The purpose of this paper is to evaluate the effectiveness of the congestion pricing scheme at the Namsan #1 and #3 tunnels in downtown Seoul four years after its implementation. The effectiveness of the scheme was measured by the changes of various traffic impacts. The traffic volume of the two tunnels was reduced by up to 25% for the first month. After that time, the traffic volume started to increase again, and then exceeded the previous volume level. However, average travel speed of the two tunnel corridors improved by up to 74%. The overall traffic volume of the four alternative routes was increased; nevertheless, their average travel speed increased as well. The number of carpool vehicles occupied by 3 or more persons including the driver during the peak periods was remarkably increased. Before the congestion fee charging, toll-charged vehicles amounted to 68.5% of the total traffic volume of the two tunnels, and then the share dropped to 29% afterwards. The empirical analysis results for the effectiveness of the congestion pricing scheme are very promising.

Seoul has earned a notorious reputation for its severe traffic congestion. In order to mitigate the congestion problem, the transportation policy of Seoul Metropolitan Government (SMG) had been mainly focused on the supply of transportation systems such as constructing new urban freeways and subway lines until the early 1990’s. However, after 1993, the SMG has approached traffic problems from a different angle in response to the limitation of the past transportation policy to solve the traffic congestion problem. The new approach is to manage the demand of transportation systems by implementing a congestion pricing scheme.

Congestion pricing is generally considered to be the most effective method to control vehicle usage, as well as to reflect time-space variations of traffic congestion among many transportation demand management (TDM) techniques. However, the scheme was not a popular alternative. Very few cities adopted congestion pricing, although it was considered for implementation by many major cities around the world. Singapore, for example, experienced a sizable success in relieving traffic congestion by using the Area License Scheme (ALS) in the CBD.

The purpose of this paper is to evaluate the effectiveness of the congestion pricing scheme at the Namsan #1 and #3 tunnels in downtown Seoul four years after its implementation. The SMG will decide on the expansion of tolled congestion sites based on the effects of the scheme’s implementation. The paper consists of five parts including: 1) background of implementing congestion pricing scheme in Seoul, 2) contents of the scheme, 3) framework of analysis and research method, 4) analysis results, and 5) summary and conclusion. Effectiveness was measured by changes in the following four parts: 1) trip reduction impacts, 2) time shift impacts, 3) route change impacts, and 4) mode shift impacts.

The current roadway network in Seoul is insufficient to sustain massive amounts of traffic volume. The paved road ratio in Seoul is only 20.8%, which is somewhat lower than those of major cities in other countries. In 1996, the total length of urban freeways was about 200km out of 7,689km of total paved roads in Seoul.

Figure 1 shows the arterial roads in Seoul. Most arterial roads in Seoul are heavily congested throughout the day. It is, however, financially not feasible to build new roadways to an extent that will mitigate the traffic con-
gestion in Seoul because of insufficient land supply and high land prices. It is noteworthy that about 35% of the CBD (the center of the map below) workers use private vehicles for commuting, and that other workers use public transit due to either traffic congestion or shortage of parking spaces\textsuperscript{1}. This implies that there are plenty of private vehicles waiting to be driven when the traffic conditions are improved. In light of this fact, it is hopeless to expect that the traffic congestion can be relieved by road construction alone.

Table 1 summarizes the changes of the number of registered vehicles in Seoul and suburban areas. The number of registered vehicles in Seoul increased 12.3% during the time period from November 1996 to November 2000, while that of suburban areas increased 34.7%. It should be noted that about 25% of the total vehicles making their daily trips to Seoul are registered in the suburban areas and the number of long distance commuters travelling from the suburban areas has been increasing steadily.

Table 2 summarizes some important results for the share of travel modes in Seoul, which was obtained from the O-D survey conducted by the Seoul Development Institute in 1996. In the case of subway trips, a transfer among different subway lines was counted as an independent trip. Buses have been the prevailing travel mode in Seoul, however the subway has carried 30.8% of all the daily trips in 1997 and then it became, temporarily for the first time, the most predominant travel mode. In the table, it can be seen that the share of bus trips was decreased remarkably from 1980 to 1997 due to fast growing subway supply. However, the share of private vehicles was sharply increased from 1996 and has been stabilized at around 20%. It seems that the bus ridership is somewhat sensitive to the implementation of the subway network, but the share of private vehicles is not highly dependent upon the level of subway service.

Traffic conditions in Seoul were without serious congestion up to the early 1980s, except during rush hour periods, but the traffic patterns changed from rush-hour peaks only to all-day peaks by the end of the 1980s. Table 3 shows the changes of average travel speed on the major arterial roads in Seoul from the year 1990 to 2000.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
\hline
Seoul Metropolitan & 2,168,182 & 2,297,726 & 2,435,253 & 12.3\% & 6.0\% \\
\hline
Kyonggi-Do & 1,809,624 & 2,245,744 & 2,469,617 & 36.6\% & 10.0\% \\
\hline
In-chon & 503,645 & 593,380 & 645,505 & 28.2\% & 8.8\% \\
\hline
Total & 4,481,451 & 5,136,850 & 5,550,375 & 23.9\% & 8.1\% \\
\hline
\end{tabular}
\caption{Changes of registered vehicles in Seoul and suburban areas.}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|c|}
\hline
\hline
Bus & 66.0 & 58.0 & 43.3 & 36.7 & 30.1 & 29.5 & 32.3 & 33.8 & 35.3 \\
\hline
Subway & 7.0 & 14.0 & 18.8 & 29.8 & 29.4 & 30.8 & 29.1 & 28.8 & 28.3 \\
\hline
Taxi & 19.0 & 16.5 & 12.8 & 10.7 & 10.4 & 10.1 & 9.7 & 9.2 & 8.8 \\
\hline
Others & 8.0 & 12.5 & 25.1 & 22.8 & 30.1 & 29.7 & 28.9 & 28.2 & 27.6 \\
\hline
[Passenger cars] & (NA) & (NA) & (14.0) & (14.5) & (21.1) & (20.6) & (20.1) & (19.6) & (19.1) \\
\hline
\end{tabular}
\caption{Share of travel modes in Seoul.}
\end{table}
The overall average travel speed on the major arterial roads continued to decline until 1996 and started to bounce back from 1997, but decreased again in 2000. The reasons for the speed changes between 1997 and 2000 will be explained later.

The Seoul Metropolitan Government started charging, from November 11 in 1996, 2,000 won (US $1.5 - 1.6) congestion toll for one and two persons (including driver) occupied private vehicles passing through the Namsan #1 and #3 tunnels. The two tunnel corridors link the southern part of the Han river and the old downtown area. The two tunnel corridors were notorious for excessive private vehicle use. In 1996, 90% of total traffic volume passing the two tunnels consisted of the private vehicles, this number was the highest among all the major corridors linked to the CBD. Furthermore, 78% of the private vehicles were one person occupied. Toll booth facilities for cash collection exist at the two tunnels, where 100 won tolls were collected from all the vehicles passing through the tunnels for 20 years until October 1996 to recover the construction costs. Prior to the implementation of the congestion toll, a seven-day public notice was given.\(^5\)

The toll charges are collected for vehicles travelling in both directions per entry from 7 a.m. to 9 p.m. during weekdays and from 7 a.m. to 3 p.m. on Saturdays. Sundays and national holidays are free of charge. The violation penalty amounts to 10,000 won (five times the congestion fee). The following vehicles are exempted from the charge: three or more persons occupying private vehicles, all buses, vans, trucks, diplomats’ vehicles, reporters’ vehicles, government vehicles, and ceremony vehicles.\(^5\)

The main purpose of congestion pricing is to relieve traffic congestion by reducing traffic volume on overloaded roadways. Congestion pricing plays the role of reducing social costs by switching the condition of the roadway network equilibrium from user-optimum to system-optimum. In theory (see the left hand side of Figure 2), where the demand curve \(D\) meets the marginal cost curve \(M_1\) in the forward bending section, it should be verified that traffic volumes decrease from \(F_e\) to \(F_s\), while traffic speed improves on the corridor where the charge is levied. Where the demand curve crosses with the marginal cost curve in the backward bending section (see the right hand side of Figure 2), it can be expected that the traffic volume increases from \(F_e\) to \(F_s\) and speed increases below \(C_2\).\(^6\)

In general, congestion tolls are imposed when congestion occurs. Accordingly, tolls are collected only during a certain time period, and vehicles tend to concentrate on the time period just before and after the congestion charging periods to escape the toll. It is desirable if traffic volumes during the morning and evening peak periods decrease due to such a time shift impact. However, if too many drivers change their trip schedule, network-wise trip reduction effects may not result.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|c|c|c|}
\hline
\hline
\textbf{Passenger car} & & & & & & & & & & & \\
\textbf{All} & 24.2 & 24.6 & 22.6 & 23.5 & 23.2 & 21.7 & 20.1 & 21.1 & 25.4 & 25.4 & 22.9 \\
\textbf{CBD} & 16.4 & 17.7 & 19.3 & 20.0 & 20.0 & 18.3 & 16.4 & 16.9 & 17.7 & 21.2 & 18.5 \\
\textbf{Other} & 25.8 & 21.9 & 22.9 & 23.8 & 23.4 & 21.9 & 21.2 & 21.3 & 25.9 & 25.7 & 23.2 \\
\hline
\textbf{Bus} & & & & & & & & & & & \\
\textbf{All} & 18.8 & 18.2 & 16.9 & 17.0 & 18.4 & 18.8 & 18.4 & 18.4 & 20.1 & 19.2 & 19.0 \\
\hline
\end{tabular}
\caption{Classification of traffic volumes in Seoul.}
\label{table:traffic}
\end{table}

Source: Seoul Metropolitan Government, 2000b\(^3\)
There are several alternative routes for the Namsan #1 and #3 tunnels, so implementing congestion pricing at the two tunnels may worsen traffic situations of alternative routes. In such a case, congestion pricing only plays the role of shifting the congestion without improving overall traffic conditions of the roadway network. Therefore, in order to validate the effectiveness of the congestion pricing scheme at the two tunnels, it is necessary to assess changes in the traffic situation of the alternative routes.

It can be expected that the majority of private vehicle drivers who want to escape the congestion charge may choose alternative travel modes instead of giving up their auto travel altogether. Currently, eight subway lines are in operation, and about 9,000 buses serve about 430 routes. Carpools and taxis may be options to use as well.

Considering the effects of the congestion pricing scheme at the Namsan #1 and #3 tunnels, the effectiveness of the scheme will be determined as a result of the changes in the following four parts:

1) Trip reduction impacts: traffic volume and speed of the Namsan #1 and #3 tunnel corridors and the composition of vehicle flows passing through the two tunnels;
2) Time shift impacts: traffic volume just before and after congestion toll charging period at the two tunnels;
3) Route change impacts: traffic volume and speed of the alternative routes;
4) Mode shift impacts: the number of toll free vehicles and the number of passengers using the alternative travel modes.

### 5.1 Trip reduction impacts on Namsan #1 and #3 tunnels

#### 5.1.1 Impacts of congestion pricing

It has been four years since the congestion pricing scheme were implemented at the Namsan #1 and #3 tunnels in November 1996. Table 4 shows the results for traffic volume and speed changes on the two tunnel corridors. Before the implementation, more than 90,000 vehicles passed through the two tunnels during the time period from 7 a.m. to 9 p.m. The traffic volume of the two tunnels was reduced by up to 25% for the first month in 1996. After that time, the traffic volume started to increase again and then exceeded 94,000 vehicles in the year 2000. The majority of the traffic volume increase consisted of the toll free vehicles such as taxies, trucks, and three or more persons occupying private vehicles. This is explained in Section 5.4.

Although the traffic volume was recovered to the previous level, the average travel speed of the two tunnel corridors has been steadily improved and maintained at over 30km/h with the exception of the year 1997. The speed was 21.6km/h previously, but it was 37.6km/h in the year 2000. Comparing the changes on traffic volume with those of speed, it can be said that the congestion pricing scheme at the Namsan tunnels has contributed not only to improve the traffic condition of the two tunnel corridors in terms of the level of congestion, but also to reduce one and two person occupied private vehicles. It is noteworthy that 93% of drivers passing through the Namsan #1 and #3 tunnels have responded in the survey that they chose the tunnel corridors because the corridors maintained relatively higher speeds than the other corridors.

#### 5.1.2 The combined impacts of congestion pricing and oil price increase

Table 5 shows the traffic volume variations at the Namsan #1 and #3 tunnels by the change of gasoline price during the period from November 1996 to December 1998. In Korea, gasoline price had been fluctuated frequently since November 1997 due to the foreign currency crisis and oil tax increase. The total number of vehicles at the two tunnels decreased as the gasoline price increased during the period between November 1997 and January 1998. After that, the traffic volume has been kept...
increasing, notwithstanding the increase of gasoline prices. This variation of total travel volume is similar to that of toll free traffic volume. However, the number of toll charged vehicles has steadily increased during the same time periods. It seems that the impact of gasoline price is not sustainable for the private vehicle drivers.

5.1.3 The impacts of temporary suspension of congestion pricing

In early August 1998, heavy rainfalls flooded the major arterial roads in Seoul and many of them were shut down for a few days. Due to this, the congestion toll charging at the two tunnels was suspended for 8 days until the arterial roads were completely restored. Table 6 summarizes the results for traffic volume changes at the tunnels during the same time period. Traffic volume of the Namsan #1 tunnel increased very quickly and, on the first day of the suspension, exceeded the traffic volume observed in November 1996 when the congestion pricing scheme was not implemented at the tunnel. However, traffic volume of the Namsan #3 tunnel increased very slowly and has not reached the previous volume level, 50,422 vehicles.

There is a possible reason for the difference of traffic patterns at the two tunnels. The Namsan #3 tunnel is connected with Banpo Bridge and Jamsu Bridge which lies underneath the Banpo Bridge. During heavy rainfalls, the Jamsu Bridge became submerged, so the bridge was entirely shut down during the period. Thus, the traffic volume travelling through the Namsan #3 tunnel corridor was much less than the traffic volume observed before the implementation of the congestion pricing scheme.

In summary, the traffic volumes at the two tunnels will gradually increase if the congestion pricing scheme is not implemented. This finding supports the argument that congestion pricing plays a key role in reducing traffic volume in a congested area.

5.2 Time shift impacts

Table 7 shows the results for traffic volume changes just before and after the toll charging periods. In the table, before the congestion pricing scheme was implemented in 1996, the traffic volume during the time period from 6 a.m. to 7 a.m. was 5,159 vehicles, and the traffic volume during the time period from 9 p.m. to 10 p.m. was 5,369 vehicles. After the implementation of congestion pricing, the traffic volumes during the same time periods were remarkably increased, especially during the evening time period. This result was clearly caused by the drivers’ travel time-shifting behavior. As expected, drivers changed their departure time in order to escape the toll charging, but the drivers’ travel patterns during

<table>
<thead>
<tr>
<th>Classification</th>
<th>Before Congestion Pricing</th>
<th>August 6th</th>
<th>August 7th</th>
<th>August 10th</th>
<th>August 11th</th>
<th>August 12th</th>
<th>August 13th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Namsan #1 tunnel</td>
<td>39,982 (1.4%)</td>
<td>40,547 (1.4%)</td>
<td>40,303 (0.8%)</td>
<td>40,467 (1.2%)</td>
<td>43,917 (9.8%)</td>
<td>44,002 (10.1%)</td>
<td>43,324 (8.4%)</td>
</tr>
<tr>
<td>Namsan #3 tunnel</td>
<td>50,422 (-30.9%)</td>
<td>34,818 (-24.9%)</td>
<td>37,881 (-24.6%)</td>
<td>37,995 (-21.3%)</td>
<td>39,678 (-20.7%)</td>
<td>39,964 (-14.3%)</td>
<td>43,192</td>
</tr>
<tr>
<td>Total</td>
<td>90,404 (-16.6%)</td>
<td>75,365 (-14.1%)</td>
<td>78,684 (-13.2%)</td>
<td>83,459 (-7.5%)</td>
<td>83,966 (-7.1%)</td>
<td>86,516 (-4.3%)</td>
<td>86,516</td>
</tr>
</tbody>
</table>

Source: Seoul Metropolitan Government, 1998"
the two time periods are somewhat different. In detail, the traffic volume change during the evening time period is much bigger than during the morning time period with the exception of June 1997. The traffic volume during the morning time period has been gradually decreased, while during the evening time period steadily increased. These results have something to do with the fact that office hours in Korea are very flexible while the opening hours are very strict, so drivers are less sensitive to the toll charging during the morning time period than during the evening time period.

5.3 Route change impacts

In order to investigate the traffic effects of the congestion pricing scheme on the alternative routes, four alternative routes which are close to the Namsan #1 and #3 tunnels and linked to the CBD were selected. These are Hangang-ro, Sowol-kil, Jangchongdan-kil, and Namsan #2 tunnel (see Figure 3). For the traffic volume survey, only private passenger vehicles were counted, since other types of vehicles would hardly change their routes to escape tolls. The survey period was from 6 a.m. to 10 p.m.

It was expected that the alternative routes would be severely congested by vehicles which would change their travel routes to escape the congestion toll. The expectation was correct, but included an interesting result. That is, while the traffic volumes on the alternative routes increased during the first two years, the average travel speeds increased as well (see Table 8). There are possible reasons for the traffic volume increase and the speed improvement.

First, the Namsan #2 tunnel was entirely closed from the year 1999 for repair work, so total traffic volume of the alternative routes was decreased. Secondly, overall traffic conditions on urban corridors are highly dependent on the level of congestion at major signalized intersections on the corridors. After the congestion pricing scheme was implemented, traffic volumes of all approaches at the signalized intersection were uniformly distributed. In other words, traffic volume approaching from the tunnels to the signalized intersection was reduced, while traffic volume approaching from the alternative routes to the signalized intersection increased. Consequently, the traffic queues forming at the major signalized intersections linked to the Namsan tunnel corridors were significantly reduced. This change improved traffic signal operation in terms of signal cycle time and signal phases, so the stopped delay at the signalized intersections was remarkably reduced.

5.4 Mode shift impacts

Table 9 shows the changes of toll-charged vehicles and toll-free vehicles. Before the congestion fee charging, toll-charged vehicles amounted to 68.5% of the total traffic volume of the two tunnels. However, the vehicles drastically decreased and then reached only 29% at both tunnels.

Table 10 summarizes the results for traffic volume composition by vehicle type. The traffic volume was obtained during the time periods from 7 a.m. to 9 a.m. and from 5 p.m. to 9 p.m. in November 2000 at the two tunnels. As expected, the ratio of passenger cars was decreased and the ratios of other vehicles increased; taxies and trucks increased over twice than the previous levels.

Table 11 presents a comparison of traffic volume compositions of the two tunnels and the alternative routes. While the ratio of passenger cars of the two tunnels was
decreased below 50%, that of the alternative routes was maintained at over 67%. This result clearly indicates that some of the toll-charged vehicles have changed their travel route after the congestion fee charging.

Table 12 summarizes the number of passengers carried by buses passing through the two tunnels during the time periods from 7 a.m. to 9 a.m. and 5 p.m. to 7 p.m. The number of bus passengers increased over 75%. Currently, four bus lines are in operation at the Namsan #1 tunnel and eleven bus lines at the Namsan #3 tunnel. At the Namsan #1 tunnel, one bus line was increased after the congestion pricing scheme was implemented.

It can be seen from Table 13 that carpool vehicles occupied by three or more passengers (including the driver) increased, while the vehicles occupied by one or two passengers (including the driver) decreased. It seems

<table>
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<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic volume (vehicles)</td>
<td>11,721</td>
<td>12,538 (7.0%)</td>
<td>12,008 (2.4%)</td>
<td>12,862 (9.7%)</td>
<td>11,303 (3.6%)</td>
<td>11,108 (5.2%)</td>
</tr>
<tr>
<td>Speed (km/h)</td>
<td>24.5</td>
<td>27.4 (+11.7%)</td>
<td>30.0 (+22.4%)</td>
<td>27.6 (+12.7%)</td>
<td>28.9 (+18.0%)</td>
<td>31.6 (+28.8%)</td>
</tr>
</tbody>
</table>

Source: Seoul Metropolitan Government, 2000a²
The effectiveness of the congestion pricing scheme implemented at Namsan #1 and #3 tunnels in Seoul was measured by the changes of various traffic impacts. The traffic volume of the two tunnels was reduced up to 25% for the first month. After that time, the traffic volume started to increase again and then exceeded the previous volume level. However, average travel speed of the two tunnel corridors was improved by up to 74%. The average travel speed of four alternative routes was increased, while the overall traffic volume of the routes increased as well. The number of carpool vehicles occupied by 3 or more persons (including the driver) during the peak

<table>
<thead>
<tr>
<th>Classification</th>
<th>Namsan #1 &amp; #3 Tunnels</th>
<th>Alternative Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Namsan #1</td>
<td>Namsan #3</td>
</tr>
<tr>
<td>Car</td>
<td>6,204 (48.3%)</td>
<td>6,774 (49.0%)</td>
</tr>
<tr>
<td>Bus</td>
<td>786 (6.1%)</td>
<td>760 (5.5%)</td>
</tr>
<tr>
<td>Taxi</td>
<td>3,076 (24.0%)</td>
<td>3,880 (28.0%)</td>
</tr>
<tr>
<td>Truck, etc.</td>
<td>2,769 (21.6%)</td>
<td>2,417 (17.5%)</td>
</tr>
<tr>
<td>Total</td>
<td>12,835 (100%)</td>
<td>13,831 (100%)</td>
</tr>
</tbody>
</table>

Source: Seoul Metropolitan Government, 2000a

that the congestion pricing scheme has played a positive role to change the number of passengers of private vehicles10.
periods was increased remarkably. The toll-charged vehicles, before congestion fee charging, amounted to 68.5% of the total traffic volume of the two tunnels. However, the number drastically decreased and then reached only 29% at both tunnels. The overall empirical analysis results are very promising, so the Seoul Metropolitan Government has a plan to extend the scheme to other major congested arterial roads in Seoul.


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