Highway Design Speed and Its Impacts: Some Evidence in South Korea

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Abstract

In an effort to increase the operational efficiency of highways, South Korea has been increasing its design speed recently. However, the use of higher design speed will also increase construction costs. Moreover, increasing the design speed is expected to have an impact on safety. Hence, there is a strong need to demonstrate that the benefits outweigh the cost of having a higher design speed. This study surveyed a sample of design engineers to determine their awareness of the consequences of increasing design speed and their assessment of the right design speed for an actual rural arterial. In addition to the survey, a case study of three recently upgraded highways was conducted to determine the changes in traffic volumes, speeds, travel times, and safety.

Ⅰ. INTRODUCTION

Most drivers want to drive as fast as they safely can on a highway and this desire is expressed by the drivers′ choice of comfort speed. Besides driver′s characteristics like perceptual and cognitive abilities as well as personality, this speed is significantly influenced by the physical characteristics of the highway they are

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travelling on (Dewar and Olson, 2007; AASHTO, 2001; Tay et al, 2003, 2005, 2007, forthcoming). These roadway features include the radius of any curve, vertical grade, types of median, width of road, number of lanes, traffic signals, posted speed limit and roadside furniture. A driver′s actual speed, however, may be influenced by external factors including traffic characteristics such as volume, mean speed and vehicle composition which compel the driver to go faster or slower than the comfort speed. Therefore, the factors contributing to drivers′ speed choice are numerous and complex (WHO, 2004).

Among the types of factors contributing to speed choice, the physical characteristics of the highway are the most amenable to engineering treatment. For example, drivers can be induced to speed up on highways with more favourable geometrics and slow down on highways with poorer geometrics. Therefore, when designing a highway, engineers should understand the relationship between speed and highway geometrics. Hence, many nations around the world, including South Korea, have been adopting the concept of a highway design speed. The design speed approach had its origins in the United States in the 1930s with the assumption that the design speed is the maximum safe speed drivers would use under favourable roadway and environmental conditions (AASHTO, 2001, 2004). Most importantly, this concept allows highway engineers to predetermine and use a standard vehicle speed in designing the highway geometry. With a correctly chosen design speed, the highway geometry incorporated in the design should induce drivers to drive at the predetermined speed.

There are two main highway geometric design guides that are published by the Ministry of Construction and Transportation (MOCT, 2000a, b) that are widely used in South Korea. MOCT(2000b) is a supplemental highway design guide that is similar to MOCT (2000a) but focuses on the highway geometric design for the national highway. MOCT (2000a) guide is the primary standard which controls every highway geometric design aspect in South Korea and shares the same highway design speed concept as the American design guide (AASHTO, 2001). It utilizes highway functional classification as the key factor for determining the highway design speed.

Additional design factors considered, such as the terrain type and area type, are also similar to those in the AASHTO guide except the MOCT guide does not have rolling terrain in its terrain specification table. It should be noted that the classification of the terrain types into three categories, instead of two, has a bigger impact than initially thought. A South Korean research found that if the terrain type was mistakenly selected as flat, when rolling was correct choice, it could lead to the use of 20 km/h higher design speed (Shim & Choi, 2006). On the other hand, with three terrain types, a mistake in the terrain type selection would make a much lesser impact on the design speed selection. 〈Table 1〉 shows the design speed criteria used in South Korea. Note that the speeds shown are minimum values. Also, if topographical condition requires, values less than 20 km/h from the recommended speeds can be adopted.

〈Table 1〉 Highway Design Speed Table in South Korea

Classification		Design speed(km/h)		
		Rural		Urban
		Flat	Mounta-inous	
Freeway		120	100	100
Highway	Arterial	80	60	80
	Sub-arterial	70	50	60
	Collector	60	40	50
	Local	50	40	40

Ⅱ. RATIONALE AND OBJECTIVE OF STUDY

There are two possible reasons for engineers to select an inappropriate design speed. First, there is a chance that engineers may select an incorrect highway function and thus result in a higher design speed. Several factors must be considered in determining highway function and design speed, including trip purpose, length of travel, traffic volume, size and type of population centres, and network continuity (AASHTO, 2001, 2004;Garber & Hoel, 2002). It is often assumed that highway engineers are fully aware of the present and future values for these factors before attempting to determine the design speed for a highway. In reality, they are often not certain and thus errors are understandable.

Second, highway engineers face more uncertainties in the selection of these design variables because of different types of terrain and environment. Unfortunately, no clear technical guideline on these issues is available to highway engineers and different engineers may make different choices. This problem becomes pronounced when either the terrain type or the area type of the highway in design happens to lie in between different categories. Unintentionally, or sometimes intentionally in order to err on the side of caution, highway engineers select the higher design speed. As a result, depending on who does the job, the selected design speeds can vary, which is not desirable. As discussed above, this problem is exacerbated in South Korea by having only two terrain classifications instead of the three classes used in the United States.

The objective of this study is to discover the perceptions of engineers on the importance of selecting an appropriate highway design speeds and their perceptions on whether higher design speeds really provide better highway geometry and performances. To achieve the study objective, several tasks were performed in this study. First, a mail survey was conducted to collect information on highway engineers′ awareness of the various consequences of using higher design speeds in the design process. Second, pre and post data on geometric features and performances on several upgraded highways are gathered and analysed. Third, to see how the use of higher design speeds led to construction cost changes, highway cost data are collected and examined. Finally, some recommendations were made to improve the current design speed determination process.

Ⅲ. MAIL SURVEY

1. Survey and Sample

A simple questionnaire was developed to collect information from practicing highway engineers on their understanding of highway design speed. Since this study is exploratory in nature and asked about very well defined engineering concepts, no psychometric analysis was conducted on the instrument. The questionnaire was then mailed to 200 design engineers in South Korea. Sixty surveys out of 200 were returned, giving a response rate of 33%. Although this response rate is higher than most mail surveys (Mutabazi & Nanan 2006; Van Hemel & Rogers, 1998), care should be exercised in generalizing the results because the effect of non response bias is unknown. As expected, all the respondents are male engineers in their thirties or forties, and have more than 3 years of job experience in prominent engineering companies in South Korea. This profile is typical of transportation engineering since females are not well represented in the field in South Korea and seniority plays a very important in one′s career.

2. Design Speed and Geometric Designs

It is reasonable to expect that engineers in South Korea would normally use the MOCT design guide as the main reference for highway geometric designs. To check this assumption, a question on the most dominant geometric design standards used during the highway designing process is included in the questionnaire. As expected, all 60 respondents answered that they use the MOCT guide as the main reference for their highway geometric design works.

Respondents were also asked what they considered to be the most important element to consider in selecting design speed. Since the most important criterion listed in South Korean and other international design guides is highway function, it is not surprising that highway function is the selected by all respondents.

It should be noted that only two terrain types are available. South Korea and Japan are probably the only two countries that do no have three terrain types because their topographies are mountainous and rolling terrain is very rare. Nonetheless, respondents are asked "Does having only two terrain types actually facilitate the designing process, or does it leave a gap in design speed selection process?" All of the respondents answered that the use of only two terrain types actually facilitate highway design process and they were not aware of any problems in using only two types of terrain.

As discussed earlier, the main role of design speed is to determine the geometric features of the highway and we would like to confirm this assumption is in fact the practice. On the question of what they considered to be the basic function of the highway design speed, the majority (78%) of the respondents answered that its basic function is for designing the geometric features of a highway.

3. Perceived Impacts of Design Speed

Also, the research team wanted to gather information on the engineers′ perceptions of the consequences of using higher design speeds. Engineers were asked to rank a set of 10 highway geometric elements that will be significantly changed by using a higher design speed. 〈Table 2〉 shows the 10 elements provided in the survey. The impact of each element was ranked from 1 = "least impact" to 10 = "most impact".

As shown in 〈Table 2〉, the survey results showed that the engineers surveyed thought that minimum curve radius is the design element to be changed most significantly when higher design speeds are adopted. This result is expected and clearly reflects the bias in a design engineer′s background and training

〈Table 2〉 Perceived Impacts of Design Speeds

Design Elements Affected	Total Score	Mean Score	10-pt Response
Minimum Radius	546	9.10	32
Operating Speed	481	8.02	27
Maximum Grade	447	7.45	4
Sight Distance	377	6.28	4
Super-elevation	331	5.52	4
Reduction in Travel Time	292	4.87	0
Cross Section	290	4.83	4
Reduction in Accident	288	4.80	4
Side Friction Factor	266	4.43	4
Construction Cost	156	2.60	3

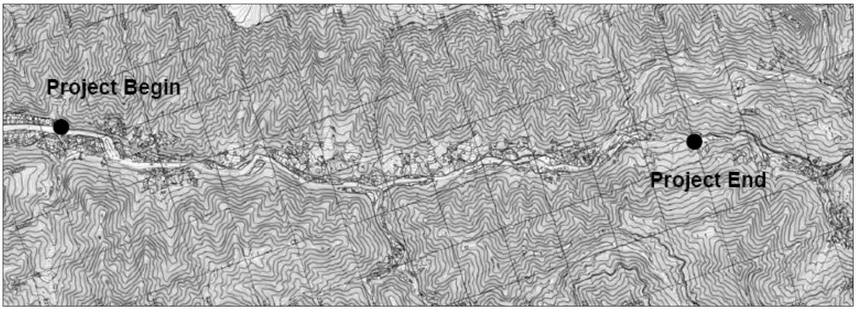
as compared to a planner, traffic psychologist or transport economist. It also has the largest number of 10-point response (greatest impact). Operating speed was clearly their second choice, with a mean of 8.02 and the second largest number of 10-pt response. The other elements with a mean score that is above 5 (median of 10 ranks) are vertical grade, sight distance and superelevation.

Interestingly, the reduction in travel time received only a moderate ranking (mean = 4.87) but operating speed received a much higher ranking (mean = 8.02) because the two elements are very closely related. This inconsistency in perception again reflects the bias in a typical design engineer′s background and training as well as their job focus. Elements with moderate ranking are cross section, reduction in accident and side friction. The moderately low mean rating for reduction in accident is somewhat surprising because it is often the basis for the public demand for the upgrading of highways in many western countries, especially in the rural areas. Another surprising result is the very mean low ranking on the impact of design speed on construction cost (mean = 2.60). This result reflects the clear separation of the design function from the planning, construction and management functions.

4. Choice of Design Speed

Finally, to check if the selection of design speeds might be dependent on the individual engineer′s preferences, a sample site was provided in the survey and engineers were asked about their choice of design speed. The sample site is a real location in South Korea and it used to have a 60 km/h design speed but was upgraded to a rural arterial road with a 80 km/h design speed. For this quick test, the research team provided the respondents with the information that this road is a national road, has four lanes and average daily traffic of 6,000 vehicles. A map of the location, shown in 〈Figure 1〉, was also provided.

Theoretically, if the current design speed determination process has a high degree of reliability, then only one value should be adopted by all the respondents. The results showed that the majority of the respondents (78%) selected a lower design speed of 60 or 70 km/h but a relative large minority (22%) adopted a higher design speed of 80, 90 or 100 km/h. This result reveals that, in spite of the existence of a national highway design standard for determining the design speed, there appears to be differences in understanding and choice of this important design parameter. Part of the difference may be the result of individual engineer′s preference and his understanding of the terrain type and traffic patterns and how these factors influence the design speed. It also



〈Figure 1〉 Sample Site for Design Speed Selection reflects the fact that the MOCT guide serves only as a guide and not as a standard or regulation and different companies may have different practices or experiences from which the design engineers draw from.

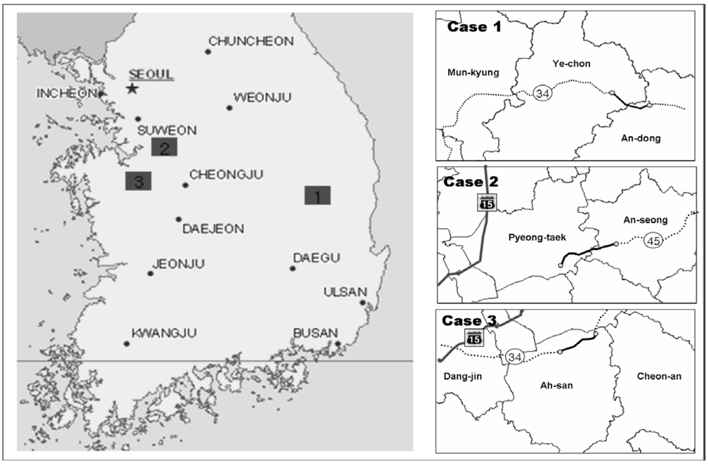
5. Additional Comments

At the end of the survey, engineers were asked to provide any additional comments or suggestions for improving the current design speed determination process. One comment is that the upgrading of highway geometric features and the use of higher design speeds was unavoidable to keep up with rapid development in automobile technologies and speed. Also, there are some concerns that the use of higher design speeds will lead to an increase in the number and severity of traffic accidents.

Ⅳ. CASE STUDY

The main purpose of the case study is to gather some information on three questions:

- How did the higher design speed affect highway geometrics and eventually the highway performances such as travel time and crash occurrences?
- How much did it cost to upgrade the highways to the higher design speed?
- What are the implications for the current design speed determination procedure?Their topographical and traffic conditions are summarized as follows.
- Site 1 (National Road 34, Yechon-Poongsan): Total length is 13.3 km it has a level terrain with less than 400 m elevation; it runs in the east-west direction and is connected to one city; its ADT was reported to be 8,945 vehicles per day before the upgrade
- Site 2 (National Road 45, Pyongtak-Edong): Total length is



〈Figure 2〉 Locations of Highways in Case Study

20.0 km; it has a level terrain with some vertical slopes at some places; it connects two cities and is close to the capital city of Seoul; its ADT was 10,303 vehicles per day before upgrading; it has an easy access to a freeway

- Site 3 (National Road 34, Youngin-Doonpo): Total length is 15.5 km; it has a level terrain; it connects two medium size cities; its ADT was 11,752 vehicles per day before the upgrade; it has an easy access to a freeway

1. Travel Time Changes

As evident from 〈Table 3〉, travel speeds before the upgrading

〈Table 3〉 Changes in Traffic Characteristics

		Volume (vehicles/day)	Length (km)	Speed (km/h)	Travel Time (min)
Case 1	Before	13,074	13.7	66.2	12.4
	After	8,945	13.3	77.4	10.3
Case 2	Before	10,303	20.2	67.4	17.9
	After	11,635	20.0	81.7	14.7
Case 3	Before	11,752	15.9	64.2	14.8
	After	11,211	15.5	75.1	12.3

were 66.2 km/h, 67.4 and 64.2 km/h for the three cases, which were a few km/h above the design speed and posted speed limit of 60 km/h. After the highways were upgraded, the operating speeds were increased to 77.4 km/h, 81.7 km/h and 75.1km/h respectively. These results suggest that travel speed increases are relatively high but they certainly are not as high as expected (based on the before cases) since the design speed and posted speed limit are now 80 km/h. Interestingly, two of the three highways experienced a substantial increase in traffic volume whereas one experienced a slight decrease in traffic volume since they have been upgraded. Finally, the lengths of all three highways have been shortened slightly due to the straightening and levelling of roads at some locations to improve both the horizontal and vertical alignments in anticipation of higher operating speed.

2. Impacts on Accidents

Again, according to the mail survey results listed in 〈Table 4〉, engineers have some expectations of a reduction in traffic accidents with the use of higher design speeds although its ranking was somewhat lower than expected. Nonetheless, this research conducted a quick check on the safety aspects of using a higher design speed.

〈Table 4〉 Traffic Accidents per Year for the Case Study Sites

		Accidents per year				Casualties per year			
		Total	Fatal	Injured	PDO	Total	Fatal	Major	Minor
Case 1	Before	6	0.75	3.5	1.75	8.25	0.75	3	4.5
	After	5	0.5	3.5	1	6	0.5	3.5	2
Case 2	Before	4.4	0.4	3.8	0.2	10.4	0.4	6.4	3.6
	After	5	1	1	3	4	1.0	2	1
Case 3	Before	6	0.2	4.2	1.6	8.6	0.2	4.4	4
	After	2	0	2	0	3	0	3	0

3. Changes in Highway Geometrics

It is clear from the results reported in 〈Table 5〉 that fewer horizontal curves are used with an increase in the higher design speed, and the curves retained have also became flatter. It should be noted that the 400 m curve radius is rarely used and no curve with less than 200 m radius is used in the upgraded highways with a higher design speed. Similarly, in the vertical alignment design, milder vertical slopes, with 5% maximum grade, are adopted with a higher design speed.

〈Table 5〉 Changes in Highway Alignments

		Case 1		Case 2		Case 3		Total	
		Before	After	Before	After	Before	After	Before	After
Radii (m)	0<R<200	1	0	2	0	6	0	9	0
	200<R<400	2	1	10	0	13	1	25	2
	400<R<600	3	5	8	1	2	2	13	8
	600<R<800	1	4	4	1	3	1	8	6
	R>800	1	5	3	10	1	6	5	21
Slopes (%)	0<S<5	36	14	15	20	21	24	72	58
	3<S<5	6	1	3	2	0	1	9	4
	S>5	2	0	1	0	2	0	5	0

4. Construction Cost Changes

The construction cost data were collected by visiting each government offices responsible for the upgrades and the estimated costs provided are summarized in 〈Table 6〉.

The highest construction cost recorded is over US$16m/km in Case 1 and a lower value of US$8-9m/km is reported for Cases 2 and 3. By individual cost item analysis, Case 1 and 3 were reported to involve more earth work to improve the horizontal and vertical alignments. Although the earth work cost for Case 2 is still very large, it is not as substantial in percentage because it incurred a large amount of land acquisition cost due to its location in the vicinity of Seoul. In all three cases, the bridge construction

〈Table 6〉 Construction Costs of Upgrades

	Case 1		Case 2		Case 3	
	US$ m	%	US$ m	%	US$ m	%
Earth Work	29.42	27.3	45.32	13.8	41.83	30.1
Drainage	11.26	10.5	17.34	5.3	13.36	9.6
Pavement	14.61	3.6	22.51	6.9	18.96	13.6
Bridges	24.01	22.3	85.14	26.0	40.73	29.3
Tunnels	9.13	8.5	26.78	8.2	-	-
Fringe Cost	9.79	9.1	21.82	6.7	12.72	9.1
Land Acquisition	4.32	4.0	93.00	28.4	4.89	3.5
Others	5.13	4.8	15.59	4.8	6.62	4.8
Total Cost	107.66	100.0	327.49	100.0	139.11	100.0

cost is significant due to the need to improve the horizontal and vertical alignments.

Ⅴ. PROPOSED REVISIONS TO THE CURRENT PROCEDURE

- Engineers in our mail survey perceived the minimum curve radius as the design element to be the most affected, and construction cost to the element to be the least affected, when a higher design speed is adopted.
- In spite of the existence of a national highway design standard for determining the design speed, there appear to be substantial differences in engineers″ choice of the design speed for a sample site. Our simple test case used in the mail survey resulted in choices that ranged from 60 km/h to 100 km/h.
- In spite of a upgrading to increase the design speed by 20 km/h in three highways, the operating speeds have increased by only 10-14 km/h. Therefore, it should also be cautioned that too much emphasis in terms of the expected benefits of a speed increase with higher design speeds should be avoided until its impact on safety and construction costs are better understood.

Based on the research findings, the following changes are recommended to improve the current South Korean design speed determination process:

- Three types of terrain classification instead of two should be adopted.
- Design speeds should be given in ranges in stead of one minimum value.
- More specific design designations like the ones used in Canada should be adopted.
- The range in the design speeds for two lane highways should be increased substantially.

Ⅵ. FINDINGS AND CONCLUSION

This research aims to discover engineers′ perceptions about the impacts of higher design speed and whether higher design speeds really provide better highway geometry and performances. To this end, several tasks including a mail survey, a comparison of the pre and post data on geometric features, and a performances analysis on several upgraded highways were done. Also, to see how the use of higher design speeds led to construction cost changes, highway cost data were examined. Based on the exploratory results obtained, we found that the use of higher design speeds did not necessarily contributed to an increase in highway user benefits such as increase use (traffic volume), travel time savings and accident reductions. Therefore, it is recommended that for future highway upgrading projects, especially in the adoption of higher design speeds, each highway section selected should be subjected to a more thorough evaluation of the expected costs and benefits.

Ⅶ. Acknowledgements

This work is a part of a research project supported by Korea Ministry of Land, Transport and Maritime Affairs(MLTM) through

Eco-intelligent Road Design Research Center(ERDRC). The authors wish to express their gratitude for the financial support.

REFERENCES

1. AASHTO (2001), A Policy on Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials, Washington D.C.
2. AASHTO (2004), A Guide for Achieving Flexibility in Highway Design, American Association of State Highway and Transportation Officials, Washington D.C.
3. Alberta Transportation (1999), Highway Geometric Design Guide, Alberta Transportation, Edmonton, Alberta.
4. Garber, N. & L. Hoel, 2002, Traffic and Highway Engineering, Wadsworth.
5. Kim, S. Y. and Choi, J. S. (2005), A Study on Context Sensitive Highway Design Based On Improved Operating Speed Prediction Methods in National Roads, Journal of Korean Society of Transportation, Vol.23 No.7, pp.17～33.
6. Lamm, R., B. Psarianos, and T. Mailaender (1999), Highway Design and Traffic Safety Engineering Handbook, McGrraw Hill.
7. McLean J.R. and Morrall John (1995), 'Changes in Horizontal Alignment Design Standards in Australia and Canada', International Symposium on Highway Geometric Design, Boston, Massachusetts.
8. MOCT (1999), A Study for Classification Functional Role and Efficient Investment Method for National Roads, Ministry Of Construction and Transportation, the Republic of Korea.
9. MOCT (2000a), Highway Geometric Design Standards and Regulation, Ministry Of Construction and Transportation, Republic of Korea.
10. MOCT (2000b), Route Selection and Geometric Design Standards for National Roads, Ministry Of Construction and Transportation, Republic of Korea.
11. Mutabazi, M. & Nanan K. (2006), Trinidad Motorists Understanding Zebra Pedestrian Crossing, TRB 2006 Annual Meeting, CD-ROM.
12. Shim, J.I (2004), Traffic Accident Cost Analysis in South Korea, Korea Transportation Institute, Seoul, South Korea.
13. Shim, K. B. and Choi, J. S. (2006), Evaluation of the Highway Design Speed Determination Process Using Case Studies: Reclassifying

Function and Terrain Types, Journal of Korean Society of Transportation, Vol.24 No.2, pp.101~112.
14. Tay, R., Champness, P. and Watson B. (2003), Personality and Speeding: Some Policy Implications, Journal of the International Association of Traffic and Safety Sciences, 27(1), pp.1~7.
15. Tay, R. (2005), The Effectiveness of Enforcement and Publicity Campaigns on Serious Crashes Involving Young Male Drivers: Are Drink Driving and Speeding Similar? Accident Analysis and Prevention, 37(5), pp.922~929.
16. Tay, R. & Churchill, A. (2007), The Effects of Different Types of Barriers on Traffic Speed, Canadian Journal of Transportation, 1(1), pp.56~66.
17. Tay, R. (forthcoming), Speed Compliance in School and Playground Zones, ITE Journal.
18. Van Hemel, S. B. and W. C. Rogers. (1998), Survey of Truck Drivers' Knowledge and Beliefs Regarding Driver Fatigue, Transportation Research Record, 1640, pp.65~73.

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