Speeding has been reported as one of the major causes for fatal traffic accidents in Korea. The resolution against this dangerous speeding comes to make the Automated Speed Enforcement (ASE) system an enforcement tool. Since April 1997, the Korean National Police Agency (NPA) has installed more than 1,000 ASE systems at a number of road sections in Korea. They aim to lower the number of speeding violations and thus reduce the severity of road accidents especially the number of deaths. The purpose of this paper is to describe the experience of Korean ASE systems, focusing on the impacts of fixed-type ASE systems on traffic speed characteristics and on the overall safety of roads. The experience in Korea shows that introduction of massive ASE systems has been very successful in terms of reducing, not only fatal accidents, but also driver incompiliances with speed limits. Some important findings are summarized as follows:

1) ASE systems in Korea prove to reduce means and variances of vehicle speeds. A recent public attitude survey indicated that more than 70% of Korean drivers reduced driving speeds by at least 5km/h after the introduction of ASE systems.

2) It was found that means and variances of speeds change due to speed cameras and decreased fatalities by about 40% to 80% in 2km of the camera influence area.

3) It was found that, in terms of camera location, fixed-type ASE systems were the most effective in reducing accidents when it was installed at the upstream of curves or downgrade sections.

4) It was also found that well designed advanced warning signs of fixed-type speed cameras have a great potential for early speed reduction in advance to the camera site. They also reduce drivers’ complaints.

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Fatalities from traffic accidents constitute one of the major public health issues as well as safety issues in Korea. Since 1988, Korea has experienced over 10,000 fatalties and 300,000 injuries annually on its roads\(^1\). “Speeding” – refers to instances when vehicles travel in excess of legally declared speed limits or any inapropriate speeding on roads – is regarded as one of the biggest road safety issues in Korea today. While thousands of people are killed or injured on the roads, the other people admit to enjoying driving fast on the roads, which reflect widespread tolerance of speeding as an acceptable social behavior. The severity of injuries resulting from an accident is directly related to the pre-accident speed of the vehicle, whether or not speeding was a factor in the accident.

In an attempt to increase drivers’ compliance to posted speed limits, the Korean National Police Agency (NPA) started to operate Automated Speed Enforcement (ASE) systems initially at 41 fixed sites with 5 local centers throughout the nation in April 1997. These systems are of particular interest, not only because of their potential to reduce police labor in speed enforcement but also because of their potential to enhance traffic safety. The total number of fixed-type ASE systems has been remarkably increased to 1,375 with 13 local centers by the end of 2002. According to NPA, the number is expected to reach 2,800 by 2003 and 5,000 by 2006. It is likely that Korea may be one of the most active countries using ASE systems for traffic law enforcement.

Over the past few decades, a number of studies have been conducted on the effects of speed cameras on traffic speed characteristics and traffic accidents. A famous study examined the effect of speed cameras introduced on a dangerous downgrade section of a German autobahn by Lam and Kloeckner\(^2\). Several studies that examined the use of speed cameras in England\(^3,4\) showed that the introduction of fixed speed camera sites resulted in a reduction of fatal accidents and mean speeds. An intensive review of the international literature on speed cameras can be found elsewhere\(^5\).

It has been reported that ASE systems helped to prevent not only speeding but speeding related accidents on Korean highways. However, the specific mechanism
responsible for these phenomena is still not clear.

The purpose of this study was to investigate the impact of Korean ASE systems on traffic speed characteristics and traffic accidents. The remainder of the sections is set out as follows: Section 2 describes details of Korean ASE systems. The analysis of results of the effects of ASE systems in terms of speed characteristics and safety are given in Section 3 and 4 respectively. Section 5 describes survey results of public attitude. Conclusions are provided in the final section, Section 6.

2.1 System descriptions

Fixed-type ASE systems in Korea provide functions of speed measurement, plate number identification, communication, and printing photograph and enforcement data automatically. It consists of a local system and central system.

The local system, which will be also called a speed camera hereafter, consists of a speed detection device (inductance loop or piezo), a digital image capturing device, a processing unit, and a communication device. The speed detection device measures speeds of each incoming vehicle using double loop or piezo sensors, and feeds the data to the processing unit. When the measured speed exceeds the predetermined threshold value the digital camera with 1 million resolution captures the image of the vehicle and the driver. Most cameras were set to enforce vehicles traveling at greater than 120 percent of the posted speed limit. The processing device automatically identifies the plate number of the speeding vehicle from the image. The communication device sends the image and the identified plate number to the local center via 56kbps dedicated telephone lines.

The obtained information is used to identify the owner of the vehicle at the local center referring database which is managed at National Police headquarters. After the identification, an infringement notification paper is automatically printed out and then mailed to the registered owner of the vehicle.

Korean NPA introduced a total 853 fixed-type ASE systems and 821 mobile-type ASE systems from 1997 to 2001. There was agreement that ASE systems had the following advantages over traditional enforcement:

1) have a higher deterrence effect because they increase road users’ perceptions of the risk of getting caught;
2) increase fairness of enforcement;
3) provide more efficiency in ticketing and payment process; and
4) allow safer and more efficient enforcement duties by police.

Those advantages along with safety improvement led to the Korean NPA deciding on a significant expansion of ASE systems. The number is expected to reach 5,000 by the year of 2006.

2.2 Camera site selection criteria

The aims of ASE systems are not only to reduce fatal accidents related to speeding but also to change drivers’ speeding behavior. The speed control strategies for fixed-type ASE systems are first to reduce the proportion of speeding vehicles on hazardous road sections, and second to increase the distance that is influenced by camera. Among the various indicators, the most important one of speeding may be the number of fatal accidents caused by speeding. Therefore, speed cameras were primarily placed on stretches of road with a record of speeding-related accidents. It is also important to consider several other factors. The following criteria were developed and recommended to select candidate speed camera sites:

1) speeding black spots;
2) upstream of the origin of a sharp curve section;
3) in downgrade section;
4) upstream of crosswalk or signalized intersections; and
5) upstream of heavy lane changing sections such as entrance ramp, weaving section.

The primary considerations given in the site selection stage were first to reduce average speeds in advance to possible dangerous sections, and second to reduce the speed difference between competing traffic streams. In statistical terms, the goal of ASE systems is to reduce average speeds and speed variances at/before dangerous road sections. After considerable argument, it was recommended to install two advanced camera warning signs before 500m and 1.0km of the camera site, to introduce early and smooth reducing of speeds. These also helped to reduce the complaints of drivers.

2.3 System operations

The traditional approach in speed enforcement is to catch or punish the speeding driver at the site where the speeding offence occurred. Compared to this, the success of ASE systems requires the following factors before punishment: the perceived certainty, the severity, and the fast
punishment. Successful achievement was possible by systematic maintenance works, multi-level fines, and fully automated process. The punishments against speeding drivers were set at three levels: 30,000 won (1 US$ = 1,200 Korean won) for drivers exceeding by less than 20km/h for posted speed limits, 60,000 won plus 15 penalty points for drivers exceeding by 21 to 40km/h, 100,000 won plus 30 penalty points for drivers exceeding by 41km/h. To allow quick punishment, drivers receive fine notifications in 1 to 2 weeks by mail. Korean NPA issued nearly 10 million citations in 2001. In 2001, the average number of citations issued by each speed camera was reported as 10 per day by a fixed-type while 63 citations per day by a mobile-type.

One of the notable features of Korean fixed-type ASE systems is the effectiveness of speed camera warning signs. If the speed enforcement is first initiated without any warning signs, speeds of vehicles near the camera site decrease abruptly. This might cause other hazardous conditions. Since the objective of automatic control is to prevent people from speeding rather than to increase the risk of being captured, drivers are informed of enforcement areas by road signs at 1km and 500m ahead of the camera site. An effective variation in the Korean speed camera program was to use hidden cameras – without warning – rather than visible ones. Hidden cameras – fixed-type without warning signs or mobile-types that take a picture in advance of 100 meters – have the potential to reduce the predictability of the cameras and hence have more generalized effects. Since a mobile-type camera is more difficult to detect by drivers, it is inferred to apply more pressure to drivers.

3.1 Changes of speeding statistics as an accident cause

Before we turn to the detailed discussion on the impact of speed cameras on traffic speed, it will be useful to investigate the recent trend of speeding as a primary accident cause in Korean expressways which have speed limits that range from 100 to 110km/h. Figure 1 presents annual changes in the percentage of speeding as a primary accident cause on Korean expressways. According to the accident statistics by the Korea Highway Corporation, speeding causes about 30% of accidents on Korean expressways. Figure 1 shows that the percentage of speeding as a major accident cause rose consistently from 20% in 1992 to 33% in 1997. The rise continued until it reached 33% in 1997.

Korean NPA started a national campaign to reduce speeding in 1998. The main strategy to reduce the number of drivers traveling at excess speeds on expressway systems was the introduction of ASE systems. The first 8 fixed-type ASE systems were installed on expressways in late 1997. The total number of fixed-type speed cameras has been continuously increased to 47 in the year 2000, and 75 in the year 2001. Furthermore, 36 mobile-type speed cameras were introduced in 1998 and had been extensively used. We observed the clear downward trend in percentage of speeding as a primary accident cause after 1997. The percentage fell from 33% in 1997 to 25% in 2000. The percentage of speeding trend decreased by an average of 3.0% per year. We have a close negative correlation between the number of speed cameras and percentage of speeding as a primary accident cause. Although there were no more scientific studies about this situation, it may be reasonable to infer that ASE systems contribute to reducing the percentage of speeding and speeding related accidents on Korean expressways.

3.2 Impact on speed distribution at Jayuro highway

Our first question was how vehicles approaching a speed camera change their speeds depending on the distances from speed camera sites. The 4.0km section of the Jayuro highway shown in Figure 2, that have 80km/h of the speed limit, was known as an accident black section caused by speeding and abrupt lane change due to entrance ramp in the middle of the section. A total of 17 accidents and 15 fatalities were reported during an 8 month period in 1995. To relieve this problem, two speed enforcement cameras were installed in 1997.

In order to investigate speed changes depending on the distances from speed camera sites, sample vehicle speeds were collected using video cameras at 10 sites
CHANGES OF SPEED AND SAFETY BY AUTOMATED SPEED ENFORCEMENT SYSTEMS J.-G. KANG

along a 4.0km section. Figure 2 depicts the geometry of the highway section and 10 speed data collection sites with distances from the origin. Two cameras are located at site 3 and site 9 respectively. Table 1 summarizes calculated means and variances of speeds. Also given are calculated 85th percentile speeds at 10 observation sites. A number of important points are evident from the data in Figure 3 and Table 1. First, the mean speed values measured upstream or downstream of the speed camera sites were consistently higher than those measured at the camera sites itself. Upon approaching a camera, speeding vehicles reduced their travel speeds to the level of the posted speed limit or slightly below, and then accelerated after passing the camera site. Further, the variances of sample speeds which were far from camera sites were consistently higher than those measured near camera sites.

The installation of 2 fixed-type speed cameras on a dangerous section of Jayuro highway resulted in significant safety enhancement: no deaths and 5 accidents were reported in 1998. The observation on the section with warning signs and speed cameras indicated that drivers start to decelerate as soon as they see the warning signs. This observation contributed to being aware that warning signs for a speed camera had significant influences on the increase of speed reduction zone.

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Distance from site (m)</th>
<th>Mean Speed (km/h)</th>
<th>Variance</th>
<th>85th</th>
<th>95th</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0</td>
<td>78</td>
<td>149</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td>8</td>
<td>150</td>
<td>64</td>
<td>102</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>9</td>
<td>250</td>
<td>74</td>
<td>135</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>10</td>
<td>750</td>
<td>82</td>
<td>153</td>
<td>93.6</td>
<td>93.6</td>
</tr>
<tr>
<td>11</td>
<td>1,250</td>
<td>82</td>
<td>333</td>
<td>99.7</td>
<td>99.7</td>
</tr>
<tr>
<td>12</td>
<td>2,750</td>
<td>83</td>
<td>207</td>
<td>99.7</td>
<td>99.7</td>
</tr>
<tr>
<td>13</td>
<td>3,060</td>
<td>79</td>
<td>129</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td>14</td>
<td>3,210</td>
<td>70</td>
<td>87</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>15</td>
<td>3,310</td>
<td>68</td>
<td>120</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>16</td>
<td>3,810</td>
<td>74</td>
<td>91</td>
<td>81</td>
<td>81</td>
</tr>
</tbody>
</table>

3.3 Speed comparison: with-and-without camera groups

It is well known that the introduction of speed cameras caused long term mean speed reduction effect. The same effect was observed in Korea. However, it is arguable that the other conditions might be different during the period of before and after speed camera introduction. It was decided to investigate the immediate effect of speed cameras on traffic speeds via with-and-without study.

The 45km long Jungbu-2 expressway line was open to the public in October 2001. The speed limit of 110km/h is the highest one among 25 expressways in Korea. Two fixed-type speed cameras were installed on April 12, 2002. A speed camera site located 17.17km from the origin was selected as a with-and-without speed comparison site. Two groups of speed data during with- and without-camera period were collected on April 2, 2002 and on May 21, 2002 respectively. Fifteen minute average speed data for each day were available from the loop detector station near the target speed camera site. The raw data were converted to produce a 1 hour average speed. We see from Figure 4 that hourly speeds of group 2 are consistently lower than those of group 1. The daily average speed dropped 9.5km/h from 98.5km/h of group 1 to 89.0km/h of group 2.

More specific discussions are possible from distributions of speeds. Two groups of speed data during the before and after periods were collected on April 2–4, 2002 and on May 21–23, 2002 respectively. Figure 5 shows speed distributions for with-and-without camera periods, where the axis of ordinates is the percent of observed speeds and the axis of abscissas is the 5 minute average speed. The average speed dropped 4.9km/h from 96.5km/h of without-camera group to 91.6km/h of the
with-camera group. This reduction was associated with a significant decrease in the spread of speeds. The variances were reduced from 26.3 to 8.6.

4.1 Before-and-after accident data comparison

To evaluate the impact of the ASE systems on accident reductions, three before-and-after accident data comparisons are given. Accident data was obtained on 2km road sections, where each camera site located in the middle of each section, were collected and compared. The results are as follows:

1) The introduction of 32 fixed speed cameras nationwide in 1997 resulted in a 60% reduction from 107 to 43 in deaths, and 28% from 801 to 576 in the number of accidents;
2) The introduction of 100 fixed speed cameras nationwide in 1998 resulted in a 37.7% reduction in deaths from 151 to 94, and 23.5% in the number of accidents from 2,645 to 2,023;
3) A recent introduction of 43 fixed speed cameras in Chungcheong-namdo Province in 2001 resulted in an 85.7% reduction in deaths from 21 to 3, and 37.2% in the number of accidents from 384 to 241.

4.2 Performance of speed cameras by road geometry

It is very true that the road geometry is an important factor on safety. In order to evaluate the accident reduction effect of the ASE systems by various road geometries, two years of accident data before-and-after installation were collected from 15 camera sites. The 15 camera sites are categorized into three geometry type groups: straight section, curved section, downgrade section. The analysis in Table 2 is summarized as follows:

1) The cameras at straight sections resulted in a 20% reduction in fatalities and 39.1% reduction in the number of accidents;
2) The cameras at the beginning of curved sections resulted in an 82.4% reduction in fatalities and 15.6% reduction in the number of accidents;
3) The cameras at downgrade sections recorded a 100% reduction in fatalities and 8.8% reduction in the number of accidents.

<table>
<thead>
<tr>
<th>Road Type</th>
<th>Straight</th>
<th>Curved</th>
<th>Downgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>No. of Crashes</td>
<td>No. of Crashes</td>
<td>No. of Crashes</td>
</tr>
<tr>
<td>Before</td>
<td>128</td>
<td>5</td>
<td>77</td>
</tr>
<tr>
<td>After</td>
<td>78</td>
<td>4</td>
<td>65</td>
</tr>
<tr>
<td>%</td>
<td>▼39.1</td>
<td>▼20.0</td>
<td>▼15.6</td>
</tr>
</tbody>
</table>

4.3 Effect of speed cameras on curved sections

Speeds on curved sections depend on how early the driver perceives a curve before entering it. Usually many accidents occur on curves and these are due to inappropriate speed on curves. This is more so at night. Sometimes drivers underestimate the curvature before entering the curve. Although various countermeasures including warning and speed limit signs are useful to improve drivers’ accuracy of speed estimation on curves, sometimes it fails. It is now clear from Table 2 that installation of a speed camera enhances safety on curved sections. However, it is not clear on what specific location a camera works best. We compared two camera location groups. One at the upstream of the curve and the other in the middle of the curve. As can be seen in Table 3, the cam-
era installed at the upstream of a curve was more effective in reducing accidents than located at the curve itself.

<table>
<thead>
<tr>
<th>Before Curve</th>
<th>At Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Accidents</td>
<td>Deaths</td>
</tr>
<tr>
<td>Before</td>
<td>57</td>
</tr>
<tr>
<td>After</td>
<td>44</td>
</tr>
<tr>
<td>%</td>
<td>▼22.8</td>
</tr>
</tbody>
</table>

4.4 Effects of speed cameras on downgrade sections

There exist an over-representation of accidents on graded sections of road compared to flat sections. These are due to the increase of vehicle speeds on downgrade sections, which may lead to a driver losing control. Table 2 indicates that installation of a speed camera at a downgrade section enhanced the safety. However, it is not clear on what specific location a camera works the best. We compared two camera location groups. One at the upper part of the downgrade section and the other at the lower part of the section. Table 4 shows that the camera installed at upper part of downgrade section was much more effective in reducing accidents than that installed at the lower part.

<table>
<thead>
<tr>
<th>Upper Downgrade</th>
<th>Lower Downgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Accidents</td>
<td>Deaths</td>
</tr>
<tr>
<td>Before</td>
<td>26</td>
</tr>
<tr>
<td>After</td>
<td>18</td>
</tr>
<tr>
<td>%</td>
<td>▼30.8</td>
</tr>
</tbody>
</table>

Public acceptance of speed cameras is very important in the success of ASE system projects. The introduction of many ASE systems in Korea has been brought to public attention as well as creating significant controversy. It is said that ASE systems in Korea tend to have advantages in accident prevention and in making profit from traffic fines. However, not much attention has been given to the public awareness. Effectiveness of any traffic regulations can be measured in terms of social acceptance. Therefore, a public attitude survey toward speed cameras was conducted in September 2001. The participants in this survey were drivers from major cities in Korea.

A high degree of acceptance of traffic regulations and safety issues promoted by ASE systems will ensure that violators will be penalized and will promote a continued high rate of observance. Some important statistics from this survey are summarized as follows:

- 96% of drivers exceed the posted speed limit in light traffic conditions;
- 92% of drivers were aware that speeding is a dangerous behavior;
- 55% of drivers experienced speed violation citations;
- 79% of drivers agreed that the accuracy of speed camera is acceptable;
- 80% of drivers responded that the location of a speed camera is not appropriate;
- 67% agreed that a speed camera is effective to prevent accidents;
- 70% agreed that a speed camera was effective to keep the posted speed limit;
- 49% favored additional speed cameras;
- 83% favored warning signs for speed cameras.

Probably the most interesting question was how much drivers changed their speeding behavior after the introduction of ASE systems. Seventy-two percent responded that they have reduced average driving speeds even at places with no cameras. More detailed results are as follows:

- 28% of drivers responded that they have not changed speed;
- 12% of drivers responded to reduce speed below 5km/h;
- 28% of drivers responded to reduce speed between 5 to 10km/h;
- 24% of drivers responded to reduce speed between 10 to 15km/h;
- 8% of drivers responded to reduce speed above 15km/h.

It should be mentioned that the above results are obtained under mixed conditions of 853 fixed-type and 821 mobile-type cameras in 2001. What was found in this public attitude survey was that Korean drivers’ support for speed cameras was high.
The intent of this paper was to investigate the impact of Korean ASE systems on the speed of vehicles and on the safety of roads. The public attitude on ASE systems was also examined.

The introduction of numerous ASE systems has been very successful in terms of reducing not only fatal accidents but also driver compliance with speed limits. The analysis of before-and-after data indicated that the ASE system was effective in reducing not only the average speed but also variances in the surrounding area. The analysis showed that the immediate effect of installing a speed camera on an expressway has been to decrease average car speeds by about 9km. It was also found that the variance of speeds decreased significantly. The analysis showed that, in terms of camera locations, fixed-type ASE systems were most effective in reducing accidents when it is installed at the upstream of curved or downgrade sections. It was also found that well designed advanced warning signs of fixed-type speed cameras have a great potential to early speed reduction in advance to the camera site.

The most notable impacts of the speed camera project may be a nationwide reduction of speeding behavior and speeding-related accidents. Traffic accidents seldom result from a single cause – usually several influences affect the situation at any given time. An error in perception or judgment or a faulty action on the driver’s part can lead to an accident. The results in this study suggest that the safety improvement mechanism of ASE systems is to reduce a faulty action and therefore leads to a smooth traffic environment.