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CALCOLATING SOCIAL BENEFIT IN TRAVEL TIME CONSIDERING SEASONAL AND DAILY VARIATION IN TRAFFIC PATTERN

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Abstract : Most transportation analysis has used an annual average day (AAD) O-D (Origin-Destination) traffic pattern for strategic plans both of urban and intercity. However, there is usually big variation in traffic pattern depending on season and day over the year. As the results, analysis results with ADD O-D might mislead decision for strategic transportation policy, because the average traffic pattern might not represent well even any one of season and day's traffic patterns. This study suggested a method to estimate approximately seasonal weekday and weekend personal O-D trips by using the Korean TCS (toll collecting system) O-D data with the AAD O-D table estimated by KOTI (Korea Transport Institutes). The study showed that there was difference in time saving in case of using the AAD O/D data from the case of using seasonally and daily varied O/D data for same strategic plan.

Key Words: Annual average daily O-D, seasonal and day varied O-D, feasibility study

1. INTRODUCTION

1.1 Background and Purpose of the Study

The most fundamental and basic data required for traffic assignment analysis is the O-D trip tables. The O-D trips can be defined as number of personal trips or number of vehicle trips from origin zone to destination zone. The O-D table is the basic input data to estimate highway link traffic volumes via traffic assignment analysis. Traffic volume is the 'number

of vehicles passing a certain point, lane, or section of road during a unit of time' (Pignataro, 1973). The annual average daily traffic (AADT) can be calculated by dividing the total sum of annual traffic volumes by 365 days. The AADT traffic volume is usually used in economic and finance evaluation for road construction, highway network design, street design, toll fee collection plan, accident analysis, and various other evaluations (Do, 1997). The traditional unit of O-D trips is the annual average daily trips.

It is well-known fact that traffic volumes are varied by seasons and days through many previous researches and studies (Baik, 2002). Increases in leisure time and incomes in Korea will make more different between weekday and weekend traffic pattern. In order to considering such seasonal and daily variation in traffic pattern, different O-D for weekday and weekend of each season rather than annual average daily O-D might reduce aggregation errors in evaluating long-term transportation policy analysis. Therefore, the study suggested a method to estimate season and day varied O-D by using the observed dynamic O-D collected through the toll collecting system (TCS) in South Korea. The Korean national-wide freeway systems are fully closed system, which means that any vehicle entering national-wide freeway exits once at the toll gate of its destination place. The estimated season and day varied O-D will be used in traffic assignment analysis to estimate link volume for weekend and weekday of each season.

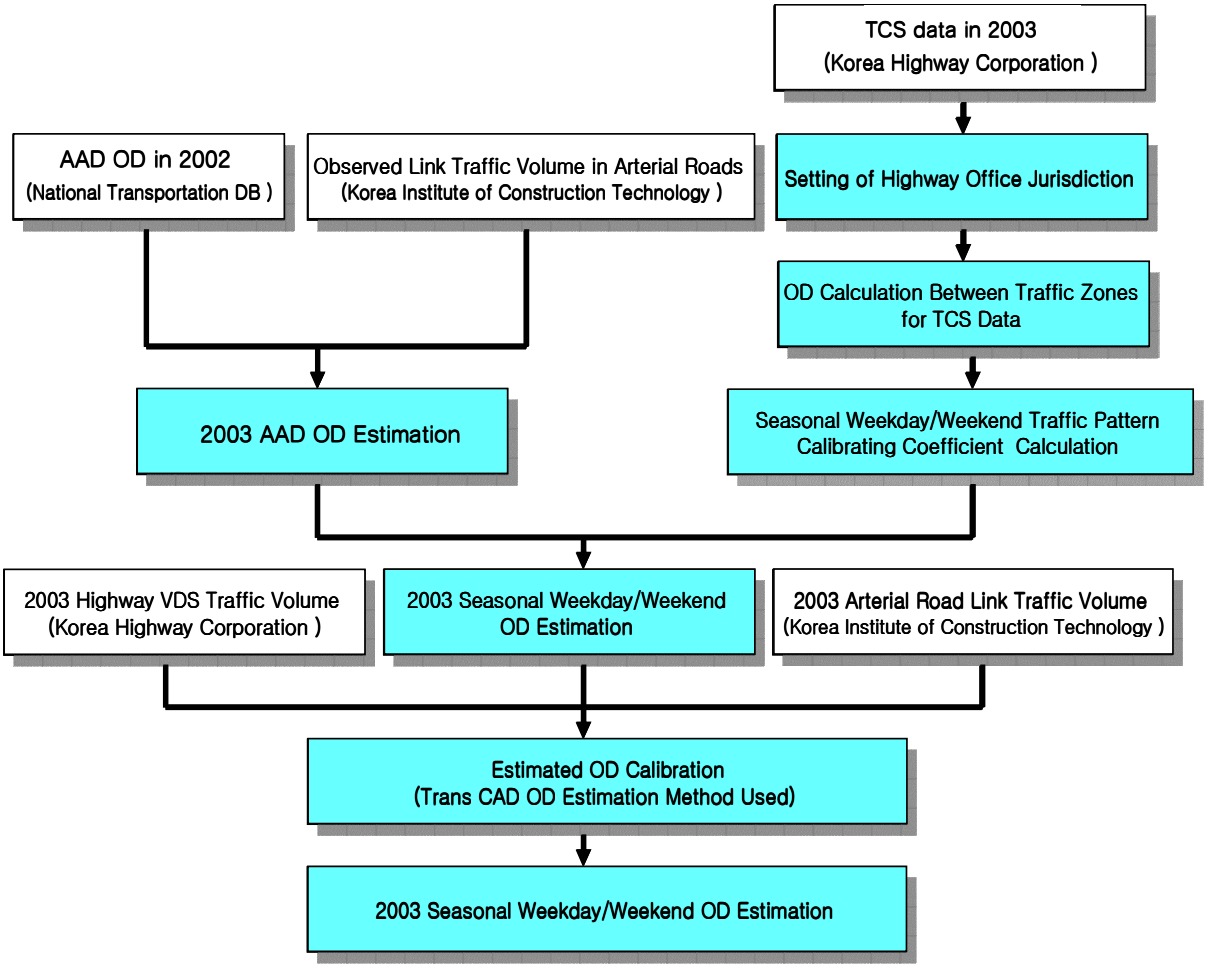
1.2 Method and Procedure

1) Suggested method

The suggested method used one year dynamic TCS (Toll Collecting System) O-D Data which only shows toll-gate to toll-gate O-D instead of traffic zone to zone O-D. The TCS data are recorded and stored in the Korea Highway Corporation whole year, of which data is very accurate because the data itself is the population data. This data is recognized to be very useful in this study in order to find value of factors for weekday and weekend of each season respect to the annual average daily O-D (AAD O-D) trip table. However, the TCS O-D data includes only the vehicle trips using national-wide freeway network, which means that other vehicle trips using other than freeway was not counted into that TCS O-D. Therefore, there is need to find way to estimate zone-to-zone season and day varied O-D trip table instead of toll gate-to-gate O-D trips. This study suggested that the season and day factors from TCS data are used by multiplying the factors to the given AAD O-D table to get season and day varied O-D trip table.

2) Procedure of estimating seasonal and daily traffic pattern

There are two main stages in estimating season and day varied link traffic volumes in national-wide network analysis of South Korea. O-D trips from given national-wide zone-to-zone AAD O-D trips. At the first stage, TCS dynamic O-D Data and the observed traffic volumes of freeways and inter-city major arterial road are used as shown in <Figure 1> to estimate seasonal and daily factors and to verify the estimated O-D. In stage 2, the seasonal and weekday OD, at the second stage, the study performed traffic assignment analysis to find link volumes for typical weekday and weekend of each season with the estimated season and day varied zone-to-zone O-D trips. is used for network analysis, Then, the results of traffic assignment are used to calculated monetary term of travel time saving in the system comparing with the do-nothing case. Finally, the newly calculated social benefits in travel time saving are compared with the social benefit calculated by using the annual average daily O-D data.



<Figure 1> Season and day varied O-D Estimating Process

2. REVIEW OF PREVIOUS STUDIES

2.1 Two Categories of Traffic Variation

The variation in traffic pattern variations can be explained by two categories such as periodical variation and temporal trend (Lee et. al., 2001).

1) Periodical variation
Traffic patterns are usually changed more or less regularly by monthly, daily and hourly. Such periodical variations are repeated within certain time interval such as a year, week or day. Such repeated pattern makes it possible to apply adjustment factors with respect to average value. The monthly (or seasonal) traffic factor can be getting by dividing the daily average volume of a specific month (or season) by the AADT volume. As the same way, the day factor (or just typical weekday factor or weekend factor) can be calculated by dividing the daily average traffic volume of a specific day (or all weekdays or weekend) during the whole year by the AADT volume. The hour factors can be also calculated by the same method.

2) Temporal trend
Temporal trend represents the long-term trend of changes in traffic patterns which are due to population changes, economical and cultural changes, transportation systems changes and so on. In addition to the periodical variation and temporal trend, traffic patterns are sometimes changed irregularly. Such irregular changes in traffic pattern could not be explained by temporal trend or periodic variations changes, so it is very hard to predicting the irregular changes in traffic patterns.

2.2 Previous Studies

The KDI's (Korean Development Institution) guideline of pre-feasibility study for a large-size government infrastructure investment plans suggested that average daily user benefit such as travel time saving and vehicle operating cost saving could be calculated by traffic assignment analysis with AAD O-D trips, then multiply the daily average benefit by 365 days. In other words, the guideline prepared by KDI does not considered seasonal and day variations of traffic pattern in calculating social benefit for the pre-feasibility analysis. In the guideline of rail investment prepared by Korean Bureau of Rail in 2003, the temporal variations are considered in evaluation of a project. It suggested applying factors representing all combination of seasonal, daily and hourly factors on link volume rather than O-D trips. It suggested to use same factors for links in same categories, which classified by street hierarchies, region and land uses of surrounding area. Because it used only link volume adjustment factors, it could not reflect any changes in route choice due to some highway network changes.

In the United States, the AASHTO analysis method was usually used in the 1980s. It did not consider any variation in traffic patterns, but only consider daily average patterns. However, the method of HERS (Highway Economic Requirements System) was adopted in the 1990s, which required huge-size of hourly traffic data. The previous studies usually adjusted link volume rather than O-D trips, which can not reflect changes in path choice. The previous studies did not classify weekday and weekend, even though there are clear differences in traffic patterns.

3. ESTIMATING WEEKDAY AND WEEKEND DAILY O-D TRIPS FOR EACH SEASON

The periodical variations in season and day are related to the different composition of trip purposes. In Korea, there are more recreational inter-city trips during summer and fall. As expected, large portion of trips are related to leisure trips in weekend as other countries. Leisure or recreation-related trips mostly used automobiles rather than transit in South Korea. Therefore, when building weekend O-D trips by each transportation mode, the occupancy rate of a vehicle and mode choice should be differently considered because of the different composition of trip purpose.

3.1 Weekday/weekend O-D adjustment factors for each season

The 5-minute interval dynamic TCS O-D Data in 2003 was used to get season and day adjustment factors as an empirical study. As mentioned before, TCS O-D is tollgate-to-tollgate O-D data rather than zone-to-zone O-D. First, we aggregated the data to daily data from 5-minute interval data. Then, we summed up the daily data as total O-D trips in 2003. The annual average daily (AAD) O-D of TCS was calculated by dividing the year total O-D trip by 365 days. We also calculated seasonal average weekday daily O-D and weekend daily O-D from TCS O-D data for each of four seasons, spring, summer, fall and winter. The zone was combined to super-zone, which can represent inter-city trips correctly. Then, we calculated season and day adjustment factor with respect to TCS AAD O-D for each super-zone pairs. The formula used to calculate the adjustment factors are as following;

$$F_{g(i),g(j),sd} = \frac{T_{g(i),g(j),sd}}{T_{g(i),g(j)}}$$

$F_{g(i),g(j),sd}$: Adjustment factors for a pair of super-zone from g(i) to g(j) for season s and day d (weekday or weekend)

$T_{g(i),g(j),sd}$: Seasonal average weekday or weekend daily O-D trips for day d from super-zone g(i) to g(j)

$T_{g(i),g(j)}$: Annual average daily O-D trips from super-zone g(i) to g(j) for the year.

3.2 Estimating season and day varied zone-to-zone O-D trips

The factors calculated from the TCS O-D data was applied to generate season and day varied zone-to-zone O-D trips with given AAD zone-to-zone O-D built by KOTI (Korea Transport Institute) in 2003. The trips between super-zones and within a super-zone were treated differently. We assumed that the trips between super-zones represent inter-city trips and the trips within a super-zone represent local trips. We assumed that inter-city trips are more related to seasonal and daily variation pattern than local trips. Therefore, season and day factors are applied to only O-D trips between super-zones. And we assumed that the trip patterns within a super-zone are similar to AAD O-D pattern. Fratar model was used to convert the factored O-D pattern between super-zones to zone-to-zone O-D trips. The procedure was summarized in following two stage expressions.

(Stage 1) The season and day specific daily O-D between super-zones are calculated by the following formula.

$$T_{g(i),g(j),sd} = \Big(\sum_{i \in g(i) org\ (j)} \sum_{j \in g(j) org\ (i)} T_{i,j} \Big) \times F_{g(i),g(j),sd}$$

(Stage 2) The O-D trips within a super-zone is calculated by the following formula

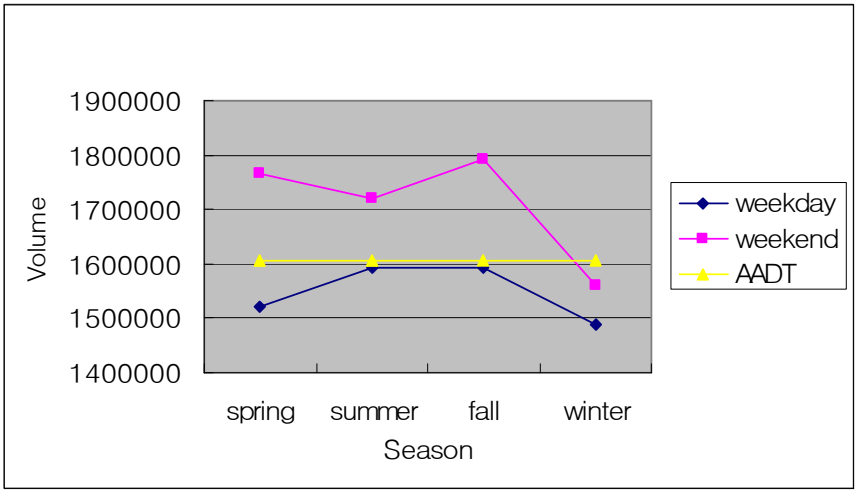
$$T_{i,j,sd} = T_{g(i),g(j),sd} \times \frac{T_{i,j}}{\sum_{i \in g(i) org\ (j)} \sum_{j \in g(j) org\ (i)} T_{i,j}}$$

Before using the estimated season and day specific zone-to-zone O-D in feasibility study, we tried to verify and adjust the O-D in order to fit them more close to observed link volumes for each season and day. To do this, the function of the O-D Matrix Estimation method with observed links was used in TransCAD 4.5. The modified season and day specific zone-to-zone O-D trip tables are used to evaluate travel time saving by construction of a planned project in South Korea. Then the results were compared with the results using the AAD O-D data.

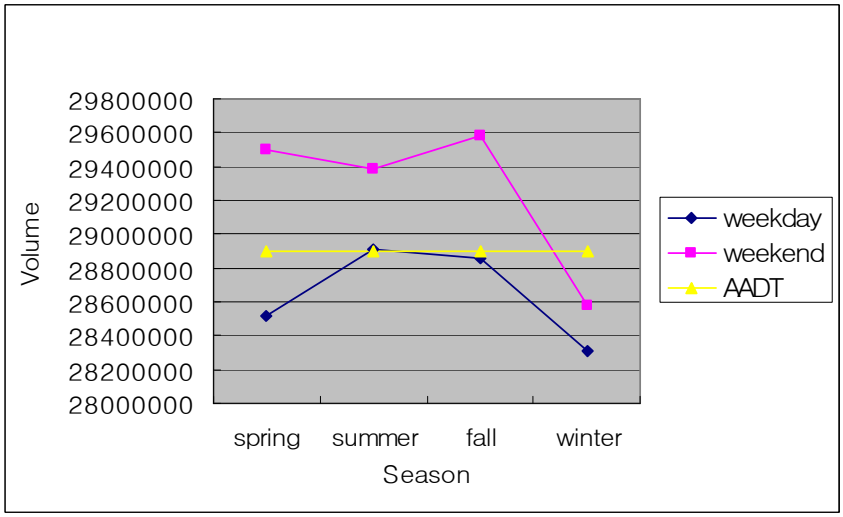
4. KOREAN CASE STUDY

4.1 Seasonal/Daily O-D Estimation

The TCS seasonal average daily total tips for weekday and weekend are shown in the figure 2. Because the TCS data are observed real population data, it showed how the actual traffic patterns are varied depending on season and day in Korean national-wide freeway system.



<Figure 2> Seasonal and day variation in TCS Data (unit: pcu/day)



<Figure 3> Seasonal and day variation in the estimated zone-to-zone O-D data (unit: person trips/day)

The figure 3 showed the seasonal and day variations explained by the estimated O-D, which was calculated by the suggested method in this study as mentioned before. As expected, the pattern of variation is very similar to the observed TCS data pattern. The analysis tells that

there are large variations among seasons and days in South Korea. The seasonal average daily total trips are much different from the annual average daily total trips. This means that there are some needs to account such variations in any feasibility study for large scale government projects. To check the reliability of the estimated O-D for each season and day, inter-city trip generation rate per capita was calculated and summarized in table 1 for each super-zone. The trip rates in the newly estimated O-D are compared with the trip rates in the AAD O-D built by KOTI (Korea Transport Institute) in 2003. We decided that the estimated O-D seems to be acceptable if the difference between KOTI data and our estimated O-D data are within reasonable ranges. As shown in the table 1, the differences are within understandable ranges.

<Table 1> Inter-city trip generation rate per capita

super-zone	AADT		Average Daily weekend of Fall			
	Inflow %	Outflow %	Inflow %	Difference	Outflow%	Difference
Seoul	0.556	0.558	0.558	0.002	0.556	-0.002
Busan	0.537	0.533	0.554	0.018	0.558	0.025
Daegu	0.636	0.641	0.652	0.017	0.648	0.008
Inchon	0.531	0.529	0.558	0.026	0.561	0.032
Gwangju	0.572	0.568	0.558	-0.014	0.555	-0.012
Daejon	0.678	0.673	0.702	0.025	0.696	0.022
Ulsan	0.590	0.591	0.600	0.010	0.634	0.043
Kyonggido	0.299	0.301	0.307	0.008	0.309	0.009
Kangwondo	0.097	0.099	0.113	0.016	0.123	0.023
Chungchongbukdo	0.329	0.325	0.277	-0.052	0.281	-0.044
Chunchongnamdo	0.135	0.136	0.169	0.034	0.167	0.032
Chollabukdo	0.144	0.145	0.142	-0.002	0.137	-0.009
Chollanamdo	0.129	0.129	0.111	-0.018	0.120	-0.010
Kyongsangbukdo	0.137	0.133	0.137	-0.001	0.132	-0.001
Kyongsangnamdo	0.150	0.146	0.167	0.017	0.152	0.006

4.2 Traffic Assignment Analysis

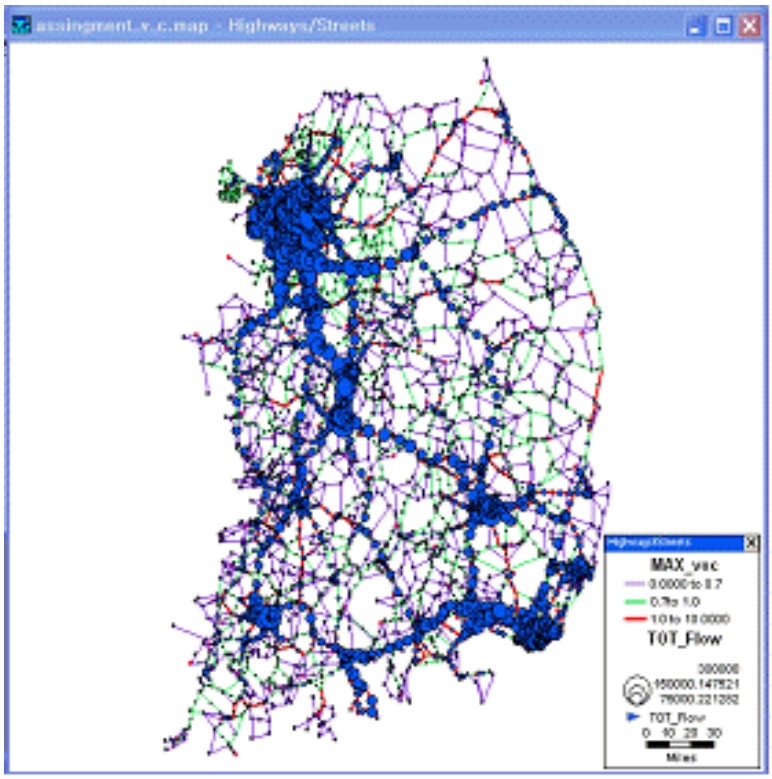
With the estimated season and day specific O-D trip table, traffic assignment analysis was performed. Using TransCAD 4.5 did the network analysis. For truck and bus traffic volume, we used the observed TCS Data, because reliable truck and bus O-D was not available, but available in TCS data which only represents traffic using national-wide freeway systems. This means we assumed that truck and bus for inter-city movements usually use freeway rather than local street. Bus and truck are assigned by using all-or-nothing assignment and the resulted link volumes are used as background traffic (pre-loaded volume) before performing user equilibrium assignment.

The assigned total vehicle trips for each season and day are summarized in the table 2. The link volumes as the results of the traffic assignment analysis are compared with the observed link volumes of freeway and inter-city major arterial roads. The differences in link volumes

are mostly within 1,000 PCU per day for weekday and weekend of each season. We considered that such results of assignment analysis represent real traffic pattern quite well. Therefore, the traffic assignment with the season and day specific O-D trip table is expected to generate reliable analysis results.

<Table 2> Total assigned vehicle tips for weekday and weekend of each season

	automobile	bus & truck (PCU)	sum
Spring(weekend)	18,722,418	262,279	18,984,697
Spring(weekday)	17,684,161	627,449	18,311,610
Summer (weekend)	18,669,861	231,508	18,901,369
Summer (weekday)	18,408,528	594,746	19,003,274
Fall(weekend)	18,614,092	268,791	18,882,883
Fall(weekday)	18,046,904	630,833	18,677,737
Winter(weekend)	18,063,524	225,836	18,289,360
Winter(weekday)	17,790,525	583,074	18,373,599



<Figure 4> Example of results of traffic assignment

4.3 Estimating travel time saving per year

In order to estimating travel time saving per year by a new freeway construction, which is a project actually planned in South Korea as a case study, two O-D data sets were used. The one is the analysis with the AAD O-D built by KOTI. The other is the analysis with the

estimated season and day varied O-D data suggested by this study. Then, the result of travel time saving analysis was compared. This study analyzed one case for comparing the travel time saving by new construction of freeway between results with AAD O-D and seasonal-day specific O-D. The case used in this study is the Seoul-Yangyang freeway construction project. The formula for obtaining annual travel time for do-nothing case and do case is as followings. In case of using the annual average daily O-D data;

$$T_{base} = \sum_{l} T_l \times Q_l \times 365$$

In case of using season and day varied average daily O-D data;

$$T_{sd} = \sum_{s} \sum_{l} \sum_{l} T_{lsd} \times Q_l sd \times K_{sd}$$

Here, T_l = travel time at link l

Q_l = Assigned link volume at link l

T_{lsd} = Travel time at link l on the day d in the season s

Q_{lsd} = Assigned link volume at link l on the day d in the season s

K_{sd} = Number of days belongs to season category s and day category d.

The total travel time from the results of traffic assignment analysis with the Seoul-Yangyang freeway and without it were summarized in the table 3.

<Table 3> Total Daily travel time in the case of Seoul-Yangyang project

Used O-D data	Daily average travel time (unit: million pcu*hour)	
	Do-nothing	Do case
Annual average	405.67	404.34
weekday in spring	371.00	369.88
weekend in spring	491.60	487.79
weekday in summer	411.24	409.33
weekend in summer	496.06	491.26
weekday in fall	399.86	398.76
weekend in fall	495.13	491.80
weekday in winter	361.29	359.77
weekend in winter	345.34	343.58

By using the average daily total travel time summarized in the table 3, the annual total travel time was calculated for the do-case and do-nothing-case. The table 4 summarized the annual total travel time, travel time saving per year and monetary amount of travel time saving in Korean currency unit (Won) for a specific year. The value of time used in this study is 9,600 Won/hour.

<Table 4> Annual Travel Time Savings in the case of Seoul-Yangyang project

Used O-D data	Annual travel time (unit: million pcu* hour)		Travel time savings (million pcu*hour)	Benefit (100 million Won)
	Do-noting	Do case		
AAD O-D	147,582	147,096	486	46,668
Proposed	147,548	146,823	725	69,587

The results shows that travel time savings could be very different depending on whether or not considering seasonal and day variations in traffic patterns. In this case study, the social benefit from travel time saving by construction of Seoul-Yanyang freeway became much larger when the seasonal and day variation was accounted than without consideration. We think this result came from the characteristic of the Seoul-Yangyang highway project which is expected to be heavily used by travelers of recreational purpose. This implies that there will be relatively large season and day variation in traffic pattern. However, the analysis with AAD O-D could not reflect seasonal and day variation, while the proposed method approximately reflects the variations. This causes the time savings by the analysis with the season and day varied O-D larger than results by the analysis with AAD O-D in this case. We expect that whether the time saving is larger or smaller depend on the characteristic of the newly constructed highway in aspect of intensity of usage in weekend or weekday and degree of seasonal variation.

5. CONCLUSIONS

The traffic patterns of weekday are usually very different from weekend. The traffic patterns of winter are also very different from summer. Therefore, the seasonal and daily variation in traffic pattern ideally needs to be accounted in traffic analysis for a strategic transportation policy decision. Unfortunately, in reality, it is so difficult to build seasonal weekday and weekend O/D pattern separately through survey due to time and budget limits. Therefore, this study suggested a method to estimate approximately seasonal weekday and weekend personal O-D trips by using the Korean TCS O-D data with the AAD O-D table estimated by KOTI . By using the estimated season and day varied O-D data, the study tried to show the possibility of aggregation errors with the annual average daily O-D data which could not correctly reflect the season and day variations in traffic patterns. As the results, analysis results with ADD O-D might mislead decision for strategic transportation policy. Through the case study of Korea, the study also showed that there was big difference in results of analysis for total time saving by constructing a new highway. The total time savings calculated with the season and day varied O-D data was much larger than result with the AAD O-D data in the South Korea case.

However, the direction of the differences might be dependent on the characteristic of the newly constructed highway in aspect of intensity of usage in weekend or weekday and degree of seasonal variation.

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