.2	-27.4
	1 month later (B)	74.6	57.3	-17.4	85.3	67.6	-17.7
	5 months later (C)	73.2	50.2	-23.1	87.0	60.4	-26.7
	B-A	-2.2	5.1		-3.2	6.4	
	C-A	-3.7	-2.0		-1.5	-0.8	

In Figure 4, the average driving speeds before and after the installation of the Peripheral Transverse Line on the curve section in Chungju interchange are plotted as a function of time. It can be seen that the driving speeds uniformly decreased compared with that of the speed before the installation. Next, further statistical analysis is performed to determine whether the speed differences are statistically significant.

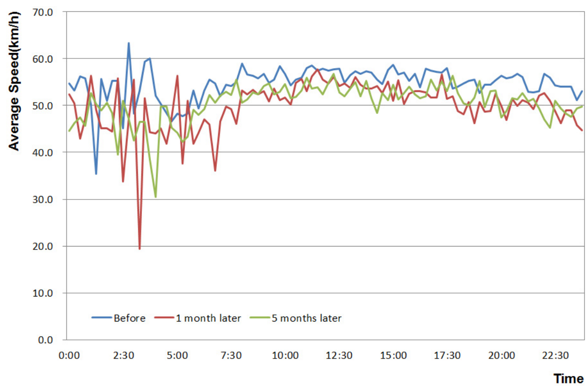


Fig. 4 The Change of Average Driving Speed on the Curve Section of Chungju Interchange[2)]

4. STATISTICAL VERIFICATIONS

4.1. Data and Analysis Method

Two different approaches are used to verify statistically the significance of the reduced speeds due to the installation of the marking. The first approach was to investigate statistically the speed reductions of both the tangent and the curve sections before and after the installation. The second approach was to determine whether the driving speeds on the tangent and the curve sections were actually reduced because of the installed countermeasure. With regard to the second approach, for the safety of the drivers, it is assumed that having smaller speed deviation between the two points are

2) It seems that the speed reduction from 0:00 to 6:00 in Figure 4 represents the low volume and the low speed of heavy vehicles which use expressway during night time to prevent themselves from terrible traffic congestions during daytime and to save total travel times and fuel.

advantageous.

To verify statistically the significance of the measured driving speed data, independent samples t-tests are performed. T-tests measure sets of samples independently. Independent samples t-tests are widely used to verify the average differences of the two independent sets of data when the user does not know if the distribution of the data has equal variance or not. This test can be useful when evaluating newly progressed projects to verify the influences or causes.

For the first approach, a t-test is performed a total of eight times for the tangents and the curves of Chungju interchange and Yeoju junction: between prior to the installation and one month after the installation; and between prior to the installation and five months after the installation. The tested sample sets are 'before the installation (A) and one month after the installation (B),' and 'before the installation (A) and five months after the installation (C).'

To verify statistically the significance of the speed differences between the tangent (D) and the curve (E) in the second approach, the independent samples t-tests are also performed. This t-test is performed a total of four times for the tangent (D) and curve (E) pairs of the Chungju interchange and the Yeoju junction. The tested sample sets are 'the differences before the installation (E-D) and the differences one month after the installation (E_1-D_1)' and 'the differences before the installation (E-D) and the differences five months after the installation (E_5-D_5)'.

4.2. Verification Result of a Speed Reduction Before & After Installation

Prior to inferring the test statistics of the independent samples t-test, a null hypothesis is first set up. Once the null hypothesis is rejected, and if the alternative hypothesis is selected, it can be considered that the measured driving speed difference is meaningful. The hypothesis is as follows:

$$H_0 : \mu_A - \mu_{B\ or\ C} = 0$$
$$H_1 : \mu_A - \mu_{B\ or\ C} \neq 0$$

After the hypothesis is established, it is usually necessary to do a normality test for small sample datasets. In this study, it is assumed that the datasets are normally distributed since the size of the datasets used in the statistical analyses was large enough.

However, using histograms and Quantile-Quantile normality plots (Q-Q plots), the normality of them was checked. The next step was to carry out F-tests to check the equal variances hypothesis of the two samples. According to the F-test results, one of two different statistics was chosen for the final t-tests.

Assuming the data has equal variances, the test statistic of the independent samples t-test is expressed in Equation 1.

$$t = \frac{\overline{X_1} - \overline{X_2}}{S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \sim t(n_1 + n_2 - 2) \qquad (1)$$

Where $\overline{X_i}$ is the average of the sample i, n_i is the number of the samples for i, and S_p is the corresponding random variable to the common variance S_p^2 within the confidence interval. The test statistic of the independent samples t-test is expressed in Equation 2 if the variance is treated unequally.

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \sim t(m) \qquad (2)$$

S_i^2 and m each represents the variance of the corresponding random variable and the degree of freedom within the confidence interval, respectively.

The independent samples t-test is performed using the data presented from Table 5, and the result is shown in Table 6. In all eight cases, the resulting p-values had less than the significance level ($\alpha = 0.05$), and the null hypothesis was rejected. As a result, the driving speed difference does statistically exist when the measured speed after the installation is compared with that of the speed prior to the installation.

However, the average driving speed on a curve section of Yeoju junction actually turned out to be increased by 5.1 km/h when the average speed was measured one month after an installation and compared with that of the speed before the installation. The preceding was an exception to this specific case, as all seven other average driving speeds are measured to consistently decrease after the installation of the marking.

To summarize the measured average speed reduction percentages, the curve section of the Chungju interchange driving speeds reduced by 9.5% one month after the installation and by 8.5% five months after the installation. For the tangent section of the Chungju interchange, speeds dropped by 7.7% one month after the installation and by 7.1% five months after the installation. In the case of the Yeoju junction, average speeds reduced by 2.9% after one month and by 4.8% after five months. For the Yeoju junction's tangent section, speeds increased by 9.8% after one month, while the speeds decreased by 3.9% after five months, leading to relatively 15% reduction in driving speed.

Table 6. Verification of Speed-Reduction Before & After Installation

Type			Average Speed				Null Hypothesis
			Diff.	STD	t	P	
Chungju Interchange	Tangent	A-B	7.09	0.45	15.87	.000	Reject
		A-C	6.36	0.45	14.08*	.000	Reject
	Curve	A-B	4.29	0.31	13.72	.000	Reject
		A-C	3.93	0.30	12.98	.000	Reject
Yeoju Jnction	Tangent	A-B	2.25	0.70	3.19*	.001	Reject
		A-C	3.68	0.67	5.54*	.000	Reject
	Curve	A-B	-5.10	0.67	-7.65*	.000	Reject
		A-C	2.03	0.58	3.49	.000	Reject

Note) Diff. = Before Installation - After Installation (Both Average Speeds)
A: Before Installation
B: 1 month after installation
C: 5 months after installation
*: Heteroscedasticity

4.3. Verification Result of Speed Differences between Tangent and Curve Sections

Along with a statistical analysis of the measured average speed differences, a statistical analysis is also performed on the different driving speeds on the tangent and the curve sections of the ramps. The hypothesis for independent samples t-test is as follows:

$$H_0 : \mu_{D-E} - \mu_{D_i - E_i} = 0$$
$$H_1 : \mu_{D-E} - \mu_{D_i - E_i} \neq 0$$

A null hypothesis stating that the average driving speed difference on the tangent (D) and the curve (E) section, before and after an installation, does not exist is the beginning setup to perform the t-test. The test result is shown in Table 7. It shows that the resulting p-values were smaller than the significance level (α=0.05), and the null hypothesis was rejected. As a result, the driving speed differences on both the tangent and the curve sections are statistically reduced when the measured speeds after installation are compared with that of the speed prior to the installation.

To summarize the measured average speed reduction percentages, on the Chungju interchange, speeds were reduced by 35.0% and 36.0% one month after and five months after the installation, respectively. For the Yeoju junction, speeds decrease by 28.8% and 8.6% one month after and five months after the installation, respectively.

Table 7. Verification of Speed Differences Between Tangent and Curve Sections

Type		Average				Null Hypothesis
		Diff.	STD	t	P	
Chungju Interchange	Before Ins.- 1 month later	9.30	0.81	11.53*	.000	Reject
	Before Ins.- 5 months later	9.56	0.82	11.65*	.000	Reject
Yeoju Jnction	Before Ins.- 1 month later	7.24	0.84	8.57	.000	Reject
	Before Ins.- 5 months later	2.17	0.75	2.88	.004	Reject

Note) 1. SPSS v.15.0 is used for the t-test verification
2. Difference (D-E) in Table 5 refers to the average speed difference on the straight and curved regions. However, the difference in Table 7 refers to individual speed difference averages.

5. CONCLUSIONS AND RECOMMENDATIONS

As previously mentioned, several loop ramps exist in South Korea, and most of them are considered to be accident-prone sections. Also, since speeding is regarded as one of the main factors of traffic accidents, various efforts are needed to reduce the average driving speeds on ramps.

In this study, the Peripheral Transverse Line, a pavement marking speed-reduction treatment which helps drivers voluntarily reduce the speeds of their cars, is installed on a highway to analyze its effect. As previously revealed from a simulation, the Peripheral Transverse Line is more effective in reducing driving speeds compared with other marking types. This was the first attempt to evaluate quantitatively the effect by implementing it on a highway.

For an experiment, we have decided to install it on the Chungju interchange and the Yeoju junction. The speeds of tangent and curve regions of ramps have been measured before installation, one month after the installation, and five months after the installation. By utilizing the collected data sets, the average reduced speeds and independent-samples t-test have been performed to statistically verify its significance. The result of this study is summarized as follows.

- For a straight region of the Chungju interchange, 7.1 km/h (-7.7%) of the average driving speed reduction is measured one month after an installation, and the speed is reduced by 6.4 km/h (-7.1%) five months after the installation.
- For a curve region of the Chungju interchange, 4.3 km/h (-9.5%) of the average driving speed reduction is measured one month after an installation, and the speed is reduced by3.9 km/h (-8.5%) five months after the installation.
- For a straight region of Yeoju junction, 2.2 km/h (-2.9%) of the average driving speed reduction is measured one month after an installation, and the speed is reduced by3.7 km/h (-4.8%) five months after the installation.
- For a curved region of the Yeoju junction, 5.1 km/h (9.8%) of the average driving speed measures an increase one month after an installation, however a speed of 2.0 km/h (-3.9%) is reduced five months after the installation.
- When the driving speeds of the tangent and the curve regions are compared with both the Chungju interchange and the Yeoju junction, it was found that 8.6%-36.0% of the average speeds were reduced by the installing pavement marking speed-reduction countermeasure.
- This result indicates that the average driving speed distribution coming from a tangent to a curve decreases. This can be considered a proper change by providing a safe driving environment.
- As various factors were tested for this study, the independent-samples t-test result verified the change of average driving speeds due to the speed-reduction treatment.

Since travel speed is not the only factor that influences traffic accidents, it is not meaningful to evaluate the changes in traffic accidents only at the sites with the installation of the countermeasure. However, it seems that there were drops in the numbers of traffic accidents at those particular sites. At the Chungju interchange, two traffic accidents occurred during two years just before the treatment (2008-2009), and only one traffic accident was reported during the two years after the installation (2010-2011). At the Yeoju junction, the change was clearer. Eleven traffic accidents occurred during two years (2008-2009), but the number dropped to five during the two years after the installation of the countermeasure (2010-2011). Based on these results, it would be worthwhile to accept the installation of the Peripheral Transverse Line as an effective countermeasure for traffic safety.

In this study, the limited data collection duration of 24 hours, before and after installation, is utilized. Therefore, more data needs to be collected in order to enhance and further confirm the analysis, along with more installation locations. In addition, pavement markings other than the Peripheral Transverse Line need to be experimented upon in order to verify the differences between various installed pavement markings.

Eventually, we believe that a better and safer driving environment will be the result if such a cost-effect countermeasure can be implemented and improved in the future.

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