Interactions of Aggregated Zoning and Network Systems: A Case Study of Seoul City

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Abstract: Travel demand forecasting is generally performed using a zoning and network system. These two elements are closely connected with each other, and the aggregation levels of them should be determined appropriately depending on the purpose and subject of research. The purposes of this paper are to analyze interactions of aggregated zoning and network systems and to propose a method minimizing spatial aggregation errors stemming from aggregated zoning and network systems. Statistical reliability tests are performed to assess the fitness of the proposed aggregation levels. The results show that the two proposed aggregation levels can make traffic assignment results within a reasonable error range and also reduce required time and costs significantly. The results of this study are expected to contribute to a methodology for proposal and preliminary feasibility studies and then to provide an objective and rational basis for the project promotions.

Key Words: *zoning system, network system, aggregation level, travel demand forecasting*

1. INTRODUCTION

One of the significant factors facing early in travel demand forecasting is to determine the level of detail of a zoning and network system. The level of detail of a zoning system is mainly related to the number of traffic analysis zones (TAZs) and their size. Each TAZ is characterized by land-use and population demographic characteristics that allow planners to estimate the number of trips likely to be produced and attracted to that TAZ (Meyer and Miller, 2001).The most detailed zoning system is made up of the individual households and generally they are aggregated to less-detailed TAZs based on the administrative district.

Determining the level of detail of a network system is concerned with how many levels to include in the road hierarchy (Ortúzar and Willumsen, 2001). The most detailed network system includes the lowest levels in the road hierarchy such as feeders, collectors, and streets.

A more detailed zoning and network system lead to increase of accuracy in travel demand forecasting. However a trade-off problem between the stability over time and accuracy of the analysis exists in practice. Namely, the detailed zoning and network system is warranted on the accuracy of analysis but not on the economy: required time and costs. For this reason, strategic studies, for example, would be carried out on the basis of lesser levels of detail of a zoning and network system. Therefore, levels of detail of a zoning and network system should be determined relying on the purpose and subject of research.

Besides, different levels of detail between a zoning and network system may lead to false conclusions, so called spatial aggregation errors. If one of them is only more detailed, it is not expected to have improved results. In other words, levels of detail of them are appropriately consistent with each other. This interaction between network level of detail and the zoning system has already been emphasized by Stopher (2004).

The purposes of this paper are to analyze interactions of aggregated zoning and network systems and to propose a method minimizing spatial aggregation errors stemming from aggregated zoning and network systems. Two new aggregated systems proposed in this study can represent traffic assignment results within a reasonable error range and also reduce time and costs required for an analysis significantly in comparison with the detailed zoning and network system. The EMME/2 program, a commercial software package, is used for the traffic assignment procedure.

This paper is organized as follows: In section 2, we review some published literature related to the aggregated of zoning and network system and present the research direction of this paper. Section 3 explains the methods of zoning and network aggregation. Section 4 presents the effects of TAZs and network aggregation by using statistical reliability tests for major measures of effectiveness (MOEs), evaluation indexes, and the socioeconomic costs related to economic feasibility analysis for transportation investment and planning assessments. In the last section, we summarize the results, discussions and make suggestions for further research.

2. LITERATURE REVIEW

2.1 TAZ Aggregation

Crevo (1991) experimented effects of zone systems on travel demand forecasting in New Castle, England. He used six criterions to determine the TAZs which were to be subdivided. Then nine TAZs were chosen for the study. He concluded a zoning which has a number of TAZs would not always improve the travel demand forecasting.

Ding (1994) showed how the size of TAZs impacts on the traffic performance characteristics, such as trip length and proportion of intrazonal trips on the fixed network by using TRANPLAN, a commercially available transportation planning software package, and ARC/INFO based on GIS. Since the intrazonal trips increased with the number of TAZs and interzonal trips decreased relatively, a vehicle kilometer and vehicle hour increased with it. Also, it was analyzed that intrazonal trips ratio to total trips was uniform if the number of TAZs was over 50.

Chang et al. (2002) used seven zoning structures and two levels of network detail to analyze effects of levels of zoning and network system detail in Idaho. Trips in a smaller zoning size have shorter trip lengths and higher proportions of interzonal trips and lower PRMSE (percentage root mean square errors) than larger zoning size.

Choi (2003) studied effects of the TAZ size on travel demand forecasting model to Uijeongbu-city which is one of the Korea cities. He used two zoning structures by means of the administrative district in Korea. One is composed of 13 TAZs and the other is 161. He reported that more trips assigned to major arterial roads than minor arterial roads in the larger TAZ size due to the increase of the interzonal trips.

Zhang and Kukadia (2005) studied the decisions of travel mode choice in the Boston. In this study, they examined the effects of the TAZ size in predicting mode choice decisions by using sensitivity analysis of the population density, network pattern, and land use balance. They concluded that using a grid with a TAZ size of 0.5 mile is the most desirable method of the data aggregation.

Martínez at al. (2007) studied potential errors caused by early methods to define a zoning scheme which is based on experience. Then they presented a set of quality criteria for a general zoning scheme using a geographic approach to the problem and some additional local optimizations to the results. They concluded that zoning system is not a trivial matter and it may cause statistical and geographical errors in the study results.

2.2 Network Aggregation

Bovy and Jansen (1983) studied aggregation level effects of zoning and network system on the link load, load kilometers, and load hours by equilibrium and all-or-nothing model to Eindhoven, Netherlands. Three network models were developed; a fine, a medium and a coarse one. The fine model consists of all streets with 1,286 TAZs. The medium model includes arterials and collectors with 183 TAZs. The coarse model is made up of only arterials with 47 TAZs. Centroid connectors are linked to all directions to travel trips equally. The PRMSE is used to estimate the differences between assigned link loads and traffic counts. They concluded that an increase in the level of detail always shows more improved results, but only marginal improvements can be obtained with increasing the level of detail of zoning and network system.

Chang et al. (2002) founded that the size of TAZs and the level of detail of network system effect on RMSE (root mean square error) values in two ways. Larger zoning system generated lower RMSE values than smaller on the less detailed network system and the detailed network system was superior to the less detailed network in terms of RMSE values regardless of the size of TAZs. The features of reviewed studies are shown in Table 1.

Discussions from reviewed papers are as follows. First, most researchers aggregated the either TAZs or network according to the purpose and direction of study and then analyzed its effects. Second, many studies compared the MOEs such as traffic volume by the size of TAZs and network detail but little attention was paid to the economic feasibility analysis of the project such as the road construction or improvement. In practice, travel demand forecasting is mainly used in the process of the economic feasibility analysis. Therefore, it is necessary to examine how much the level of details of a zoning and network system may affect the economic feasibility analysis in practice.

Therefore, as discussed above, three broader approaches in this paper are as follows. The first is to develop the two new aggregated zoning and network systems and to analyze the aggregation level effects of them on three MOEs such as traffic volume, travel time, and speed by the level in the road hierarchy of Seoul City by using the statistical reliability tests. Three reliability indicators are used to assess the fitness of the two systems multilaterally. The second is to calculate the socioeconomic costs used in the economic feasibility analysis of the project so that we can recognize the impacts of the aggregation levels of a zoning and network system on the project promotions. Lastly, a method to minimize the spatial aggregation errors stemming from the aggregated systems is suggested.

Table 1 Existing pertinent literature

Author	Zoning system	Network system	Reliability Indicators
Bovy and Jansen (1983)	Aggregation	Fine Medium Coarse	- RMSE - PRMSE
Crevo (1991)	Detail	Fix	- Correlation coefficient - Coefficient of determination
Ding (1994)	Aggregation	Fix	- Ratio of inter-zonal trips - Average speed - Vehicle hours - Vehicle mileage
Chang et al. (2002)	Aggregation	Less detail detail	- PRMSE
Choi (2003)	Detail	Fix	- Correlation coefficient - Chi-square - RMSE
Zhang and Kukadia (2005)	Aggregation	Fix	- Significant test of mean
Martinez at al. (2007)	Frequesias Grid TAZ TAZ GBRI	Fix	- Percentage of intra-zonal trips - Percentage of trips in non-statistically significant O/D matrix cells - 75th percentile of the zone equivalent radius

3. TAZS AND NETWORK AGGREGATION

Travel demand forecasting for Seoul city in Korea is usually performed by using the zoning and network system offered by Seoul Development Institute (SDI). This data consists of 522 TAZs and 12,949 network links and thus can improve the accuracy of the travel demand forecasting due to its detail. On the other hand, travel demand forecasting based on these detailed data requires considerable time and costs, which depend on the level of detail of a zoning and network system.

Table 2 shows major characteristics of the Seoul City network system offered by SDI. Since a sum of the length proportions from the "expressways" level to the "feeders and collectors" level is nearly 95%, the levels have a majority of roads in Seoul City. Figure 1 shows road networks in Seoul City by the level in the road hierarchy.

Table 2 Road network information in Seoul City

Road hierarchy (VDF number)	The number of links	Free flow speed	Total length (Ratio)
Expressways (1)	51	90km/hr	24.39km (0.8%)
Inner beltways (2)	52	80km/hr	76.70km (2.4%)
Urban express ways (3)	520	80km/hr	265.09km (8.3%)
Major arterial roads (4)	3,654	60km/hr	760.81km (23.9%)
Minor arterial roads (5)	4,578	50km/hr	1,021.68km (32.1%)
Feeders and Collectors (6)	3,483	50km/hr	900.10km (28.3%)
Other lower level roads (7)	26	50~70km/hr	16.90km (0.5%)
Ramp	585	40km/hr	116.88km (3.7%)
Total	12,949	-	3,182.54km (100.0%)

(a) Urban expressways (b) Major arterial roads

(c) Minor arterial roads (d) Feeders and collectors

Figure 1 Seoul city network by road hierarchy

3.1 Network Aggregation

A network aggregation method is adapted from that of Bovy and Jansen (1983). So network models are developed two different networks from the SDI network: a medium and coarse model. The medium model contains all roads of the SDI network except for the "feeders and collectors" level (VDF 6). The Coarse model is a network deleted both the "minor arterial roads" level (VDF 5) and the "feeders and collectors" level (VDF 6) on the SDI network. Additionally, the SDI network which is nearly similar to the actual road network is regarded as a standard model in this study.

The network models are strictly hierarchical, which means that a link included in a lower level network model should be also included in a higher level network model (Bovy and Jansen, 1983). So it is possible to analyze the each individual link.

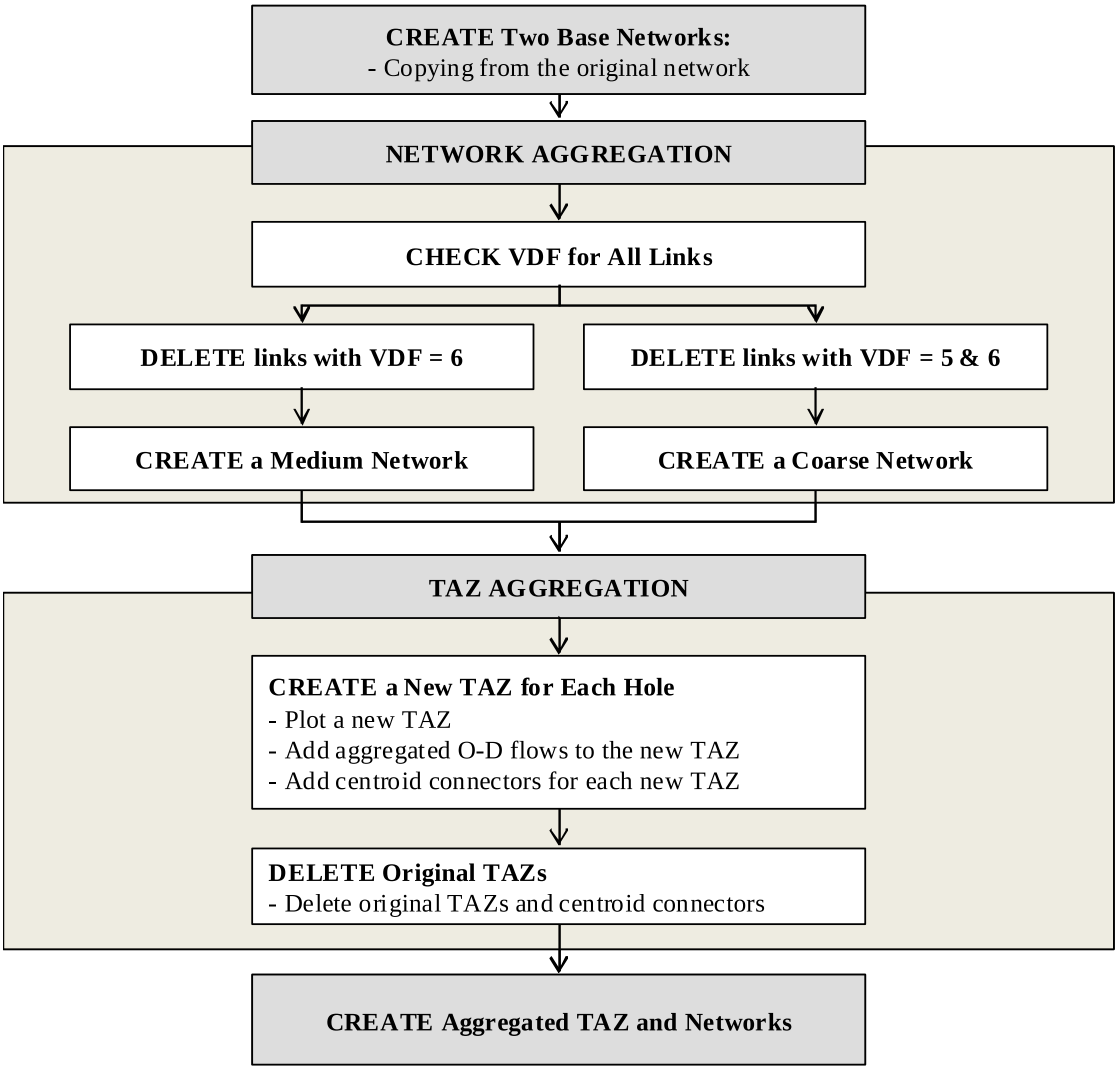


Figure 2 Flowchart of the method to establish aggregated zoning and network system

3.2 TAZ Aggregation

Seoul Metropolitan Area is made up of 1,142 TAZs and Seoul city consists of 522 TAZs of them in SDI data. A TAZ aggregation method is also applied from a concept of 'hole' used by Bovy and Jansen (1983). By removing the links, holes are made by remaining links and then one hole is regarded as one TAZ.

In this manner, existing TAZs in a hole are aggregated to new one TAZ. Then a centroid, is a point in which trips start and end at a TAZ, is linked to all directions by centroid connectors to travel trips equally. Centroid connectors are only linked to the lowest road level. For example, all centroid connectors are connected to the major arterial roads in the coarse network model. To minimize effects of the location of centroid, the lengths of all connectors are considered 0.01km. Figure 2 shows a flowchart of the method to establish the aggregated zoning and network system, such as the medium and coarse network models, from the original data.

4. RESULTS

4.1 Statistical Reliability Indicators

Statistical reliability tests consist of three parts. First, by using the paired z-test, two tail hypothesis tests are conducted based on major MOEs such as traffic volume, travel time and speed. Second, socioeconomic costs required for the economic feasibility analysis of a project are calculated and compared with these of the SDI network. Lastly, we compute three evaluation indexes (PRMSE, Theil's inequality coefficient, and correlation coefficient) which are used to evaluate the fitness of the estimates.

a) Paired z-test

The paired z-test is used to compare the average difference between two samples when their standard deviations are known (Stagliano, 2004). A Null hypothesis (H_0) and alternative hypothesis (H_1) are as shown below. Significant level (α) is set to 0.05 in this study.

H_0 : No difference exists $(\delta = 0)$
H_1 : Difference exists $(\delta \neq 0)$

The formula for the paired z-test is:

$$Z_p = \frac{d - \delta}{\sigma_{\bar{d}}} \tag{1}$$

where,
Z_p : the test statistic
d : the average difference between SDI and medium network (or coarse)
δ : the hypothesized paired difference (δ is zero by means of the purpose in this paper.)
$\sigma_{\bar{d}}$: the standard error of paired differences

If $|Z_p|$ is greater than $Z_{\alpha/2}$, we can reject H_0 and accept H_1. Whereas if $|Z_p|$ is less than $Z_{\alpha/2}$, we can accept H_0 as being true.

b) Socioeconomic Costs

Socioeconomic costs are generally defined as all measurable costs to users and communities in connection with a new project. Recognizing the changes of socioeconomic costs depending on the implementation of the project is an important part of the economic feasibility study since the study is generally performed by comparing the differences of socioeconomic costs (benefits) with the investment costs. Socioeconomic costs consist of four parts that are presented by Korea Development Institute: a vehicle operation cost, a travel time cost, an environment cost, and a traffic accident cost.

c) Evaluation indexes

Each formula of evaluation indexes used in this study is as shown below.

- PRMSE (Percentage Root Mean Squared Error) = $\frac{RMSE}{\bar{x}} \times 100\,(\%)$ (2)

- Theil's inequality coefficient = $\dfrac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2}}{\sqrt{\frac{1}{N}\sum_{i=1}^{N}{y_i}^2} + \sqrt{\frac{1}{N}\sum_{i=1}^{N}{x_i}^2}}$ (3)

- Correlation coefficient = $\frac{1}{N}\sum_{i=1}^{N}\frac{(y_i - \bar{y})(x_i - \bar{x})}{\sigma_y \sigma_x}$ (4)

where,
y_i : the value of estimate of link i (the medium or coarse network model)
x_i : the value of standard of link i (the SDI network)
N : the number of links
$\bar{y}$, $\bar{x}$: the average of the estimate and standard value, respectively
$\bar{\sigma}_y$, $\bar{\sigma}_x$: the standard error of the estimate and standard value, respectively

4.2 Network Models

Table 3 shows the major features of the SDI, medium, and coarse network models. In the medium network model, the number of TAZs was decreased from 522 to 309, which is about 59% of the SDI network model and the "feeders and collectors" level in the road hierarchy was deleted from the SDI network model. Running time required for traffic assignment procedure of the medium network model was about 24 minutes, which is about 20% of SDI network model (120 minutes).

In the coarse network model, the number of TAZs was aggregated from 522 to 86, which is about 16.5% of the SDI network model. Both the "minor arterial roads" level and the "feeders and collectors" level were deleted from the SDI network model. Running time to complete the traffic assignment procedure is about 10 minutes (8.3% of SDI network model).

Table 3 Major features of the SDI, medium, and coarse network models

Features	SDI network	Medium network	Coarse network
The number of TAZs	522	309 (59%)	86 (17%)
The number of links	12,955	9,426 (73%)	4,817 (37%)
Link length(km)	3,183	2,279 (72%)	1,252 (39%)

* The numbers in parentheses mean ratios of the medium or coarse network to the SDI network

4.3 Results of Reliability Tests

Table 4 and 5 show the results of reliability test statistics for MOEs and the socioeconomic costs, respectively. As shown in Table 4 and 5, the volume of the expressways and all MOEs of the inner belt ways in the coarse network model are resulted in lower test statistics than 1.96. Therefore, we can accept H_0, which means there is no evidence of differences of results between inner belt ways of the SDI network and that of the coarse network.

It should be noted that some differences exist among the MOEs of the other roads. Especially, major arterial roads that are linked directly to TAZs via centroid connectors in the coarse network have considerable differences. However, with the exception of travel time of the expressways, volume of the major arterial roads and all MOEs of the minor arterial roads in the medium network model, all other MOEs have lower test statistics than 1.96. It is a common trait in the both network models that links connected directly to TAZs via centroid connectors have significant differences in comparison with the SDI network.

Consequently, it is quite clear that the medium network model produces more improved results than the coarse network model as the study of Bovy and Jansen (1983). Similarly, the cost of inner belt ways in the coarse network model has the lowest difference from that of the SDI network. Total costs of all roads, however, have fairly significant difference about 146% due to the difference from major arterial roads. The medium network model, on the other hand, has a little bit differences in most of the roads. Especially, costs of urban expressways, inner belt ways, and major arterial roads are nearly identical with the SDI network.

Table 4 Reliability tests of MOEs by road hierarchy (Paired z-test)

MOEs	Expressways		Inner belt ways		Urban expressways		Major arterials		Minor arterials	
	Medium	Coarse	Medium	Coarse	Medium	Coarse	Medium	Coarse	Medium	Coarse
Volume	0.315	1.859	1.102	1.424	1.103	13.612	2.841	35.671	8.773	-
Travel time	2.064	3.176	0.237	0.157	0.312	8.291	1.433	24.398	6.179	-
Speed	1.278	2.345	0.214	0.757	0.285	13.207	0.501	27.830	5.877	-

Table 5 Reliability tests of socioeconomic costs by the level in the road hierarchy

Road hierarchy	Coarse network	Medium network	SDI network	Ratio	
				Coarse to SDI	Medium to SDI
Expressways	89,609	84,587	82,410	109%	102.6%
Inner belt ways	61,813	59,412	59,320	104%	100.2%
Urban expressways	743,014	640,990	640,165	116%	100.1%
Major arterials	1,970,285	1,397,386	1,373,803	146%	100.4%
Minor arterials	-	743,738	688,005	-	104.9%
Total	2,864,721	2,926,113	2,843,703	134%	102.9%

Table 6 shows the results of computing PRMSE, Theil's inequality coefficient, and correlation coefficient by the level in the road hierarchy. The medium network model has more improved results in all evaluation indexes than the coarse network model. According to the correlation coefficient, some values are founded by measurement to be high in spite of quite a few differences. It is because that the correlation coefficient tends to increase with the number of samples. Therefore, it is necessary that various evaluation indexes are examined to compare the errors.

Table 6 Reliability tests of three evaluation indexes by the level in the road hierarchy

Road hierarchy	Volume		Travel time		Speed	
	Medium	Coarse	Medium	Coarse	Medium	Coarse
Expressways	9%	12%	6%	12%	4%	8%
Inner belt ways	13%	25%	4%	10%	3%	5%
Urban expressways	7%	22%	8%	24%	6%	15%
Major arterials	19%	53%	13%	40%	11%	24%
Minor arterials	39%	-	21%	-	14%	-
Total	23%	45%	17%	36%	12%	21%

(a) PRMSE

Road hierarchy	Volume		Travel time		Speed	
	Medium	Coarse	Medium	Coarse	Medium	Coarse
Expressways	0.041	0.058	0.021	0.044	0.022	0.037
Inner belt ways	0.055	0.106	0.014	0.039	0.013	0.023
Urban expressways	0.035	0.098	0.028	0.078	0.028	0.074
Major arterials	0.088	0.211	0.048	0.145	0.052	0.121
Minor arterials	0.164	-	0.081	-	0.070	-
Total	0.088	0.178	0.062	0.121	0.059	0.107

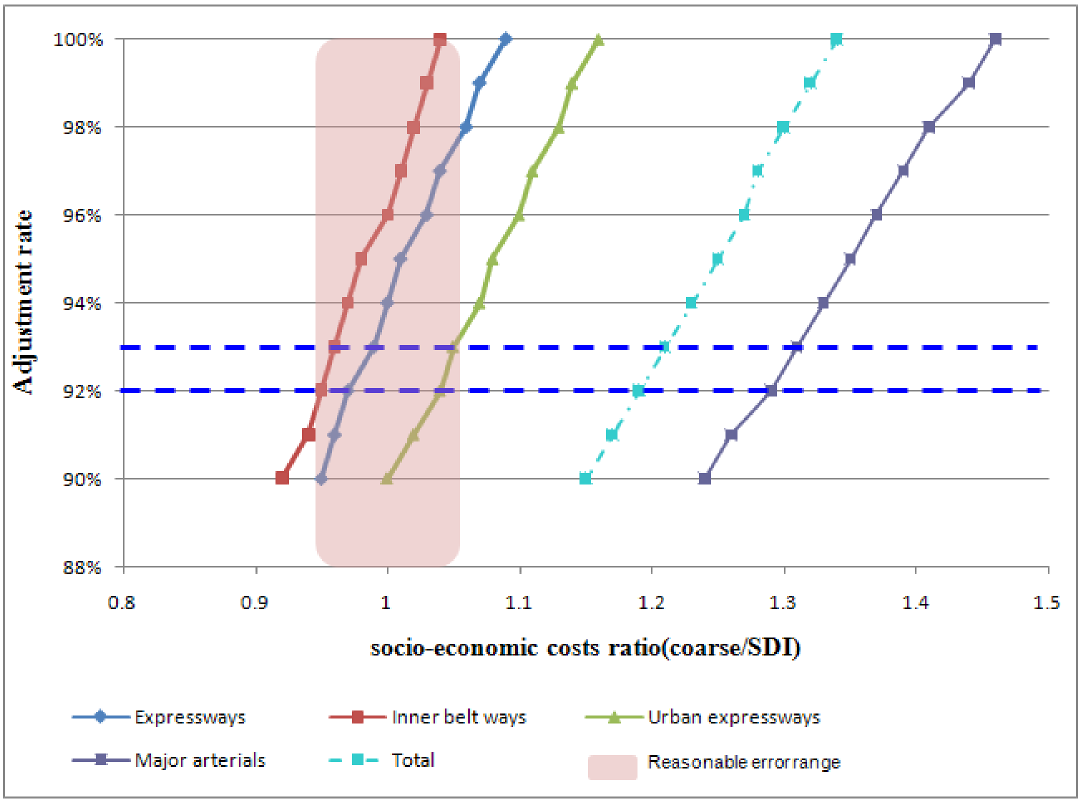
(b) Theil's inequality coefficient

Road hierarchy	Volume		Travel time		Speed	
	Medium	Coarse	Medium	Coarse	Medium	Coarse
Expressways	0.97	0.95	0.99	0.99	0.99	0.98
Inner belt ways	0.98	0.92	0.99	0.99	0.97	0.89
Urban expressways	0.98	0.89	0.99	0.98	0.97	0.85
Major arterials	0.91	0.65	0.99	0.93	0.88	0.60
Minor arterials	0.80	-	0.97	-	0.76	-
Total	0.96	0.80	0.98	0.95	0.89	0.81

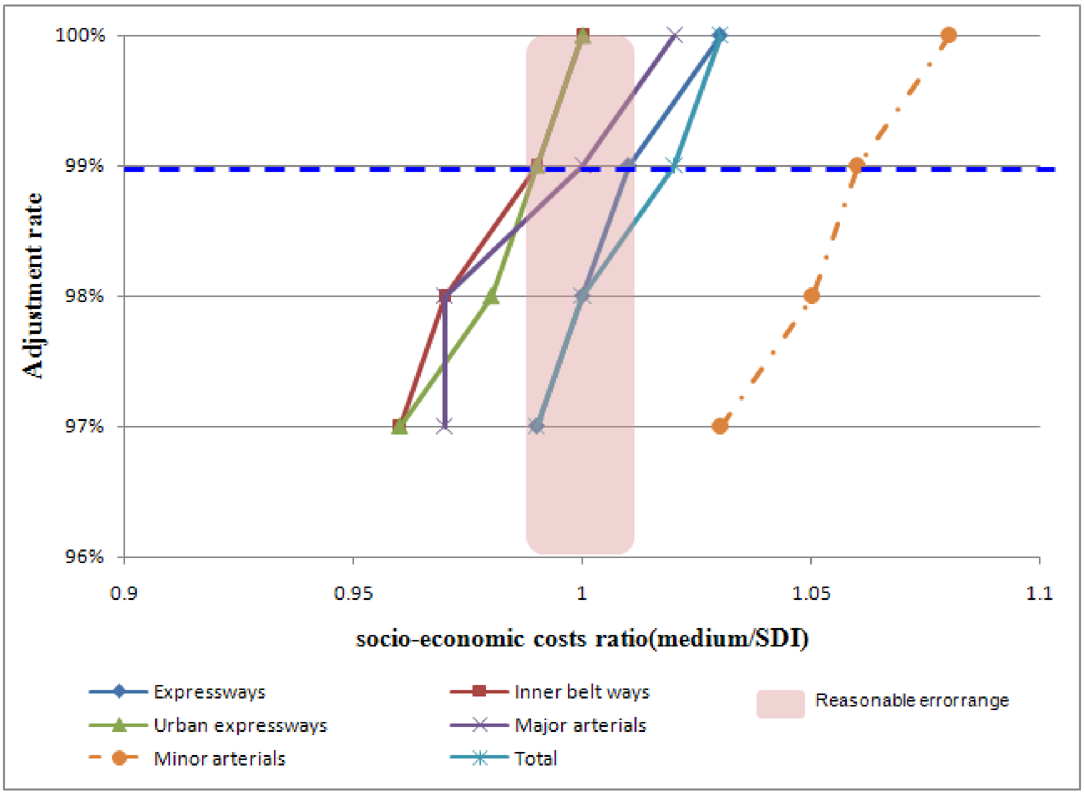
(c) Correlation coefficient

4.4 Modifying the Amount of Total O/D Flows

As examined above, traffic volumes on the whole are overestimated in the aggregation network models owing to the detours. For this reason, we compute the socioeconomic costs by decreasing each one percent of the amount of total O/D flows and find the rate of them which is satisfied with fewer differences of the costs. Figure 3 shows the cost ratios with the adjustment rates of total O/D flows in the coarse and medium network model, respectively, to suit the result of the SDI network. The values of x-axis mean the ratios of socioeconomic costs of the medium or coarse network to the costs of the SDI network.



(a) Coarse network



(b) Medium network

Figure 3 Cost ratios with adjustment rate in two networks

From Figure 3 (a), although we reduced the rate of total O/D flows from 100% to 90%, total costs ratio is still overestimated in the coarse network model due to the cost difference of major arterial roads (the alternated long and short dash line). The result shows that 92-93% of total O/D flows (the dashed lines) is reasonable in analyzing the levels in the road hierarchy from expressways to urban expressways when the reasonable error range is ±5%. In other word, the coarse network model reduced total O/D flows to 92-93% is appropriate for analyzing the higher level roads such as expressways, inner belt ways, and urban expressways.

From Figure 3 (b), when the rate of total O/D flows is 98%, socioeconomic costs of urban expressways, inner belt ways, and major arterials are more underestimated than before. Therefore, 99% of total O/D flows which meet the costs of each level in the road hierarchy within a reasonable error range are appropriate for considering higher level roads from expressways to major arterial roads in the medium network model when the reasonable error range is considered ±1% to increase the reliability more than in the coarse network model.

5. CONCLUSIONS

The purposes of this paper are to analyze interactions of aggregated zoning and network systems and to propose a method minimizing spatial aggregation errors stemming from aggregated zoning and network systems. Statistical reliability tests are performed to assess the fitness of the proposed aggregation levels.

The aggregation method proposed by Bovy and Jansen (1983) were applied to the zoning and network system of Seoul City and then both the medium and coarse network were developed, respectively. Besides, the amount of total O/D flows was adjusted to suit the result from the SDI network since the detours from lower level roads to higher in the road hierarchy may cause the overestimation of the aggregated flows.

The results of the coarse network show that it can be used for the transportation planning and investment assessments for the express ways, inner beltways, and urban expressways when total O/D flows are decreased by 7-8%. And the assignment results with the medium network proposed in this paper were more similar to the results with the SDI network while they required a little more time than with the coarse network. Furthermore, 1% decrease of total O/D flows can make closely similar results to them of the SDI network and it is possible, therefore, to apply the medium network instead of the SDI network to examine both the MOEs of roads and the economic feasibility analysis within a reasonable error range.

The aggregated zoning and network systems for Seoul City proposed in this paper are expected to be used for transportation planning for roads such as expressways, inner belt ways, urban expressways, and major arterials. Especially, the aggregated zoning and network systems are expected to contribute to a methodology for proposal and preliminary feasibility studies and then to provide an objective and rational basis for the project promotions.

This paper was examined to Seoul City, Korea. To generalize the aggregation methods, it is believed that further experimentation to the other cities with the aggregation methods outlined is worthwhile.

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