공학박사 학위논문

Effects of Changes in Bus Supply Level on Urban Rail Demand Forecasting

버스 공급수준의 변화가 도시철도 수요예측에 미치는 영향

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Abstract

The problem of misleading forecasts on the road is less severe and less one-sided than for rail. As the cause of this severe and nonrandom error of rail demand forecasting, this study focuses on the unexpected increase of bus supply level and the modal share prediction errors caused by the unexpected bus supply level change in the process of mode split. If a new rail line is planned for an area where large land developments are expected, the level of bus supply at the time of development planning and level of bus supply at the time of development completion would be different, and this may cause overestimation of rail demand.

Therefore, this study developed a model to forecast the bus supply level and suggested a method to apply the model in the urban rail demand forecasting process. To consider the effect of change of future bus supply level, post-processing analysis which re-estimates urban rail demand by using cross-elasticity and the differential rate between bus supply level of existing model and the proposed model.

By using the proposed model, four cases of previous urban rail demand forecasting studies were re-reviewed. In Shinbundang-line, Yongin light rail, Gimpo metro line and Byollae-line case studies, the impacts of bus supply level change on the rail demand forecasts ranged from 16% to 41%. In this proposed model, the error was less than 5% and showed high predictability except for the case of Byollae-line.

In Byollae-line case, the results of both of the existing model and proposed model showed large error rate to the observed demand. The source of this relatively large error of Byeollae-line case is supposed that several land development plans are neighboring, and buses running through the districts may be overlapped. It is assumed that the overlapping buses cause errors in several districts, as a result, causing relatively large errors.

This study suggests the unexpected change of bus supply level as a major source of rail demand forecasting error, which has been failed to be considered in previous studies and guidelines. This study is distinct from previous studies regarding the impact of change of bus supply level on urban rail demand forecast was quantified, and a model to forecast the bus supply level was developed and applied to improve the reliability of demand forecasting.

Keywords : demand forecasting error, bus supply level, land development, mode choice, cross-elasticity

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Chapter 1. Introduction

1.1. Background

Establishing a transportation plan is to determine the location and size of traffic facilities, and how to deploy them to meet the transport demand. Construction of transport facilities required a substantial amount of budget investment, whereas the available funds are limited. Therefore, the funds are invested in projects which have the greatest benefits on the cost spent. Analysis of traffic demand, costs and the benefits of facility construction is needed to assess the feasibility of a traffic facility project and determine the priorities among the projects.

In traffic planning process, traffic demand forecasting is essential not only to assess the priority of investment but also to determine the proper supply size and timing of construction and to analyze the impacts on surrounding area and the environment. Also, for a private investment project, the traffic demand estimation result is the key indicator for determining the feasibility of the project, fares, government subsidies and the rate of return.

For large-scale transport facilities construction, future demand for about 30 to 40 years ahead is predicted. For the difficulties in long-term prediction, various sources of errors and uncertainties in the demand estimation process are causing the errors in estimating traffic demand, resulting in controversy over the inaccuracy of the traffic demand forecasting.

In particular, the demand for transportation was overestimated for private investment projects, which put a burden on the government's national finance by providing huge operational subsidies to private businesses. Also making it uncomfortable for citizens as it is unclear whether the private project operators will go on the business as they go bankrupt due to operational difficulties stemming from the failure to predict demand for the facilities.

Table 1.1 Traffic demand for road project(predicted vs. observed)

Highway	Section	Opening year	Traffic demand for the 3rd year of operations (vehicle per day)		
			predicted	observed	error rate (%)
Seoul Ring Expressway	Pangyo - Anhyun	2000	114,981	147,933	-22.28
Jungang Expressway	Seoandong - Jecheon	2000	10,652	15,005	-29.01
	Jecheon - Manjong	2001	17,901	20,085	-10.87
	Manjong - Chuncheon	2001	8,640	12,863	-32.83
Seohaean Expressway	Donggunsan - Daecheon	2000	36,216	41,252	-12.21
	Mokpo - Muahn	2001	21,366	15,693	36.15
Tongyeong Daejeon Expressway	Muju - Sannae	2001	30,831	29,042	6.16
Jungbu Naeryuk Expressway	Yeoju - Chungju	2002	38,179	34,145	11.81
	Gimcheon - Sangju	2001	32,106	118,004	-72.79
Iksan Pohang Expressway	Dodong - Chungtong Wachon	2004	42,852	22,320	91.99

Source: Chung and Chang(2007)

Table 1.2 Traffic demand for rail project(predicted vs. observed)

Highway	Opening year	Opening year		
		predicted	observed	error rate (%)
Incheon Int'l Airport Railroad Express	2007	248,294	20,111	-91.9
Shinbundang-line (Gangnam - Jeongja)	2011	273,318	112,407	-58.9
Seoul Metro 9th line (Gaehwa - Sports complex)	2009	220,279	194,630	-11.6
Busan-Gimhae Light Rail	2011	198,848	38,112	-80.8
Uijeongbu Light Rail	2012	98,472	21,166	-78.5
Yongin Light Rail	2013	174,712	23,406	-86.6

Source: Kim (2016)

Various studies have been conducted to identify the causes of errors, uncertainties, and risks in predicting traffic demand. Also, various studies have been conducted to quantify the effects of errors and the magnitude of future errors to occur by applying techniques such as sensitivity analysis, scenario analysis, and Monte Carlo simulation analysis.

Despite various efforts to identify and quantify the causes of traffic demand forecast error, studies on the quantification of the impacts of uncertainties of assumptions and prospects are limited. Moreover, although traffic demand forecasting techniques have improved and socioeconomic indicators data used to predict traffic demand have become more accurate, the accuracy of traffic demand forecasting is not shown to improve over time.

Fyvbjerg et al.(2005) studied the accuracy of traffic demand forecasting for 234 transportation infrastructure projects. The result has shown the problem of misleading forecasts on the road is less severe and less one-sided than for rail. For road projects, the traffic estimates are highly, systematically and significantly inflated. The same result was observed in the forecast of domestic road and rail projects. The comparison result of predicted and observed traffic demand is presented in Tables 1.1 and 1.2.

As for the source of errors, to identify the what causes the severity and nonrandomness of rail demand forecasting, Flyvbjerg et al.(2005) conducted a survey targeting project managers to account for the factors that would explain why observed traffic was different from forecasted traffic. The results of the survey show that the "uncertainty about trip distribution", "deliberately slanted forecasts" were suggested as the most important causes of errors for rail projects. For road projects, the two most often stated causes for inaccurate traffic forecasts are uncertainties about "trip generation" and "land-use development."

That is, the rail project analysts are under pressure to overestimate the demand for window dressing, self-serving and the pressure is greater than for the road projects.

The fact that various studies on the causes of demand for transportation projects point to the intentional bias of analyst as one of the main causes supports this assumption.

Despite the difficulties in proving quantitatively and empirically, intentional bias is judged as the major cause of errors, so, punishing analysts when forecasting error occurs and emphasizing analysts ethics and morality are suggested as a way to improve demand forecast accuracy.

Unlike Flyvbjerg et al.(2005), Namgung et al.(2010) indicate that demand forecast of rail projects takes an additional process of mode split while it is not necessary for road projects. Namgung et al.(2010) suggested the unexpected increase of the number of bus lines and the modal share prediction errors caused by the unexpected bus line increase in the process of mode split as the major cause of errors. This study has proved that as the future supply level of other competitive transport mode is uncertain at the point of demand analysis, the change of the supply level of bus affects rail demand estimates.

As for the demand forecasting of rail projects, the level of transportation supply, especially bus, varies from time to time. This variability is greater in areas where drastic population growth is expected as a result of larger land development plans. If a new rail line is planned for an area where large land developments are expected, and the population is expected to increase, one can assume that the level of bus supply at the time of development planning and level of bus supply at the time of development completion would be different.

The results of the survey on the changes in bus supply levels before and after the large-scale developments in the Seoul metropolitan area are shown in Table 1.3 below. The results of the survey showed that the number of bus lines when the population growth caused by a land development has completed(or partially completed) increased by 54% to 467%.

Table 1.3 Number of bus lines before and after land development completion

Land development district	# of bus lines before land development*	# of bus lines after land development**	Change rate of the number of bus lines(%)
Goyang Samsong	9	17	88.9%
Gimpo Hangang Newtown	15	31	106.7%
Namyangju Byeollae/Guri Galmae	5	21	320.0%
Suwon Gwangyo	43	71	65.1%
Suwon Homaesil	14	24	71.4%
Osan Segyo	5	12	140.0%
Yongin Dongbaek	3	17	466.7%
Paju Gyoha	5	8	60.0%
Paju Unjeong	13	20	53.8%
Seongnam Pangyo New Town	8	33	312.5%
Hwaseong Dongtan	26	49	88.5%
Hwaseong Dongtan2	14	40	185.7%
Hwaseong Hyangnam	3	17	466.7%

* : the number of bus lines at 2010 was suggested as the number of bus lines before land development due to data limitation

** : the number of bus lines realized at the point of completion of land use development or present time(2017.12)

Source: Gyenggi Traffic Information Center(http://gits.gg.go.kr)

Rail facilities are developed to handle the traffic demand in areas that have already developed, and the population growth is stable or, areas with larger development plans and drastic population growth is being expected in the future. For areas that have already developed and the population growth is stable, the possibility of bus supply levels change in the future is relatively low. On the other hand, for areas with larger development plans and drastic population growth is being expected, the bus supply level increased to satisfy the increasing traffic demand. If the bus supply level increases by the number of bus lines or the service frequency in an area where new rail line is going to be developed, the modal share of bus increases. On the contrary, the modal share of rail decreased.

This trend is apparent in rail projects, especially urban rails. Inter-regional rails compete with aviation or express buses, and they do not alter the supply levels significantly with regional development plans. Urban rails, on the other hand, compete with passenger cars, taxis, and intra-city buses. Among modes, buses tend to change their supply levels according to regional land developments and population change. Therefore, if the change of bus supply level caused by population growth in land development district is not properly forecasted and applied in the demand forecasting process, the rail demand will be overestimated.

The change in the bus supply level can be expected to be even greater in the situation that the time delay between that rail facilities are built, and traffic demand in the developed areas occurs. If rail facility is not yet developed, in spite of the development of land development and population growth, buses will attract public transport users, and its supply level will increase to satisfy the demand. The more the demand, the more supply will be provided, and this increases the utility of bus users. When the rail is completed, the supply level of the buses is higher than the supply level at the time of demand forecast, and the forecast result for the urban rails is incorrect.

As a result, surveying the existing rail project cases, we have verified that there were some cases in which the design and construction process took longer than ten years and delayed due to various factors. Therefore, we can expect that the longer the construction of rail facility is delayed the bigger the rail demand forecasting errors.

Table 1.4 Temporal data on the land developments and new rail facilities

land development district	Opening year (expected)	1st-year move-in	Rail facilities	Rail opening year
Pangyo new town	2011	2010*	Shinbundang-line (Gangnam - Jeongja)	2011
Yongin Heungdeok	2010	2009*	Shinbundang-line (Jeongja - Gwangyo)	2016
Yongin Dongbaek	2009	2007*	Yongin Light Rail	2013
Namyangju Byeollae	2011	2012**	Byeollae-line	2022
Gwangyo	2011	2012*	Shinbundang-line (Jeongja - Gwangyo)	2016
Gimpo Hangang new town	2012	2012*	Gimpo metro line	2018

* : partially completed

** : fully completed

Source: Korea land and housing corporation(http://www.jigu.go.kr)
Statistics Korea(https://sgis.kostat.go.kr)

Although various studies have been conducted to determine the cause of the demand forecast error for rail facilities and to quantify the effects, studies on the change of bus supply level and its effects on demand forecasting error are limited. Most of the studies focusing on the effects of competitive mode stay at the very basic level.

To reflect the change in bus supply levels in the process of rail demand forecasting, it is necessary to forecast that future bus supply levels at an appropriate level based on development plans. However, most of the studies concerning the level of bus supply are limited to the study of the design of optimal bus routes or to the study of determining the service frequencies considering bus capacity. Also, there are no guidelines on determining of bus supply level nor bus route design to follow.

To improve the accuracy of rail demand forecasting, it is necessary to investigate the change in bus supply levels before and after completion of the land development where population growth is expected. And applying the developed model in the process of urban rail demand forecasting, the errors can be improved, and reliability of demand forecasting model can be enhanced in the future.

1.2. Purpose of this study

Developing new rail line may take ten or more years from the time planned to construction complete. And once the construction is completed, it is not easy to change the routes or improve service levels. On the other hand, buses that are a competitive mode of rail are flexible to change their service level and introduce new routes following the changing demands.

Although bus supply levels can fluctuate as population and traffic demand changes, the existing urban rail demand forecasting method does not reflect the change of bus supply level caused by the increase in population and traffic demand. Instead, existing demand rail demand forecasting method assumes that bus supply levels at the forecast point of demand will remain the same in the future.

If an incomplete development plan exists within the impact area of new rail project and the change of bus supply level was not accounted in the forecasting process, errors will be generated in calculating the modal shares of bus and rail depending.

In this study, asides from the uncertainty of the socioeconomic indicators, the change of bus supply level due to land development is being suggested as the major source of errors in urban rail demand forecasting.

Exogenous variables like the socioeconomic indicators(population, the number of workers), land development plan contains inherent uncertainties. On the other hand, changes in the supply level of the bus have not previously been considered as a major cause of errors, but can be analyzed when the data on bus supply level is accumulated.

By applying a model to predict the changes in bus supply levels due to the land development plans in the process of urban rail demand forecast, demand forecast errors which are generated when the existing method is applied can be reduced. And the reliability of demand forecasting model can be improved.

The purpose of this study is to analyze the impact of changes in bus supply levels due to land development plans on urban rail demand forecast errors and to develop a model to predict the changes in bus supply levels and a demand forecasting method applying this model. As the result of this study, the rail demand errors can be mitigated, and the reliability of demand forecasting model can be improved.

1.3. Research flow

The flow of this study is as follows.

In Chapter 2, a literature review is conducted concerning the cause of traffic demand forecast errors to investigate the cause of the urban rail demand forecast failure. And the existing literature on the factors determining bus supply levels is reviewed. Since this study suggests that the change of bus supply levels is the major source of urban rail demand forecasting error, the method to forecast the bus service level change and apply in demand forecasting process is being examined.

Chapter 3 presents the framework for the analysis of urban rail demand forecasting model proposed by this study. Based on the prediction model of bus supply levels, data of explanatory variables affecting bus supply levels and bus supply levels are collected. And a regression analysis is performed to build the bus supply level prediction model.

In chapter 4, case studies are being conducted by applying the urban rail demand forecast model of this study suggests. Through the case studies, the impact of bus supply level change on demand forecast errors is being quantitatively identified. And the comparison of forecasted and observed demand when applying the model to this study verifies the accuracy of the forecast model proposed in this study. And by comparing the predicted demand estimated using the model proposed in this study and the observed demand, the accuracy of the model proposed in this study will be verified.

Finally, Chapter 5 presents the conclusion and the future research.

Chapter 2. Literature Review

2.1. Studies on sources of errors in demand forecasting

The type of error that is typical in traffic demand analysis is divided into measurement errors, model specification errors(structural errors) and external errors(Mackie and Preston, 1998; Flyvbjerg et al., 2005; World Bank, 2005; Chung and Chang, 2007).

Measurement errors are driven by the inaccuracy of data used for traffic demand analysis, mostly resulted from biases and blunders. Model specification errors occur in the process of the development and application of the traffic demand forecast model, mostly resulted from mistakes and uncertainties. Lastly, external errors are caused by external input variables or assumptions used to estimate traffic demand. They have mostly resulted from the uncertainties which are out of control of the study(Chung and Chang, 2007).

Measurement error is caused by the insufficiency of data. Despite the traffic demand patterns, current states of traffic and parameters describing traffic patterns are essential to the accurate description of the current situation, acquiring cost of these data is high. Also, in most cases, only a portion of the data needed to predict demand can be obtained or is too old to explain the current situation sufficiently. Building the model based on such incomplete data causes errors.

World Bank(2005) suggests that the type of measurement error occurs when the hourly, daily and seasonal variations in road traffic are not considered. Also, the lack of bus passenger data due to the difficulty in surveying bus passengers and the lack of freight data due to the data privacy of corporation is suggested as the source of measurement errors. If reliable data on the frequency and route of public transport services are not available, supply-side measurement errors may occur due to the difficulty of obtaining the data without additional investigation. For conversion of the single day observations into an average daily level require continuous observed data throughout the year, and the surveys are costly. If sufficient data cannot be accumulated, the parameters describing the transit behavior are estimated incorrectly and resulting in measurement error.

Model specification errors are caused by misspecification of the correlation between variables in the traffic demand prediction model, which includes mathematical relationships between variables. Errors are generated when the effects of important explanatory variables such as income, GDP, trip distance, and cost, are missing or misinterpreted in demand forecasting models. Also, when it is not appropriate to apply the same model built for a specific time or location to another time and location, and to apply aggregated data on a model constructed based on disaggregated data model using non-constructional data, Model specification errors occurs.

Finally, external errors are associated with external inputs or assumptions used in demand forecasting models.

Various socioeconomic indicators such as population, incomes, GDP, number of students and workers, are difficult to predict and contains inherent uncertainties since they are estimated outside the traffic demand forecast model. The land development plan reflected at the planning stage may or may not be realized. Since land development plans are assumed that they will be fully realized, they can cause the errors by not being fully realized.

In World Bank(2005), 1) GDP and income growth forecasts, 2) Population forecasts, 3) Vehicle ownership forecasts, 4) land development planning, 5) Future year supply-side inputs such as fares, service frequencies were suggested as exogenous variables which contain uncertainty.

Chung and Chang(2007) suggested the cause of the error for each stage of the traditional four-step model of traffic demand forecasting. In trip generation step, in which estimates the rip productions and attractions from traffic zones using socioeconomic indicators, if the data is lack of representability or the hourly, daily and seasonal variations in road traffic are not considered, errors can be generated.

In trip distribution step, in which traffic is allocated between traffic zones, errors are caused by uncertainty in the social, economic indicators and the limitations in the traffic survey method.

In trip assignment step, reasonable paths between traffic zones are generated, and the traffic volumes are allocated on these paths. At this step, errors are generated concerning the calculation of internal traffic rates, average passenger occupancy, passenger car equivalents, volume-delay function, the setting of traffic analysis zone and the unreasonable standard for error tolerance.

In mode split step, the traffic volumes are being split among modes, so, in case a new transport mode such as high-speed rail or aviation is implemented and failed to reflect the utility of new mode properly, errors are generated. Also, the omission of rival transport mode is presumed as typical error source.

In a study on traffic demand forecast error, Flyvbjerg et al.(2005) analyzed 208 road projects, and 26 rail projects in 14 European countries and the results on the accuracy of the demand forecast of these traffic projects were presented. Also, through a questionnaire survey targeting transport project operators, the sources of traffic demand errors were investigated.

As a result of a survey, demand forecast errors were shown a noticeable difference in road and rail project. For rail projects, the errors tend to be overestimated and while that of road projects balanced between overestimation and underestimation was and relatively low. If the uncertainty in the forecast of traffic volume is a problem with the demand forecast model or the uncertainties of information due to the lack of data, the error should show randomness. However, the survey result shows that the errors show non-random bias, and this non-random bias is greater especially on rail projects.

Flyvbjerg et al.(2005) suggested that the "uncertainty about trip distribution," "deliberately slanted forecasts" as the most important causes of errors for rail projects. And for road projects, the two most often stated causes for inaccurate traffic forecasts are uncertainties about “trip generation” and “land-use development.”

Table 2.1 Types of errors in each demand forecast step

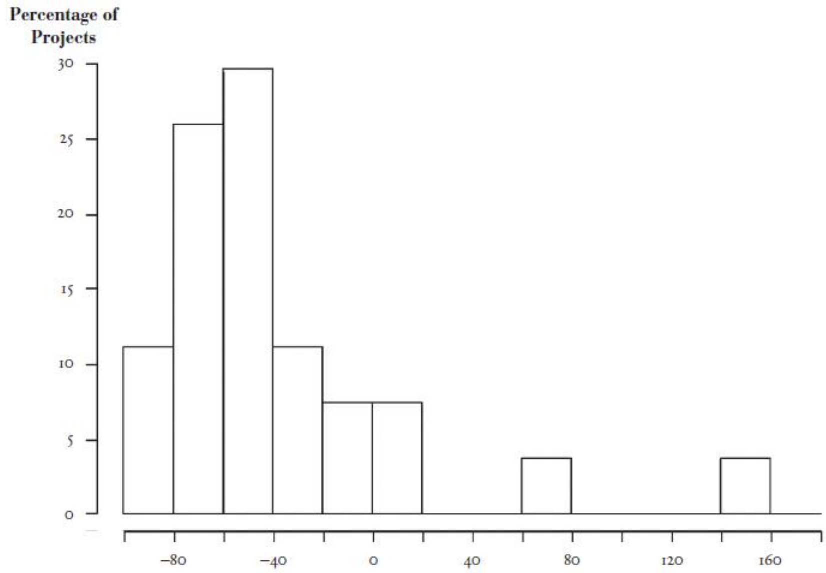
categories	Types of errors		
	measurement errors	model specification errors	external errors
major causes	biases, blunders	mistake, uncertainties	uncertainties
Trip Generation	• representativeness of sample data • limits of interviewing method • issues on weekend and leisure traffic volume estimation • issues on the validity of samples • problems in the process of actualizing	-	• uncertainties of development plans

Table 2.1 Types of errors in each demand forecast step(Continued)

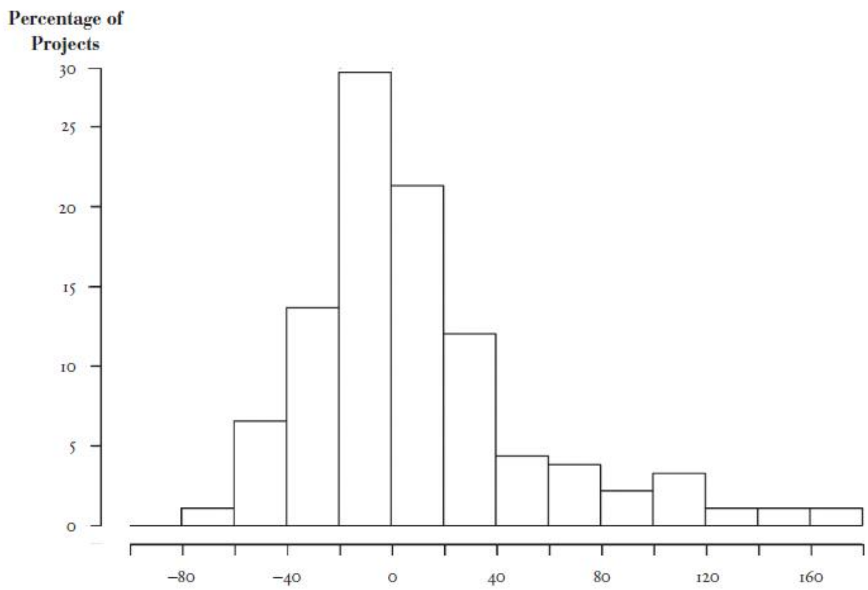
categories	Types of errors		
	measurement errors	model specification errors	external errors
Trip Distribution	• issues with the calculation of internal traffic rates • errors in converting 167 zones to 250 zones	• errors in converting daily traffic data into hourly data • problems with application of pratar models • problems with adjustment coefficients • issues with zero cell	• uncertainties of socioeconom ic indicators
Mode Split	-	• issues with transferability of model • the omission of rival modes	-
Trip Assignment	• problem with the calculation of peak and non-pink traffic volume • the setting of traffic analysis zone • discordance between O/D and network	• problem with calculation of average passenger occupancy and passenger car equivalents • issues with volume-delay functions • unreasonable standards for error tolerance • errors due to the convergence level of the model • problem with the selection of calibration point and its randomness	-

Source: Chung and Chang(2007)

Figure 2.1 Inaccuracy for road and rail projects



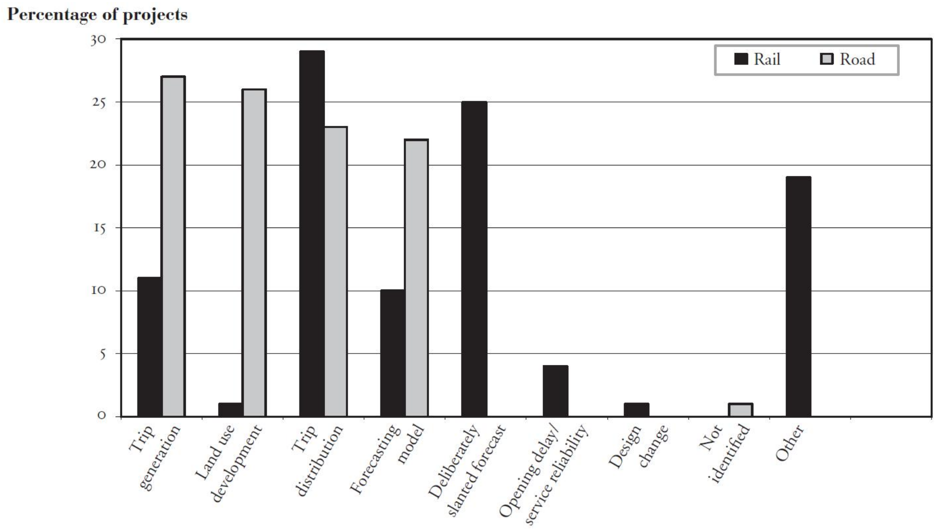
Inaccuracy (%) for Rail Projects



Inaccuracy (%) for Road Projects

Source: Flyvbjerg et al.(2005)

Figure 2.2 Stated causes of inaccuracies in traffic forecasts(N=26 rail projects and 208 road projects)



Source: Flyvbjerg et al.(2005)

Deliberately slanted forecasts are cited as the cause of errors in various studies on traffic demand forecast errors(Kain, 1990; Walmsley and Pickett, 1992; Pickrell, 1989; Wachs, 1986; Wachs, 1992; Mackie and Preston, 1998; Yiftachel, 1998; Flyvbjerg, Holm, and Buhl, 2002; Flyvbjerg, Bruzelius, et al., 2003; Watson, 2003; Flyvbjerg et al., 2003; Kim, 2010). Optimistic forecasts are seen as a means to getting projects started and raising funds. Thus, the planners estimate the demand optimistically, despite the fact that it is violating the public interest,

Wachs(1982) approached the tendency of overestimation of the traffic demand forecast analysts as an ethical aspect. The ethical dilemma faced by traffic demand forecasting analysts, or the inherent dilemma of circularity, in the forecasting process, is cited as the main cause of demand forecasting failures. If the forecasting result suggests that the project is not feasible, then the project is no longer going to go ahead. And the subsequent contract may not be awarded. So, the analyst is under pressure to adjust demand forecast results for a self-serving purpose.

Wachs(1982) suggested that the pressure for overestimation will be intensified since the forecast is inherently unverifiable, the outcome of a forecasting exercise is to a great extent determined by its core assumptions, and the activity of forecasting is technically complex, revealing to most users its results but not its mechanisms or assumptions.

Kain(1990) studied the failure of the demand forecasting failure of Dallas Area Rapid Transit construction project case, presented the reasons for the failure identified in interviews with project managers

The project managers judged that they failed to include the most viable technologies and alternative the evaluation process of DART projects. Also, land development and the rate of employment of CBD regions were falsely estimated and the data is too old to explain the current situation sufficiently. On the other hand, it was suggested that the demand analyst would be influenced by the preferences of policy makers. The public official's preference for rail was so strong that the demand analyst did not add any alternative, except for the rails. To support the result, the land development plan, the forecast of the employment rates in the CBD region was inflated.

In a study on the cause of the demand forecast error for rail projects, Kim(2010) suggested uncertainties in error, measurement error, model specification error and factors in political, institutional and psychological aspects as the causes of the error.

Kim(2010) assumed that the errors were not likely to occur randomly but systematically overestimated due to political, institutional and psychological aspects. Also, there is a temptation toward expansion of the organization and window dressing and the influence by the preferences of policy makers.

Flyvbjerg et al.(2003) analyzed the feasibility of a mega project. The risks and causes of uncertainties occurring in the process of planning and construction were identified. The methodological errors, poor database, the effect of discontinuous behavior of travelers, the unexpected changes of exogenous factors, unexpected changes of policies and the implicit appraisal bias of the consultant were suggested as the key sources of errors.

When comparing observed traffic volume to predicted traffic volume after the opening of a mega transport project, the result was shown that the projects analyzed by the project promoters were more optimistically biased than the projects analyzed by demand forecast experts. This is because there is a clear interest for those who are pursuing the project, and because the pressure to keep the professional criteria for estimating traffic volume and comply with the guidelines were less than that of experts.

Various studies have suggested that the uncertainties of data and model as the sources of errors. At the same time, the optimism bias in political, institutional and psychological aspects was considered as a major source of errors, especially for rail projects. Such optimism bias is greater in rail projects, that is because there are incentives to encourage the demand forecast analysis to overestimate the demand for a self-serving purpose, or because the policy makers prefer rail.

Unlike most studies on optimism bias suggesting optimism bias is concerned with the intention of analysis experts or policy makers, Mackie and Preston(1998) suggested there is a systematic tendency to appraisal optimism. In the study of Mackie and Preston(1998), 21 sources of error and bias in the appraisal of transport projects were identified. In identifying these sources, they have verified the systematic tendency to a mega error that of appraisal optimism. Among 21 sources of errors, 12 sources tend to act systematically in one direction to promote appraisal optimism, while 8 other sources are less likely to act systematically to promote appraisal optimism.

In Mackie and Preston(1998), it is notable that this study focused on the demand forecasting system itself not only the optimistic tendency of the analyst. Failure to take into account the slow build-up in demand, failure to take into account the dynamics of traffic system and the behavior of travelers, underestimation of the reaction of rival transport operators and infrastructure owners are those errors.

Table 2.2 Sources promoting appraisal optimism

Category	Sources of errors
Sources promoting appraisal optimism	1. Prior political commitment
	2. Overestimates of existing travel volumes
	3. Full range of low cost 'do-something else' options omitted; performance of base case unrealistically poor
	4. Subsequent Gold plating* of the 'do-something' option
	5. Overestimate of population and economic growth
	6. Overestimate of the performance of the new transport facility, particularly regarding speed
	7. Underestimate of the reaction of rival transport operators and infrastructure owners
	8. Failure to take into account the slow build-up in demand/Dynamics not taken into account
	9. Asset lives overestimated
	10. Quantifiable costs excluded
	11. High valuations attached to scheme benefits
	12. Benefits counted twice or even three times in different parts of the appraisal

*Gold Plating: Inflation of cost by including of expensive items that are not needed for construction or renovations to justify a substantial increase in a large budget

Source: Mackie and Preston(1998)

Table 2.3 Sources less likely to promote appraisal optimism

Category	Sources of errors
Sources less likely to promote appraisal optimism	1. Unclear objectives may help promote or reduce the prospects of a scheme going ahead
	2. If the study area is defined too tightly, this may reduce forecast net benefits (e.g., park and ride schemes) or increase them
	3. Planning bias may arise due to developments that were expected to take place but did not happen or were not expected to take place but did
	4. Model error may lead to under- or over-estimates of impacts
	5. Problems with transfers most commonly occur when an impact is treated as a net benefit but is, in fact, a transfer. However, in some cases, a net benefit may be treated mistakenly as a transfer(as occurred with rail revenue from non-bus users in the Cambrian Coast line closure study (Sugden, 1972)).
	6. The omission of non-quantifiable impacts may go either way.
	7. The omission of systems effects may go either way.
	7. Rule changes during the planning period may increase or reduce the chances of a scheme going ahead, with the latter being the more common.

Source: Mackie and Preston(1998)

About the dynamics not taken into account, Mackie and Preston(1998) presented the Manchester Metrolink cases in the U.K.. At the point of demand analysis of Manchester Metrolink, which opened in 1992, demands for former suburban rail service were expected to move to the Manchester Metrolink. But, when the Manchester Metrolink opened, it has been revealed that only three-quarters of the users of suburban rail used the Manchester Metrolink.

Vaughan and Gane(1994) believed that because of the suspension of the suburban rail service for over a year while the Metrolink was being built. For some rail users found alternatives which they continued to use after the Metrolink was opened. As a result, the demand for Manchester Metrolink was not fully realized as forecasted.

The case of Manchester Metrolink can be linked to the inaccurate prediction of the performance of rival transport mode or the reaction of rival transport operators. In forecasting demand for Manchester Metrolink, the failure to forecast the suspension of suburban rail services which led the rise of alternative transport mode resulted in the inaccurate prediction of the performance of rival transport mode. As a result, the rival transport mode of Manchester Metrolink was underestimated, caused the errors in demand forecasting of Manchester Metrolink. This result implies the possibility that the inaccurate prediction of the performance of rival transport mode may have been intentional, or may not have been intended.

Moreover, inaccurate prediction of the performance of rival transport mode has strongly correlated with the long planning period of the transportation project.

Large-scale SOC projects take more than ten years to complete from planning to construction, during which time the transportation system may change due to the dynamic characteristics. As a result, the estimations about the rival transport mode may do not correspond with actual condition, even further, the most likely scenario may be omitted from forecasting analysis. Again, the study of Mackie and Preston(1998) suggests that if the change occurred during the long planning period, the generation of demand forecasting error is inevitable. And the direction of the error will be toward overestimation rather than underestimation.

About the variability of the bus network, Namgung et al.(2010) suggested that the changes in bus lines were one of the major causes of errors in rail demand forecasting in the case of Incheon International Airport Railroad Express. Namgung et al.(2010) indicated that the number of bus lines connecting the airport to other cities increased than expected at the point of forecasting. Bus lines to the airport were found to have increased from 25 lines expected at the point of forecasting to 120 lines at present which is 10th year of operations. As a result, the SP survey designed to estimate future modal share failed to consider the impact of the increased bus lines.

The percent difference between expected modal share of rail and observed was analyzed as about 33%. While, the percent difference between expected trip generation and observed was analyzed as 14%, so, this result implies the influence of error in the mode split step is greater than the influence of error in the trip generation step.

Although this study is limited to a case of Incheon Airport Railroad Express, it carries a important implication in the sense that it identifies the change of bus service level as a major source of errors, analyzed in depth and suggested quantitative result.

The case study of Manchester Metrolink and Incheon Airport Railway Express had provided the research direction for this study. That is, since the large transport project, especially rail, takes several years to open from planning to completion of construction, factors affecting transport demand such as bus service level may change during this period. Unlike rail, bus service is easily changed depends on demand, and large investment is unnecessary. If the impact of bus service change during the long period of rail construction is not considered in the demand forecast process, the generation of errors is inevitable.

Since a dramatic change in bus service level can be expected to occur primarily as a result of large population growth due to the land development plan, the bus service levels usually increase. This causal relation between bus service level and rail demand causes optimistic forecasting of rail projects and explains why the rail project produces larger and nonrandom errors than the road project.

From the lessons learned from the review of literature on the sources of rail demand forecasting errors, verified the importance of accurate estimation of future bus service level. So, in the next chapter, reviews on the guidelines for demand forecasting process are conducted and investigate how the changes in the service level of buses are neglected in the process of demand forecasting and how these changes could be reflected in the future forecasting process.

2.2. Guidelines for travel demand forecasting

2.2.1. A Study on Standard Guidelines for Pre-feasibility Study on Road and Railway Projects(5th edition) (KDI, 2008)

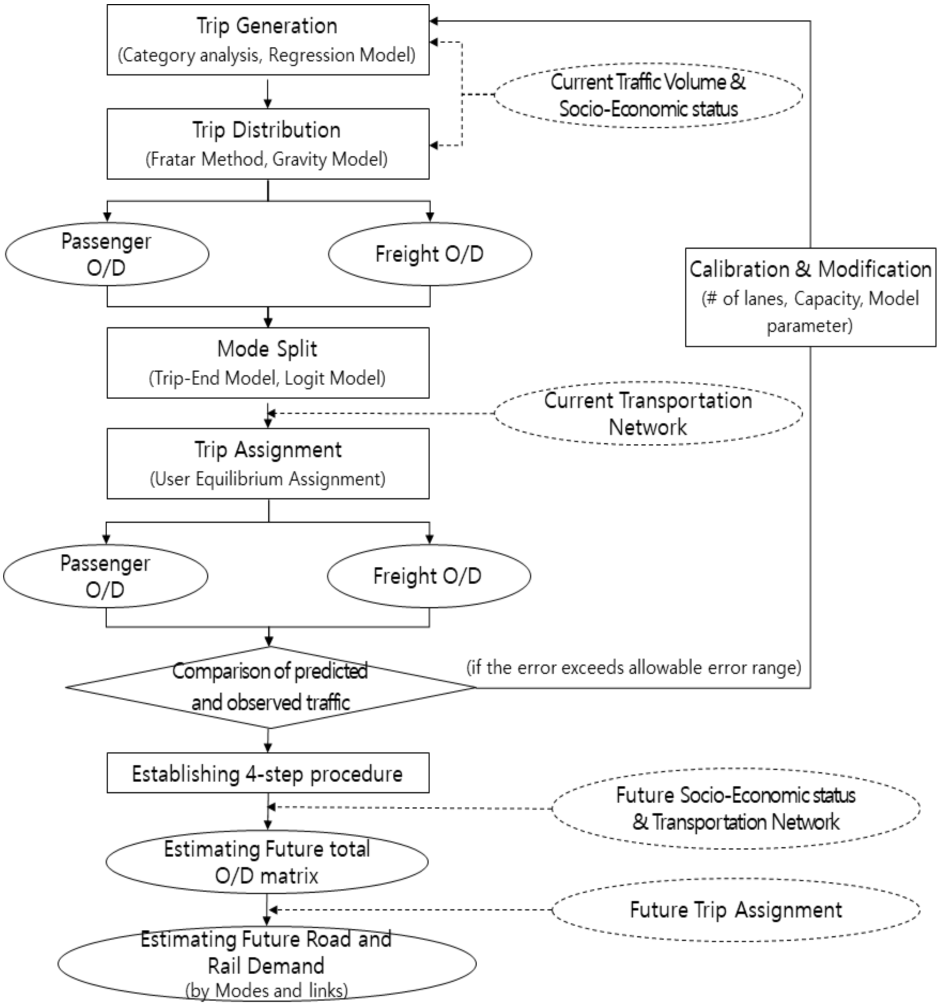
The pre-feasibility analysis is an economic feasibility analysis on large new projects with total project cost of more than 50 billion won and national financial support of more than 30 billion won.

The Study on Standard Guidelines for Pre-feasibility Study on Road and Railway Projects(Korean pre-feasibility guideline) aims to improve the objectivity and the consistency of inter-project evaluation by defining basic procedures and methodologies for analysis. This guideline provides a methodology for estimating traffic demand for road and rail facilities, calculating benefits based on estimated traffic demand and analyzing the economic feasibility with the estimated cost.

In this study, the methodology for estimating traffic demand for transport facilities, especially rail, was reviewed.

In the process of forecasting the traffic demand, 4-step model is widely used in Korea. 4-step model is consists of 4 steps which is trip generation, trip distribution, mode split and trip distribution. The detailed process of traffic demand forecasting is as suggested in the Figure below.

Figure 2.3 Process of traffic demand forecasting in 4-step model



Source: Korea Development Institute(2008)

To keep the objectivity and consistency among analyses, Korea Transport Database(KTDB) provides current and future O/D and transport network data. In establishing the data, KTDB examines the key development plans that affect the future traffic generation and apply them to calculate the future projection.

Korean pre-feasibility guideline recommends analysts to additionally include land development plans whose population exceed average population growth and possibility of completion is concrete, but not included in KTDB data.

Future O/D constructed through the above process is allocated on the future transport network. Future transport networks should be built based on current transportation network, including future transportation facilities plans. The guideline recommends to additionally include transport network plans whose possibility of completion is concrete.

In developing current transport network, data on the lengths of roads, numbers of lanes, volume-delay function for road and rail, the location of stations/stops, operation schedule of public transport service based on current condition are used.

For future transport network, the guideline recommends reflecting the operation schedule based on possible future rail plan. On the other hand, the guideline do not provide any basis for future bus operation. As a result, the future bus operation data is as same as the current condition.

Recently, KTDB reflected additional bus line plan provided by Metro-wide Transport Improvement Schemes[1] to future

1) Metro-wide Transport Improvement Schemes, implemented in 2001, is a traffic policy to investigated and analyzed the influence of the increase of the traffic demand and the change of traffic flow when a large-scale land

transportation network. However, for development plans which the planned population is under 20,000 person and planned before 2001, Metro-wide Transport Improvement Schemes are not established. Also, the numbers of bus lines planned in the schemes are very different from the number of bus lines added to the actual development plan. Therefore, it can be said that the bus supply level changes according to land development plans are not reflected in pre-feasibility analyses properly.

Table 2.4 The number of bus lines planned and realized

Land development district	# of predicted bus lines addition*	# of realized bus lines addition**
Goyang Samsong	5	8
Gimpo Hangang Newtown	3	16
Namyangju Byeollae/Guri Galmae	2	16
Suwon Gwangyo	2	28
Suwon Homaesil	4	10
Seongnam Pangyo New Town	5	25
Hwaseong Dongtan2	2	26

* : the number of bus lines planned on Metro-wide Transport Improvement Scheme

** : the number of bus lines realized at the point of completion of land development or present time(2017.12)

Source: Gyenggi Traffic Information Center(http://gits.gg.go.kr), Metropolitan Transportation Authority(2012)

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development project is being planned. To minimize the impact of the increase of traffic demand, traffic infrastructure and public transport operation plans are established are established.

The guideline allows skipping mode split step since most of the traffic volume shifted by a new road construction are from the same transport mean and the volume shifted from rail is insignificant

Unlike road project, the process of mode split is essential to forecasting rail project demand. In calculating the utility of the passengers, the travel time and cost of each transport modes are used. For the utilities of each transport modes affect the mode choice of travelers, they should be reasonably estimated. Lack of consideration of changes in the utility of bus users can cause errors in the modal share, especially buses and rail.

The guideline suggests calculating the in-vehicle travel time of the bus by applying the ratio of 1.2 ~ 1.35 times to the passenger car travel time in case of Seoul metropolitan area.

The guideline also suggests applying 7 to 30 minutes of out-vehicle travel time of bus depending on the travel distance and type of area. Table 2.5 shows the bus travel times by travel distance and type of area.

About the bus transit time, a uniformly calculated value is applied without considering the detailed characteristics by area or bus type. There is criticism that the values suggested in the guideline cannot reflect the variation of bus travel time.

Table 2.5 Bus travel time(for Seoul metropolitan area)

Category		Intra-city	Between cities in metropolitan area	Between cities outside metropolitan area
In-vehicle time		1.2 times of the passenger car time	1.3 times of the passenger car time	1.35 times of the passenger car time
Out-vehicle time	access distance within 10 km	metropolitan cities: 7분 others: 10분	15 min	20 min
	access distance over 10 km	15분 (대기+환승시간)	22 min	30 min

Source: Korea Development Institute(2008)

2.2.2. Transport Analysis Guidance(U.K. DfT, 2017)

Department for Transportation of U.K. provides information on the role of transport modeling and appraisal which is called TAG(Transport Analysis Guidance). This guidance contains guidance on the conduct of transport projects or studies that require government approval. For projects or studies that do not require government approval, TAG serves as a best practice guide. This guidance provides 1) detailed description of the transport appraisal process, 2) guidance on preparing the necessary outputs for the appraisal of transport schemes and policies which are cost economic analysis, economic impacts analysis, and environmental impact analysis, 3) advice on developing, calibrating and validating highway and public transport, such as rail, assignment models, 4) advice on using transport models to prepare future forecasts of demand and supply.

Since forecasting is, by nature, uncertain, this guidance gives instructions on how various sources of uncertainty should be taken into account throughout the forecasting process. As the source of uncertainty, 11 exogenous growth factors/drivers are suggested and regarding bus service, cost, journey time and headway are the ones of those.

In treating uncertainties, this guidance suggests that public transport operators can respond to changes in demand by either changing the capacity they provide or by changing the fares they charge. This requires due consideration to appropriately represent public transport services in future years.

In some cases, there may be more than one outcome of operator response consistent with the definition of a core scenario. Where this is the case, the most likely outcome should be chosen for the core scenario, and any other outcomes should be tested using sensitivity tests and scenario analysis.

For the scenario analysis, in the process of rail projects demand assessment, if there are uncertainties on different supply and demand assumptions, alternative scenarios with different sets of assumptions should be developed, and produce the without-scheme and with-scheme forecasts.

Since the response of public transport operators including bus service operators are likely to occur and this response can have an effect on rail demand, the expected change of bus service as the response to the establishment of new rail line or expansion of existing rail system can be included in alternative scenarios.

Meanwhile, according to this guidance, the Without-Scheme Forecast should be updated from the Reference Forecast by incorporating all the core transport supply assumptions identified in the uncertainty log. In some cases, it may be clear that further improvements to the transport system, that had not been identified in the published plans, are likely to be required to accommodate future demand.

This is to say, without the establishment of new rail line or expansion of existing rail system, the improvement of bus service will be required to meet the expected growth of traffic demand. In this case, this guidance advises to apply this probable bus service improvement to the Without-Scheme scenario.

2.2.3. Passenger Demand Forecasting Handbook(U.K. PDFC, 2013)

Passenger Demand Forecasting Handbook(PDFH) is a technical document, summarizing research on the various factors affecting forecasts of demand for passenger rail services, published by the Passenger Demand Forecasting Council(PDFC).

This handbook provides the general framework for forecasting rail passenger demand. It summarizes collective rail industry knowledge of the effect of various influences on passenger demand and draws forecasting parameters from previous experience and research. It also provides guidance on applying this knowledge to the preparation of passenger demand forecasts.

This handbook suggests that the most effective structure for forecasting rail schemes is an elasticity-based model, in contrast to the approach used for other surface schemes. A series of cross elasticities for use in forecasting rail demand in response to changes in car ownership, fuel costs and journey times; and bus costs, journey times and headway, crowding, rolling stock improvements and station facilities, a clarification of guidance on optimism bias and changes to treatment of demand caps are provided.

Like TAG, this handbook also advises considering the competitions among modes. The competition from other modes can have a significant effect on route specific flows, and guidance is therefore provided in PDFH on assessing the impacts of changes in other modes on these flows. Analysis of the influences on rail demand, which includes a broad estimate of changes in car journey times, shows that an increase in road congestion is one of the factors that has contributed to the growth in rail demand, helping to explain the more rapid growth in rail trips to the increasingly congested London area.

Changes in the costs of air travel and the frequency of flights influence only the longest-distance trips. Car cost and journey time elasticities are typically between 0.1 and 0.3, as are the equivalent elasticities for bus: fares and bus travel times. Advice is also provided on the application of diversion factors to estimate modal shift in those circumstances where rail's market share is atypical and the standard cross elasticities are therefore unreliable. Estimates of these cross elasticities have come from some sources.

2.3. Studies on bus supply level

The purpose of this study is to analyze the impact of changes in bus supply levels due to land development plans on urban rail demand forecast. So, it is required to develop a model to predict the changes in bus supply levels.

In this chapter, literature review was conducted on the factors that affect the supply level of bus. Studies on the impact of bus supply level on rail demand were also included in the literature review.

Most of these studies on the supply of bus service were limited to the study on the design of optimal bus route, evaluation of the bus route or the study on frequency considering capacity. Also, no guidelines or manuals on bus route design was not found.

Fairhurst(1979) provide a service headway elasticity which increases from −0.35 for a 10-minute service frequency to −0.55 for a 30-minute service. This result suggests that change of bus supply level such as headway do have effects on the demand of bus and as a result lead the change of rail demand.

Paulley et al.(2006) produced a guidance manual on the factors affecting the demand for public transport. The paper concentrates on the findings regarding the influence of fares, quality of service and income and car ownership. Quality of service has attributes such as access and egress time, service intervals and in-vehicle time and directly involve time and the effects on demand forecasting using these factors can be quantified with relative ease.

This study defines service intervals as total vehicle-kilometers or hours, frequency, headway/service interval, wait time and schedule delay. The dominant indicator is the number vehicle-kilometers operated. By reviewing several studies on the vehicle-kilometers' elasticity of bus demand, Paulley et al. suggest the elasticity of bus demand concerning vehicle kilometers approximately 0.4 in the short run and 0.7 in the long run.

Webster and Bly(1982) studied the various relevant factors that affect public transport ridership. This article showed the importance of the background factors such as income, car ownership and land on public transport usage and reviewed the current state of knowledge on the effects of changes in fare levels and quality of service and the introduction of various traffic and transport measures (traffic restraint, bus priority, etc.).

As for the level of service, the amount of service and quality of service were suggested as affecting factor. And among various service level factors, for the lack of available information, the numbers of vehicle-km operated is suggested as the only widely-available measure of level of service. Changes in vehicle-km usually reflect changes in service frequency(and therefore in passenger waiting time) and changes in route coverage(and therefore in mean passenger walking time), though they may also reflect an expansion of the network into areas not previously served. This study suggests that the elasticity relative to scheduled vehicle-km is likely to be, on average, 0.4 or 0.5 (that is a 10% increase in vehicle-km scheduled will attract 4% or 5% more patronage).

Bresson et al.(2002, 2004) described service quality as a function of transport supply As for the transport supply, the quantity of supply (in seats*km) and quality of service (frequency and network density) were chosen as explanatory factors. And they pointed out that these factors, for example, the quantity (seat-km) have a greater impact than quality (frequency of service and network density) for public transport demand and the use of public transport is quite sensitive to the volume supplied.

About the estimation of bus supply level, Im(2014) researched the appropriate supply level of intra-bus in Gwangju. Factors influencing the supply level of bus operated were identified using principal component analysis and a model calculating the optimal bus supply level by region was developed.

In selecting the factors affecting bus supply level, land characteristics, industrial characteristics and demographic characteristics of the region were considered. The level of bus supply was defined as the total number of bus lines and used as a dependent variable of the optimal bus supply level estimation model.

As a result, the number of tertiary industries, the number of secondary industry workers, land size and the size of commercial area per population were selected as influential factor of bus supply level. The result shows that, as the number of tertiary industries increases, as the number of secondary industry workers increases, as the size of area gets larger and as the population per commercial area grows, total number of bus lines increases.

According to Shin(2008), the Federal Transit Administration in the U.S. suggested 15 indices that should be considered in the process of bus route design or evaluation. These indices are population density, employment, distance from other bus routes or traffic corridors, and so on.

By reviewing previous studies, it was confirmed that changes in the level of bus supply affects demand for buses and therefore, demand of rails.

As a term to describe level of service on the supply-side of the bus, bus service headway, service interval, amount(quantity) of service, quality of service and route coverage were used. As the indices measure the supply level of bus, total vehicle-kilometers or hours operated, frequency, headway/service interval, wait time, schedule delay, seats-km, network density and number of bus line were used.

As for the temporal indices of bus supply level, headway or frequency is used. As for the spatial indices of bus supply level, route coverage, network density or the number of bus lines is used. By combining these two characteristics, vehicle-kilometer operated was proposed as an index of bus supply level. According to Webster and Bly(1982), the numbers of vehicle-km operated is suggested as the only widely-available measure of level of service for bus.

Unlike studies on the impact of bus supply level on public transport demand, the existing studies on the determination of bus supply level are insufficient.

The only common influential factor that suggested in Im(2014) and the guideline of Federal Transit Administration of U.S. is population density, and a comprehensive evaluation of explanatory variables is not possible. Therefore, it is not appropriate to apply the results of literature in this study without further consideration.

2.4. Review result and direction of this study

Literature on the causes of forecasting errors in rail demand focus on the non-randomness of errors of the rail forecasting and find the causes of overestimation in optimism bias caused by human factors such as decision maker, forecast expert and public official.

Despite the difficulties in proving quantitatively and empirically, intentional bias was suggested as the major cause of errors. The countermeasure of forecasting errors was limited to the punishing of analysts when forecasting error occurs and emphasizing of analysts ethics and morality.

By restricting the cause of optimism bias to human factor and neglecting the finding of causes in aspect of system, the feedback effect that connects the lessons learned from former analysis with next demand forecasting is blocked in advance.

In Mackie and Preston(1998), it is notable that this study focused on the demand forecasting system itself not only the optimistic tendency of analyst. Failure to take into account the slow build-up in demand, failure to take into account the dynamics of traffic system and the behavior of travelers, underestimation of the reaction of rival transport operators and infrastructure owners are those errors.

About the underestimation of rival transport mode, Namgung et al.(2010) suggested the unexpected increase of the number of bus lines and the modal share prediction errors caused by the bus line increase in the process of mode split as the major cause of errors.

Rail projects take several years to construct from planning to completion of construction, bus service level may change during this period since bus service is easily changed depends on demand. If the impact of bus supply level change during the long period of rail construction is not considered in the demand forecast process, the generation of errors are inevitable. Since the change of bus supply level tends overestimation, this explains why the rail project produces larger and nonrandom errors than the road project.

Changes in the supply level of bus have not been considered in the past as a major cause of errors, but if the various bus supply level data is accumulated and analyzed in time and space, it will be possible to develop accurate bus supply level prediction model. By developing a model to predict the changes in bus supply levels and applying this model to demand forecasting method, the rail demand errors can be mitigated, and the reliability of demand forecasting model can be improved.

About the change of supply level in rail demand forecasting, guidelines for transportation demand forecasting were reviewed. Korean pre-feasibility guideline does not recommend to consider the change of bus supply level due to land development.

On the other hand, TAG and PDFH of U.K. specify the need to reflect the change of bus service that occur in response to the construction of new rail. Scenario analysis, sensitivity analysis or elasticity analysis is suggested as analysis method. Still, there are limitations in these guidelines that they have failed to present the degree of change in bus service due to future land development plans.

Regarding bus supply level, study on the determination of bus supply level are very limited. Due to the lack of studies, it is not appropriate to apply the results of literature in this study without further consideration.

This study suggests the unexpected change of bus supply level as a major source of rail demand forecasting error, which has been failed to be considered in the previous studies and guidelines.

This study is distinct from the previous studies regarding the impact of changes of bus supply levels on urban rail demand forecast was quantified, and a bus supply level prediction model was developed and applied to improve the reliability of demand forecasting.

Chapter 3. Framework

3.1. Outline of methodology

In the previous chapter, it was confirmed that forecasting demand error could occur due to the reaction of competitive modes when a new rail line is built through the case of Manchester Metrolink in U.K. and Incheon International Airport in Korea. Also, through literature review on manuals on the traffic demand forecast methodology, it was confirmed that the change of bus supply level is not taken into account when forecasting rail demand.

TAG and PDFH of U.K. specify the need to reflect the change of bus service that occur in response to the construction of new rail. However, there are limitations in these guidelines that they have failed to present the degree of change in bus service due to future land development plans.

Table 1.3 shows the results of the comparison of the number of bus lines before and after completion of land development construction in Seoul metropolitan area. The number of bus lines increased by 54% to 467% due to land development projects. In situation that the supply level of bus in land development district increases more than four times, if the change of bus supply cannot be considered in rail demand forecasting, the competitiveness of bus will be underestimated and the competitiveness of the rail will be overestimated.

This analysis is consistent with the trends in road and rail demand errors presented in Table 1.1 and Table 1.2. This study seeks the reason why the forecast error of rail demand is larger than the road forecast error and is nonrandom in the existing forecasting method. The existing method does not reflect the changes in the bus supply level due to the development plan in the rail demand analysis, and consequently, the rail demand tends to be overestimated.

This study proposes a rail demand forecasting method that applies a bus supply level forecasting model in the modal split process.

First, to develop the bus supply level forecast model, a regression analysis was performed using the information of the land development projects as explanatory variables. And then, as a method to apply the change of bus supply level to rail demand forecasting, a post-processing step which re-estimates rail demand by using cross-elasticity was established.

As a method to calculate the cross-elasticity of rail demand concerning the change of bus supply level, log arc elasticity were employed which is presented in TCRP report 95.

This chapter consists of the following steps. First, a process that is related to choice of alternative types of public transport modes and the effect of bus supply level is considered. Next, a forecasting model of bus supply level by regression analysis is constructed. Finally, the cross-elasticity of rail demand concerning the change of the bus supply level is calculated.

3.2. The choice of transportation mode

3.2.1. A behavioral model for mode choice

Mode choice step is to find the percentage of the trips for each transport zone by the available travel modes. Among mode choice models, the disaggregate individual mode choice model is based on the theory of utility of a certain mode to a particular travel. The transport mode which maximizes the utility of traveler is supposed to be chosen for trip. The utility of each transport mode consists of deterministic utility and random utility which cannot be observed(Im, 2010)

$$U_i = V_i + \epsilon_i$$

Where, U_i : the true utility of the alternative i

V_i : the deterministic or observable portion of the utility of alternative i

ϵ_i : the error or the portion of the utility unknown of alternative i

The probability that alternative i will be chosen for trip is as follows.

$$\begin{aligned} P_i &= \mathrm{Pr}ob(U_i \geq U_j\,,\ \forall j \in M) \\ &= \mathrm{Pr}ob(V_i + \epsilon_i \geq V_j + \epsilon_j,\ \forall j \in M) \\ &= \mathrm{Pr}ob(V_i - V_j \geq \epsilon_j - \epsilon_i,\ \forall j \in M) \end{aligned}$$

Where, P_i : the probability of choosing alternative i
M : the set of alternatives

Assuming that the probabilistic utility follows the normal distribution, it becomes a probit model. And assuming that it follows the Weibull distribution, it becomes a logit model. The pre-feasibility analysis manual in Korea recommends logit model among individual mode choice models.

Logit model

In logit model, the probability that traveler will choose a particular mode K can be expressed as:

$$P(K) = \frac{e^{U_k}}{\sum_i^n e^{U_i}}$$

Where, $P(K)$: the probability that alternative K will be chosen
U_K : the utility of alternative K
U_i : the utility of alternative i
n : the number of alternatives

The utility for a particular mode of a traveler is determined by the travel time and the travel cost. Therefore, the utility function can be expressed follows.

$$U_{ijk} = \alpha_1 (T_{TIME})_{ijk} + \alpha_2 (T_{COST})_{ijk} + (Dummy)_k + (Constant\ term)_k$$

Where,

U_{ijk}	: the utility of alternative k between zone i and j
$(T_{TIME})_{ijk}$	: the total travel time of alternative k between zone i and j
$(T_{COST})_{ijk}$	: total travel cost of alternative k between zone i and j
$(Dummy)_k$	: dummy variables other than constant term(Reflects the characteristics of each alternative)
α_1, α_2	: parameters

Input data for the calculation of utilities

Travel time and costs should be reasonably estimated since they determine the mode choice.

The travel time consists of in-vehicle time and out-vehicle time. Out-vehicle time includes access time, waiting time, and transfer time. The travel time can be calculated by allocating each O/D pairs for each mode to road or rail links.

The travel cost consists of oil cost, operation cost and the parking cost for the passenger car, and it can be calculated by using the average travel time and the travel distance by allocating each O/D pairs for each mode to road or rail links. For taxi, it is calculated by applying the fare system base year of analysis. For bus and rail, each analysis shall be based on the fare system of base year of analysis.

In calculation of travel time, the accuracy of the calculation of travel time by modes depends on the accuracy of the road and rail network configuration. The road and rail networks of base year of analysis must project actual roads, and the networks of the target year should be able to reflect the future network changes.

Travel time using public transport modes are determined by route coverage and frequency, and no recommendation on future changes of buses service are presented in manuals, unlike rail. The bus service level for future year are mostly based on the network of the base year of analysis, so, there is a possibility of error.

The change of utility

There are two models that calculate the utility change and modal share due to project implementation. These are the incremental logit model and additive logit model.

The incremental logit model computes the selection probability of each alternative using the change in the utility value due to changes in the explanatory variables.

The incremental logit model computes the probability of each alternative using the change in the utility due to changes in the explanatory variables In other words, by calculating the utilities of “do-nothing” scenario and “do-something” scenario, and comparing them the new modal share is calculated.

In this model, since the observed modal share is considered together with the utility change, it is not necessary to apply the modification dummy variable with the purpose to match the observed modal share with model estimation. As a result, this model can reflect the effects of project implementation more accurately. Though, the model has limitation that the modal share of the new mode becomes zero when the previous modal share does not exist. Therefore, it is suggested to apply the additive logit model only to the zone where the zero cell exists.

The function of incremental logit model is as follows.

$$P_i^* = \frac{P_i \times \exp(\Delta V_i)}{\sum_{j=1}^{n} P_i \times \exp(\Delta V_j)}$$

where,

P_i^* : the probability of alternative i in do something scenario

P_i : the modal share of alternative i in do nothing scenario

ΔV_i : the change of utility of alternative i before and after project implementation

n : the number of alternatives

3.2.2. Proposed methodology

The accuracy of the existing mode split model depends on the accuracy of calculation of the utility of each alternative and the accuracy of the road and rail network configuration and prediction.

The utility for a particular mode of a traveler is determined by the travel time and cost. While the travel cost for public transportation is of little variability, the travel time varies depend on the route coverage and frequency.

To calculate the modal share of before and after the implementation of rail project, the route coverage and frequency data of public transport modes are in need. While the data on future rail operation and planning are easy to acquire and relatively credible, the data on future bus operation and planning is not easy to acquire. So, the change of bus service levels such as frequency and route is not considered in the existing model. Therefore, the bus service level for future year are mostly based on the network of the base year of analysis, so, there is a possibility of error.

To improve the error due to the changes of bus operation frequency and route coverage which will be phrased as bus supply, the bus supply level due to land development plans should be considered in the process of the modal split. So, this study establishes a model to predict the change of bus supply level and a method to apply the model in the process of the modal split. The method to apply the bus supply level model is suggested in the figure below.

Figure 3.1 Process of traffic demand forecasting proposed in this study

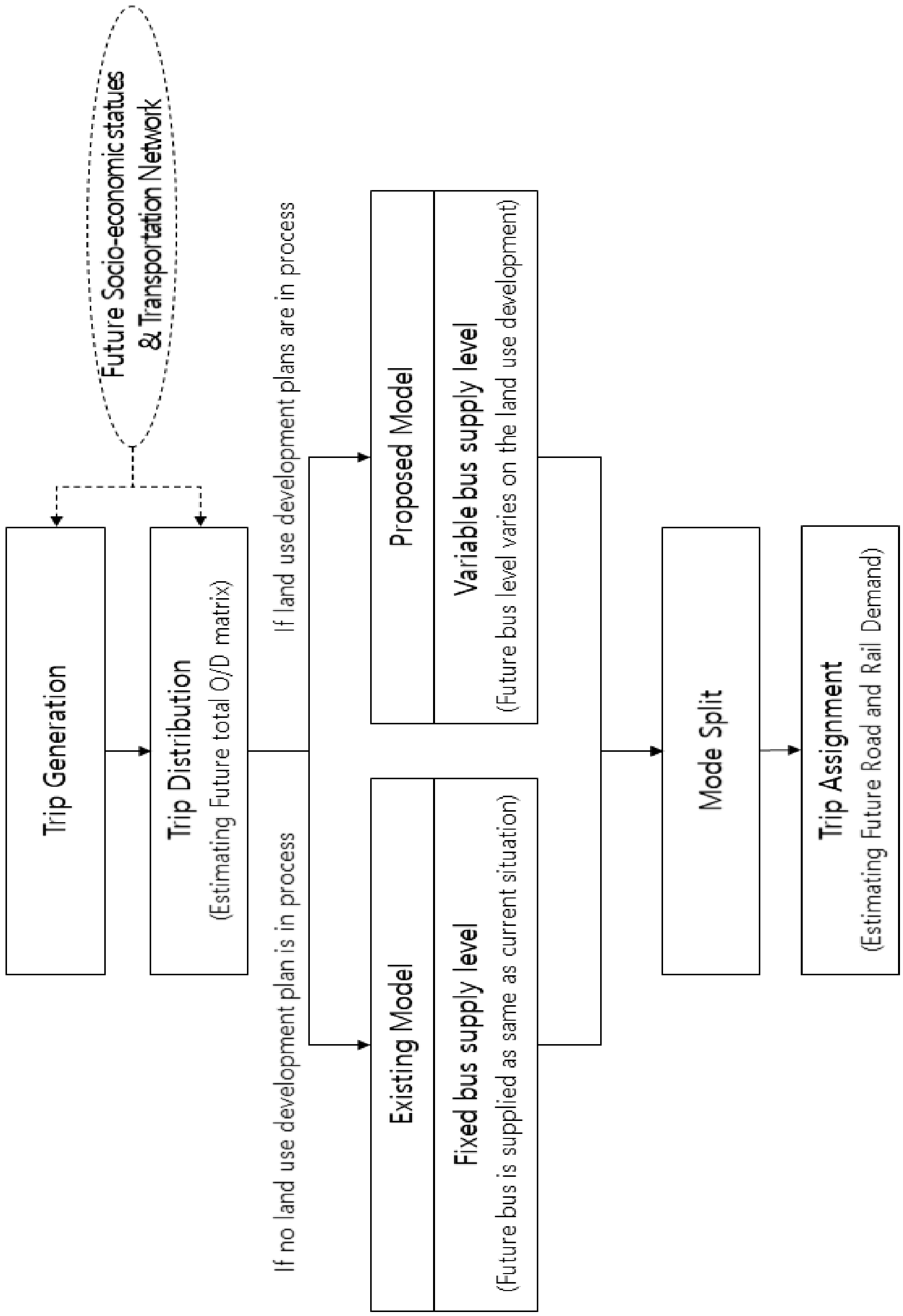
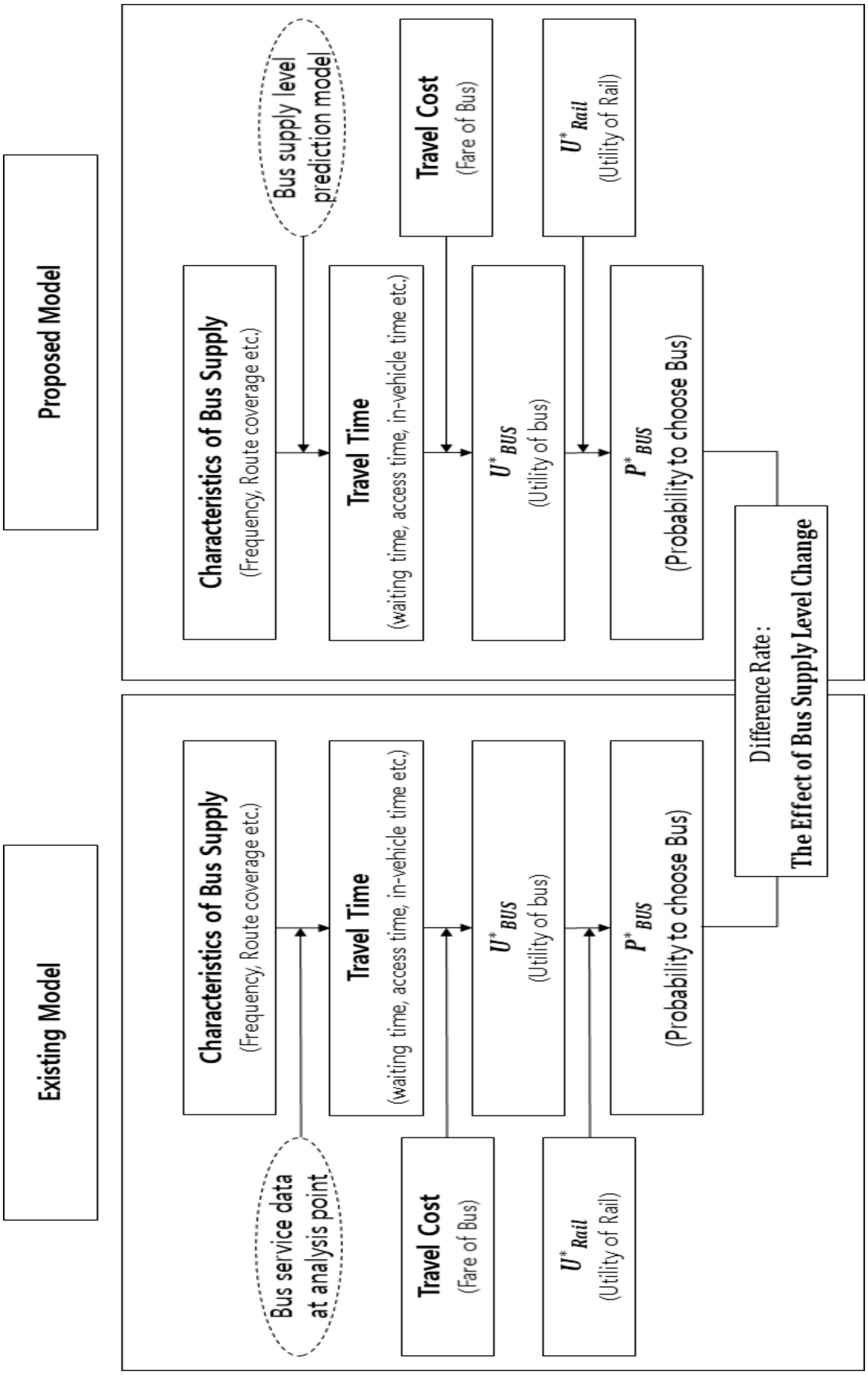


Figure 3.2 Comparison of utility calculation concept



For considering the effect of change of bus supply level, it will be best to plan for the future bus routes and frequencies on land development district and apply these plan to the future transportation network.

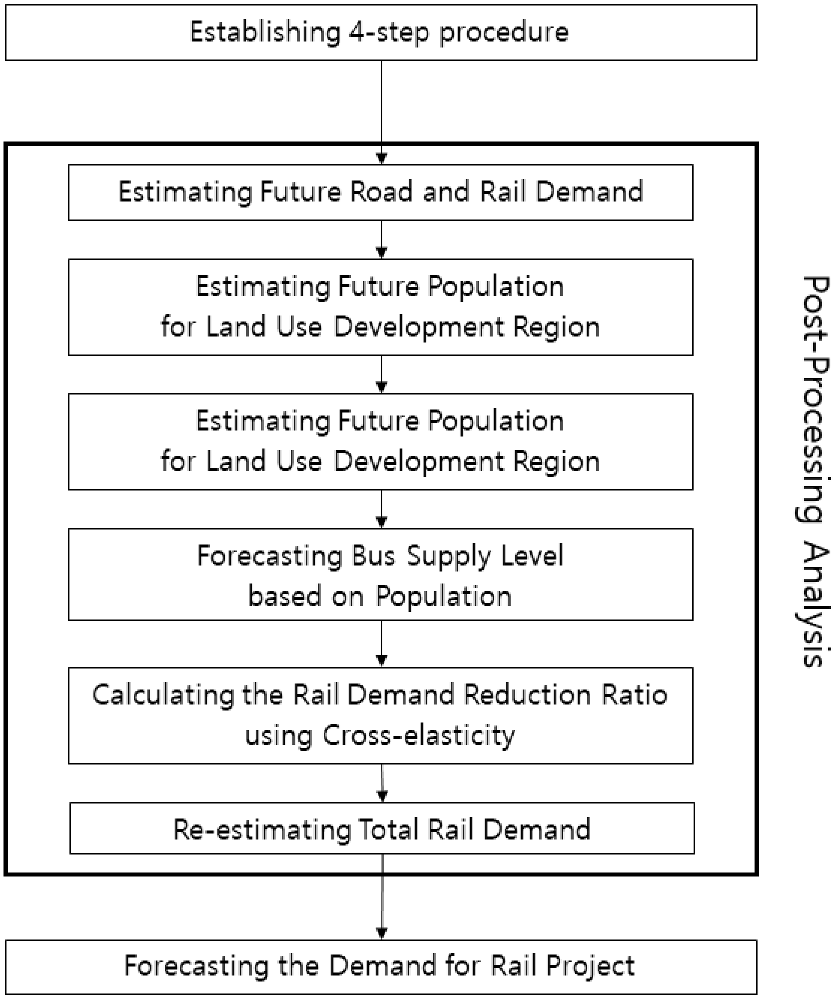
Since future bus operation schemes for land development districts are not planned, that means the bus operation schemes should be designed in the process of demand forecasting. But, as reviewed in the previous chapter, there is no guideline or manual on the designing of bus supply level. So, the designing of bus scheme to apply in the demand forecasting process can be another source of error.

Instead, this study suggests an alternative method using a post-processing step which re-estimates rail demand by using cross-elasticity and the percent difference between bus supply level of existing model and proposed model.

The post-process analysis is conducted as follows.: 1) estimating the future population of the land development district, 2) estimating the bus supply level based on the future population and calculating the bus supply level change, 3) re-estimating the rail demand using cross-elasticity concerning the change of bus supply level

The analysis flow for the post-process of total demand is as suggested in Figure 3.3.

Figure 3.3 .of post-process analysis



3.3. Bus supply level forecasting model

The supply level of bus affects the utility of the bus passengers, and as a result, influences the modal share by modes. Especially, in urban rail who usually have large-scale land development plans within its impact area, if the change of bus supply level is not considered in the process of rail demand forecasting, there may be an error in calculating the modal share of rail.

The purpose of this study is to apply the changes of bus supply level due to land development plans to improve the reliability of the urban rail demand forecasting model. For this purpose, a bus supply level prediction model was constructed.

a) The index for bus supply level

Through literature review, an indicator that explains the supply level of bus was selected. In literature, as for the level of service, the amount of service and quality of service were suggested as affecting factor. And among various service level factors, for the lack of available information, the numbers of vehicle-km operated is suggested as the only widely-available measure of the level of service. Changes in vehicle-km usually reflect changes in service frequency(and therefore in passenger waiting time) and changes in route coverage(and therefore in mean passenger walking time)

The operation frequency of bus effects the waiting time of bus passengers as the waiting time is assumed as the half of the average waiting time. The route coverage determines the accessibility and the distance between origin and destination and affects the access-time and in-vehicle time of bus passengers.

To consider the utility change in an aspect of temporally and spatially, the vehicle-km was selected as the index of bus supply level.

b) Bus supply level forecasting model

In the literature review on the bus supply level, it has been confirmed that the time series data on bus supply level, guidelines or manuals, and studies on bus supply level are very limited or even absent.

In this study, cross-sectional data on bus supply level in Gyeonggi province in 2017 were used to develop a bus supply forecasting model by regression analysis. As a dependent variable of the model, a vehicle-km of buses was selected. The vehicle-km of buses was calculated as the sum of the product of the operation frequency per bus line and the route length per bus line.

As the influential factor, demographic factors, land use factors and transportation factors were considered.

For regression analysis, statistical software package SPSS was used. The statistical data used in the model are presented in Appendix A.

Table 4.1 Data description for bus supply level forecasting model

Data		Bus operation data and socioeconomic indices in Gyeonggi province in 2017
Dependent variable		vehicle-km operated* for bus
Influential factors	Demographic factors	population, population over 15 years old, number of employees, number of students, population density
	Land use factors	size of the total area, the ratio of the urbanized area, size of urbanized area, number of schools
	Transportation factors	road density, number of the car registered, number of metro stations and lines

* : $\sum Operation\,Frequency \times Route\,Length$

Source: Gyeonggi Transport Information center(http://gits.gg.go.kr)

As a result of the regression analysis, the population was selected as the independent variable showing strong predictability. Other variables were excluded from the analysis because they did not satisfy the significance level. The developed bus supply forecasting model is as follows.

$$S_{i,\,BUS} = \alpha \cdot Pop_i$$

Where, $S_{i,\,BUS}$: bus supply level of the zone i

Pop_i : the population of zone i

α : parameter (0.815 for Gyeonggi Province)

The results of model estimation are as follows. The coefficient of determination(R^2) of the model was estimated as 0.865, indicating that the model has strong predictability. And the Durbin-Watson value was estimated as 1.94, indicating there is no autocorrelation.

Since the t-value is greater than 1.96 and the significance probability is 0.000, this model satisfies the significance level.

The only explanatory variable of the bus supply levels is population. As the population of the research area increased, the supply level of bus also increased. The coefficient was analyzed to be 0.815.

Table 4.2 Model summary

R	R^2	$adj.R^2$	$Durbin-Watson$
0.930	0.865	0.861	1.942

Table 4.3 Result of parameter estimation

Explanatory variable	Nonstandardized coefficient		Standardized coefficient	t	Significance level
	β	Standard error	β		
Population	0.815	0.059	0.930	13.866	0.000

3.4. Post-processing of rail demand

For applying the change of supply level, it is thought to be the most appropriate to design the future bus routes and frequencies on the future analysis network

But the future bus operation schemes for land development districts are not planned, and there is no guideline or manual on the designing of bus supply level. So, the designing of bus scheme to apply in the demand forecasting process can be another source of error.

Instead, this study suggests an alternative method using a post-processing step which re-estimates rail demand by using cross-elasticity and the percent difference between bus supply level of existing model and proposed model.

The cross-elasticity of rail demand according to the change of bus supply level means is an index that shows how many of the rail demand changes when 1% of bus supply increases. According to previous studies, as the level of supply of buses increases, the demand for competitive modes(passenger cars, rails) decreases.

a) Log arg elasticity

In the analysis of cross-elasticity, log arc elasticity was adopted. Log arc elasticity is defined by a logarithmic formulation and, except for very large changes in P and Q, is closely approximated by a mid-point (or linear) formulation which makes use of the average value of each independent variable(Bly,1976; Mayworm, Lago and McEnroe, 1980; Pratt et al., 2000).

The function of log arc elasticity is as follows.

$$\eta = \frac{\triangle \ln Q}{\triangle \ln S} = \frac{\ln Q_2 - \ln Q_1}{\ln S_2 - \ln S_1}$$

Where, η : the elasticity of rail demand

S_1 : the supply level of bus before the supply change

S_2 : the supply level of bus after the supply change

Q_1 : the rail demand before the bus supply change

Q_2 : the rail demand after the bus supply change

b) Post-processing of rail demand

To re-estimate the rail demand, the post-processing step using cross-elasticity and the percent difference between bus supply level of existing model and proposed model. Given a proposed bus supply change, to compute the rail demand which may be expected given an arc elasticity value thought to be applicable, the equations to use are as follows(Pratt et al., 2000).

$$Q_2 = \exp^{\eta(\ln P_2 - \ln P_1) + \ln Q_1}$$

c) cross-elasticity of rail demand

The cross-elasticity of rail demand according to the change of bus supply level is usually analyzed using stated preference survey and revealed preference survey. In this study, the cross-elasticity was analyzed using cross-sectional data of bus supply in Siheung-si, Gyeonggi province.

To analyze the log arc elasticity, a log multivariate regression model was developed. The explanatory variables were substituted as natural logarithm and used in the multivariate regression analysis. The standard coefficient can be interpreted as the cross-elasticity of the dependent variables for the explanatory variables.

The data used in this analysis are the data on bus lines running in Siheung-si, the number of bus passengers and the number of passengers who boarded or alighted from stations located in Siheung-si.

Table 4.4 Data description for cross-elasticity analysis

Temporal scope	2012.07~2017.08
Spatial scope	Siheung-si in Gyeonggi province.
Bus lines and number of bus passengers*	data on buses that running in Siheung-si and the number of bus passengers on the weekday
Number of rail passengers	the number of passengers who board or alight from stations located in Siheung-s which are Oido, Jeongwang, Darwol and Wolgot Station

* : intra-city bus, Metropolitan bus, express city bus(intercity bus, community bus, express bus are not included)

Source: Gyeonggi Transport Information center(http://gits.gg.go.kr)

In the analysis of cross-elasticity, several socioeconomic variables on Siheung-si was included in the analysis but excluded from the analysis because they did not satisfy the significance level. So, the bus supply level(vehicle-km) and the number of bus passengers were used as the explanatory variable.

As the result of log regression, the cross-elasticity of rail demand for bus supply level was calculated as -0.398. It means that when the bus supply level increased by 1%. 0.4% of rail demand decreases.

Table 4.5 Result of cross-elasticity analysis

Explanatory variable	Coefficient(β)		P-value	R^2 ($adj. R^2$)	Significance level
	Nonstandard	Standard			
Constant	13.258	-	0.001^{**}	0.397 (0.376)	0.000^{***}
$\ln(S)$	-1.023	-0.398	0.027^{*}		
$\ln(Q_{BUS})$	0.765	0.906	0.000^{***}		

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.1$

The result of this regression analysis does not show strong predictability. Due to the high p-value of explanatory variables considered, only two explanatory variable could have been used in regression analysis. The reason of this weak predictability is assumed to be the lack of data. The data on bus supply level has been just started to be collected, and data on many influential factors are not yet collected or provided. When the data on bus supply at a reliable level, the predictability on cross-elasticity can be improved.

The statistical data used in the analysis are presented in Appendix B.

Chapter 4. Case Study

4.1. Overview of case study

In this chapter, case studies on actual urban rail demand forecasting are reanalyzed. And demand forecast errors occurred due to the lack of consideration of the change of bus supply level are quantified. Also, the reliability of the model proposed in this study is verified by comparing the demand forecasted using the prior demand forecasting model and the demand forecasted using the proposed model.

For the analysis, standards and methodologies recommended in Korean pre-feasibility guideline(KDI, 2008) which is the guideline for analysis of traffic demand forecasting are applied. Also, O/D and transport network data provided by KTDB in 2010 is used. The opening year of each rail line is used as the target of analysis.

Case projects are selected among the urban rail projects in the metropolitan area, whose related land development plan is expected to increase the population resulting in the increase in traffic demand. And the effect of the change of bus supply level on rail project demand is examined.

It is assumed that as the planned population of the land development increases, and, as the time lag between the completion of land development and increase of traffic demand lengthened, the change of bus supply level will be larger.

Based on the above guideline, the Shinbundang-line and Yongin Light Rail whose constructions are completed and operation started were selected as the analysis case. Meanwhile, Gimpo metro line and Byeollae-line whose constructions are not yet completed were also selected as the analysis case.

Table 4.1 Analysis outline

Application guideline	Korean pre-feasibility guideline 5th edition(KDI, 2008)
Data	KTDB origin-destination passenger trip data and Transportation network(2010)
Modeling software	EMME/3.0 Transportation modeling software package
Temporal scope	Opening year of target rail project
Spatial scope	Rail project located in Seoul Metropolitan area • Shinbundang-line • Yongin light rail(ever-line) • Gimpo metro line • Byeollae-line(Seoul metro 8th line extension)

4.2. Shinbundang-line project

4.2.1. Overview of the project

The Shinbundang-line project started in 2001 when KDI analyzed the pre-feasibility of the project. The implementation plan has been authorized in 2005 and the construction began in the same year.

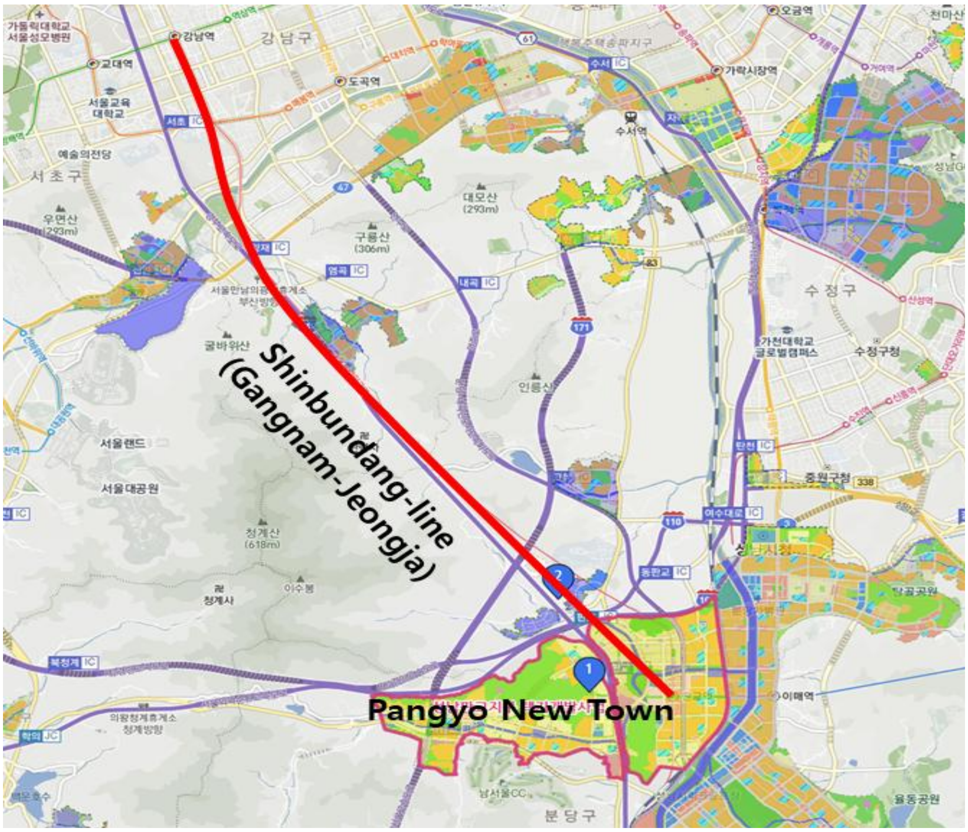
The first section of this line which is from Gangnam to Jeongja was constructed with the purpose of dealing with the traffic demand of Pankyo new town scheduled for completion in 2011. The second section from Jeongja to Gwangyo had an intention of handling the traffic demand of the Yongin Heungdeok district which was scheduled to be completed in 2009 and Gwangyo district which was scheduled to be completed in 2011.

Table 4.2 Implementation process of Shinbundang-line project

Year	Implementation Process
2001.	Pre-feasibility analysis was conducted by KDI
2002.07	Proposal for public-private partnership was submitted
2003.12	Competent project promoter was selected
2005.06	Implementation plan was authorized
2005.07	The construction began
2011.10	The 1st section from Gangnam to Jeongja was completed and opened
2016.01	The 2nd section from Jeongja to Gwangyo was completed

The first section of Shinbundang-line was constructed with the purpose of dealing with the traffic demand of Pankyo new town. That is, Pangyo new town development project is located within the impact area of Shinbundang-line.

Figure 4.1 Location of Sinbundang-line and Pangyo new town



Pangyo new town is located in Seongnam-si, Gyeonggi-do and is a large-scale residential development project with a total planned population of 87,789 person.

At the point of Shinbundang-line demand forecasting, the Pangyo new town development project was expected to be completed in 2011. In fact, the project has not yet been completed at present(2017). But, the first partial completion occurred in January 2010. In 2010, 71% of the planned population was inhabited, and in 2015, more than 100%. Therefore, it can be considered that the impact of the completion delay of Pangyo new town on the degree of realization of the planned population will be insignificant.

Table 4.3 Pangyo new town development project overview

Project period	2003.12.30 ~ 2017.12.31
Location	Gyeonggi-do Seongnam,-si Bundang-gu Pangyo-dong, Unjung-dong, Sampyeong-dong, Baekhyeon-dong
Completion year(predicted)	2011
1st partial completion year(observed)	2010.01.22
population(predicted)	87,789(person)
Population of 1st partial completion year(observed)	62,380(person) (71% of total forecasted population)

Source: Korea Land and Housing Corporation(http://www.jigu.go.kr)

The traffic demand from Pangyo new town increased from 2010 when more than 60,000 person moved in since the land development project was partially completed. However, Shinbundang-line started running in December 2011 resulting in a time lag of about two years between the increase of traffic demand and supply of rail.

Despite the drastic traffic demand increase, rail facilities were not supplied in a timely manner. As a result, the number of buses increased during the time lag.

Table 4.4 Analysis of transport condition(Shinbundang-line)

Trip generation point in time	Pangyo new town project was partially completed in January 2010. Over 60,000 people have moved in, and traffic demand increased.
Rail opening point in time	The rail was supplied with the opening of the 1st section of Shinbundang-line in December 2011.
Time lag	From the beginning of 2010 to the end of 2011, there was a delay of about two years between the increase of traffic demand and the supply of rail.

4.2.2. Comparison of predicted and observed rail demand

At the analysis point in time, the demand for Shinbundang-line was estimated as 245,899 trips per day in 2012 and to increase to 307,047 trips per day by 2015. But, only 93,013 trips per day were observed in 2011. Also, since the opening of the second section, which was scheduled for opening in 2013, was delayed to 2016, subsequent demand also fell short of the forecast.

The changes in the conditions for the demand analysis of Shinbundang-line were investigated, and factors affecting the demand forecast error except for the change of the bus supply level were identified.

Table 4.5 Comparison of predicted and observed rail demand(Shinbundang-line)

Year	2012	2013	2014	2015
predicted demand (trips/day)	245,899	273,318	290,175	307,014
observed demand (trips/day)	93,013	112,407	121,702	125,982
proportion of observed to predicted(%)	38%	41%	42%	41%

Source: Korea Transport Institute(2016)

Factors affecting the demand forecast error except for the change of the bus supply level are 1) the opening delay of 2nd section of Shinbundang-line, 2) the opening delay of Seongnam -Yeoju rail line, 3) delay of completion of Pangyo new town, 4) the expansion of exclusive median bus lane in Seoul Metropolitan area.

Table 4.6 Comparison of predicted and observed analysis condition (Shinbundang-line)

Change of analysis condition	Condition(predicted)	Condition(observed)
opening year of 2nd section(Jeongja - Gwangyo)	2013	2016
opening year of neighboring rail line(Seongnam-Yeoju line)	2012	2016
Completion year of Pangyo new town	2011	2016
exclusive median bus lane	4.5km	195.6km(in 2012)

4.2.3. Analysis of bus supply level change

The bus supply level of Pangyo new town amounted to 29,937 vehicle-km for eight lines at the analysis point in time. The bus supply in 2012, which is the time of completion of Pangyo new town, increased to 112,123 vehicle-km for 33 lines.

For the application of the urban rail demand forecasting method proposed in this study, the bus supply level forecast model based on the population level presented in Chapter 3 was used to predict the supply level of bus in 2012 for Pangyo new town.

The traffic analysis zones used for the population analysis are Pangyo-dong, Unjung-dong, Sampyeong-dong, and Baekhyeon-dong in Seongnam-si, where the Pangyo New Town is located. The total population of these zones was estimated at 130,425 person in 2012. As the result of the application of bus supply level forecast model, the bus supply level for the population of 130,425 person was estimated at 106,296 vehicle-km.

The bus supply level of Pangyo new town at the completion point in time had increased by about 275% compared to the bus supply level at the analysis point in time. It is reasonable to assume that there will be an impact on the rail demand due to the change in the level of bus supply.

When applying the bus supply level forecasting model proposed in this study, the predicted bus supply level amounts to 106,296 vehicle-km for Pangyo new town, and the error rate to the observed bus supply level is about -5.20%. It can be concluded that the error of the bus supply level model is insignificant.

Table 4.7 Comparison of predicted and observed bus supply level(Pangyo new town)

Category	Point of analysis	Number of Bus lines*	Bus supply level (vehicle-km)**	Error rate(%)***
Survey data	2002 (agreement year)	8	29,937	-
	2012 (opening year)	33	112,123	-
Model prediction	2012 (opening year)	-	106,296	-5.20%

* : intra-city bus, Metropolitan bus, express city bus(intercity bus, community bus, express bus are not included)

** : bus supply level is the sum of the multiplication of route length and number of bus runs for each bus route

*** : $Error\ rate(\%) = \frac{(Model\ prediction - Survey\ data)}{Survey\ data} \times 100$

Source: Gyeonggi Transport Information center(http://gits.gg.go.kr)

4.2.4. Scenario analysis

To analyze the impact of the change of bus supply level on rail demand forecasting error and the reliability of the model suggested in this study, scenario analysis was conducted. Since the purpose of this study is to analysz the effect of bus supply level change, other sources of rail demand forecasting error were excluded from the scenario analysis.

The analysis scenarios consisted of three scenarios depending on whether the changes of bus supply level is reflected or not and the way these changes applied in the scenarios. The target year was set to 2012.

Table 4.8 Scenario description(Shinbundang-line)

Scenario number	Scenario 1	Scenario 2	Scenario 3
Model	Prior model	Prior model	Proposed model
Bus supply level change	-	Observed	Predicted
Bus supply level (vehicle-km)	29,937	112,123	106,293
Cross-elasticity of Rail Demand	-	-	-0.4

a) Scenario 1

In Scenario 1, rail demand forecasting method suggested in the existing preliminary feasibility guidelines was applied. In this scenario, the change of bus supply level according to the land development plan was not taken into consideration, and the bus supply level at the time of demand analysis was assumed to remain the same at the time of opening of the new rail facilities.

Therefore, at the time of opening of Shinbundang-line, the supply level of the bus running through Pangyo new town was estimated at 29,937 vehicle-km for eight lines, which is the same as the bus supply level at the time of the analysis.

Since the change of bus supply level was not considered in this scenario, the errors of rail demand forecasting are inherent. By comparing the result of scenario 1 with the result of scenario 2, the impact of bus supply level change on rail demand forecasting error can be quantified.

b) Scenario 2

Like scenario 1, rail demand forecasting method suggested in the existing preliminary feasibility guidelines was applied in scenario 2. But, the change of bus supply level according to the land development plan was taken into consideration. The data of bus supply level for 2012 was acquired based on the observed bus network information of 2012.

The bus supply level of this scenario is higher than the bus supply level of scenario 1 reflecting the increase in traffic demand due to the land development plan. At the time of opening of Shinbundang-line, the supply level of the bus running through Pangyo new town was observed to be as 112,123 vehicle-km for 33 lines.

In this study, the result of this scenario is assumed to be the observed value of Shinbundang-line demand.

c) Scenario 3

In scenario 3, the method suggested in this study which takes into account the bus supply level forecasting model was applied. In this scenario, the change of bus supply level due to the land development plan was considered. But, unlike scenario two which used the observed bus network information of 2012, this scenario reflects the change of bus supply level by applying the cross-elasticity and post-processing the total rail demand.

The reliability of the proposed method was verified by comparing the demand of Shinbundang-line in scenario 3 with the result of scenario 2.

As the result of the application of the bus supply level forecasting model, the bus supply level for the population of 130,425 person was estimated at 106,296 vehicle-km.

Table 4.9 Bus supply level prediction(Pangyo new town)

Analysis point in time	Forecasted population (person)	Bus supply level (observed) (vehicle-km)	Bus supply level (predicted) (vehicle-km)
2002 (agreement year)	-	**29,937**	-
2012 (opening year)	130,425	112,123	=130,425*0.815 =**106,296**

Rail demand reduction ratio was calculated by using the bus supply level in 2002 of 29,937 vehicle-km, the predicted bus supply

level in 2012 of 106,296 vehicle-km, and the cross-elasticity of －0.4 as suggested in chapter 3.

As a result, the rail demand reduction ratio for scenario 3, was calculated as 0.602. That is, the demand for rail in Pangyo new town will decrease by 39.8%, since the bus supply level increase in 2012 by 255% compared to 2002.

Table 4.10 Rail demand reduction ratio(Pangyo new town)

Analysis point in time	Bus supply level (vehicle-km)	Cross-elasticity of rail demand	Rail demand reduction ratio
2002 (agreement year)	29,937	-0.4	=exp[-0.4*{n(106,296)-ln(29,937)}] =0.602
2012 (opening year)	106,296		

4.2.5. Result of scenario analysis

By comparing the demand of Shinbundang-line in scenario 1 with the result of scenario 2, the impact of bus supply level change on rail demand forecasting error was quantified. Also, The reliability of the proposed rail demand forecasting method was verified by comparing the demand of Shinbundang-line in scenario 3 with the result of scenario 2.

EMME/3.0 Transportation modeling software package was used to perform demand forecasting, and the data of bus supply level for

2002 and 2012 was acquired based on the observed bus network information.

The 2012 bus network used in scenario 2 increased from 8 to 33 bus lines compare to the 2002 bus network used for scenario 1 and scenario 3. These increased routes mainly connect Gangnam and Pangyo new town and are similar to the route of shinbundang-line.

Figure 4.2 shows the comparison result of bus lines of scenario 1(&3) and 2. The figures on links mean the number of increased bus lines in Scenario 2.

Figure 4.2 Comparison of bus line between scenario 1(&3) and scenario 2 (Shinbundang-line)

The results of analyzing the demand for public transport in Pangyo new town and the demand for Shinbundang-line are as shown in the following table.

Table 4.11 Results of scenario analysis(Shinbundang-line)

(Units: trips per day)

Scenario number	Proportion of trip generation by mode at Pangyo New Town		Demand for Shinbundang-line	Ratio comparison
	Subway	Bus + Subway		
Scenario 1	3,212	12,933	107,789	116%
Scenario 2	3,018	14,865	93,206	100%
Scenario 3	1,935	7,792	95,889	103%

As a result of scenario analysis, the demand of Shinbundang-line without consideration of bus supply level change(scenario 1) is about 16%p overestimated than the demand of Shinbundang-line with consideration of bus supply level change(scenario 2). As expected, the increase in bus supply level due to the population increase in the land development plans have been an overestimation error factor for rail demand.

Next, the demand of Shinbundang-line that the method proposed in this study was applied in the analysis(scenario 3) is about 3%p overestimate than the result of scenario 2. It is expected that the method proposed in this study can reduce the demand forecasting error of new rail more than 10%p compared with the prior model.

Also, this result suggests that the accuracy of the proposed method using the cross-elasticity of rail demand and the change of bus supply level seems is within an acceptable range, showing only 3% of difference.

4.3. Yongin Light Rail Project

4.3.1. Overview of the project

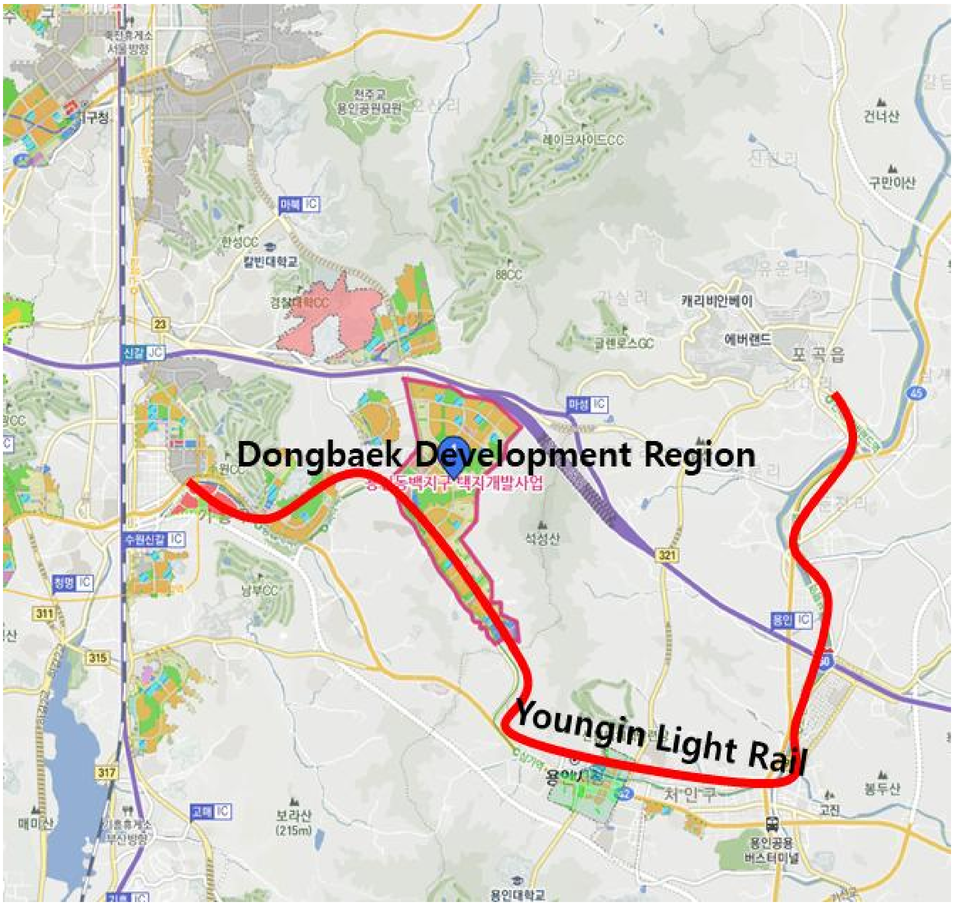
The Yongin light rail project started in 1996 when Korea Transport Institute(KOTI) established the master plan for the project. The project proceeded as a private investment project, and the construction started in 2005. In 2010, the private contractor submitted the completion report but denied by Yongin city. Due to the disagreement between the city government and the private contractor, the opening delayed for 3 years. In April 2013, Yongin light rail started operation.

At the time of opening, the rail had separate fare system and charged 1300 won. In September 2014, it joined the integrated transfer system in Seoul metropolitan area and charged 200 won.

Table 4.12 Implementation process of Yongin light rail project

Year	Implementation Process
1996.	Master plan for Yongin Light Rail was developed by KOTI
2001.12	Proposal for public-private partnership was confirmed
2002.09	Competent project promoter was selected
2004.02	The enforcement agreement with private contractor was completed
2005.11	Implementation plan was authorized
2005.12	The construction began
2010.07	Completion report was submitted but denied.
2010~2013	Due to the disagreement between the city government and the private contractor, completion delayed.
2013.04	The construction was completed, and operation started
2014.09	The fare system was included in the integrated transfer system in Seoul metropolitan area

Figure 4.3 Location of Yongin light rail and Dongbaek district



The Yongin light rail was constructed with the purpose of dealing with the traffic demand of Dongbaek district. That is, Dongbaek district project is located within the impact area of Yongin light rail.

At the point of Yongin light rail demand forecasting, the Dongbaek district project was expected to be completed in 2006. In fact, the project was completed in 2009 after 3 years of delay. But, the first partial completion occurred in March 2007. In 2007, the population of this district was more than 43,000 person which is 83% of the planned population.

Therefore, it can be considered that the impact of the completion delay of Dongbaek district on the degree of realization of the planned population will be insignificant.

Table 4.13 Yongin Dongbeak development project overview

Project period	1999.12.31~2009.6.30
Location	Gyeonggi-do Yongin-si Giheung-gu Jung-dong
Completion year(predicted)	2006년
1st partial completion year(observed)	2007.3
population(predicted)	51,646(person)
Population of 1st partial completion year(observed)	42,979(person) (83% of total forecasted population)

Source: Korea Land and Housing Corporation(http://www.jigu.go.kr)

The traffic demand from Dongbaek district increased from 2007 when more than 40,000 person moved in since the land development project was partially completed. However, Yongin light rail started running in December 2013 resulting in a time lag of about six years between the increase of traffic demand and supply of rail.

Despite the drastic traffic demand increase, rail facilities were not supplied in a timely manner. As a result, the number of buses increased during the time lag.

Table 4.14 Analysis of transport condition(Yongin Light rail)

Trip generation point in time	Dongbaek district was partially completed in March 2007. Over 40,000 people have moved in, and traffic demand increased.
Rail opening point in time	The completion report was submitted in July 2010 but denied. The opening was delayed until April 2013 due to a disagreement between private and public sector.
Time lag	From March 2007 to April 2013, there was a delay of about 6 years between the increase of traffic demand and the supply of rail.

4.3.2. Comparison of predicted and observed rail demand

At the analysis point in time, the demand for Yongin light rail was estimated as 167,716 trips per day in 2013 and to increase to 178,319 trips per day by 2016. But, only 8,713 trips per day were observed in 2013.

The changes in the conditions for the demand analysis of Yongin light rail were investigated, and factors affecting the demand forecast error except for the change of the bus supply level were identified.

Table 4.15 Comparison of predicted and observed rail demand (Yongin Light Rail)

Year	2013	2014	2015	2016
predicted demand (trips/day)	167,716	171,178	174,712	178,319
observed demand (trips/day)	8,713	13,922	23,406	25,872
proportion of observed to predicted(%)	5%	8%	13%	15%

Source: Korea Transport Institute(2016)

Factors affecting the demand forecast error except for the change of the bus supply level are 1) the opening delay of Seongnam -Yeoju rail line, 2) the implementation of the integrated transfer system in Seoul metropolitan area, 3) the expansion of exclusive median bus lane in Seoul Metropolitan area.

Table 4.16 Comparison of predicted and observed analysis condition(Yongin Light Rail)

Change of analysis condition	Condition(predicted)	Condition(observed)
opening year of neighboring rail line(Seongnam-Yeoju line)	2012	2016
fare system	separate fare system of 1300 won	Integrated transfer system in Seoul metropolitan area & additional fare of 200 won
exclusive median bus lane	4.5km	195.6km(in 2012)

4.3.3. Analysis of bus supply level change

The bus supply level of Dongbaek district amounted to 15,504 vehicle-km for three lines at the analysis point in time. The bus supply in 2013, which is the time of completion of Yongin light rail, increased to 77,607 vehicle-km for 17 lines.

For the application of the urban rail demand forecasting method proposed in this study, the bus supply level forecasting model based on the population level presented in Chapter 3 was used to predict the supply level of bus in 2013 for Dongbaek district.

The traffic analysis zones used for the population analysis are Dongbaek-dong and Sanghe-dong in Yongin-si, where the Dongbaek district is located. The total population of these zones was estimated at 96,565 person in 2013. As the result of the application of the bus supply level forecasting model, the bus supply level for the population of 96,565 person was estimated at 76,259 vehicle-km.

The bus supply level of Dongbaek district at the completion point in time had increased by about 400% compared to the bus supply level at the analysis point in time. It is reasonable to assume that there will be an impact on the rail demand due to the change in the level of bus supply.

When applying the bus supply level forecasting model proposed in this study, the predicted bus supply level amounts to 76,259 vehicle-km for Dongbaek district, and the error rate to the observed bus supply level is about -1.74%. It can be concluded that the error of the bus supply level model is insignificant.

Table 4.17 Comparison of predicted and observed bus supply level(Dongbaek district)

Category	Point of analysis	Number of Bus lines*	Bus supply level (vehicle-km)**	Error rate(%)***
Survey data	2001 (agreement year)	3	15,504	-
	2013 (opening year)	17	77,607	-
Model prediction	2013 (opening year)	-	76,259	-1.74%

* : intra-city bus, Metropolitan bus, express city bus(intercity bus, community bus, express bus are not included)

** : bus supply level is the sum of the multiplication of route length and number of bus runs for each bus route

*** : $Error\ rate(\%) = \frac{(Model\ prediction - Survey\ data)}{Survey\ data} \times 100$

Source: Gyeonggi Transport Information center(http://gits.gg.go.kr)

4.3.4. Scenario analysis

To analyze the impact of the change of bus supply level on rail demand forecasting error and the reliability of the model suggested in this study, scenario analysis was conducted. Since the purpose of this study is to analyze the effect of bus supply level change, other sources of rail demand forecasting error were excluded from the scenario analysis.

The analysis scenarios consisted of three scenarios depending on whether the changes of bus supply level is reflected or not and the way these changes applied in the scenarios. The target year of analysis was set to 2013.

Table 4.18 Scenario description(Youngin Light Rail)

Scenario number	Scenario 1	Scenario 2	Scenario 3
Model	Prior model	Prior model	Proposed model
Bus supply level change	-	Observed	Predicted
Bus supply level (vehicle-km)	15,504	77,607	76,259
Cross-elasticity of Rail Demand	-	-	-0.4

a) Scenario 1

In Scenario 1, rail demand forecasting method suggested in the existing preliminary feasibility guidelines was applied. In this scenario, the change of bus supply level according to the land development plan was not taken into consideration, and the bus supply level at the time of demand analysis was assumed to remain the same at the time of opening of the new rail facilities.

Therefore, at the time of opening of Yongin light rail, the supply level of the bus running through Dongbaek district was estimated at

15,504 vehicle-km for 3 lines, which is the same as the bus supply level at the time of the analysis.

Since the change of bus supply level was not considered in this scenario, the errors of rail demand forecasting are inherent. By comparing the result of scenario 1 with the result of scenario 2, the impact of bus supply level change on rail demand forecasting error can be quantified.

b) Scenario 2

Like scenario 1, rail demand forecasting method suggested in the existing preliminary feasibility guidelines was applied in scenario 2. But, the change of bus supply level according to the land development plan was taken into consideration. The data of bus supply level for 2013 was acquired based on the observed bus network information of 2013.

The bus supply level of this scenario is higher than the bus supply level of scenario 1 reflecting the increase in traffic demand due to the land development plan. At the time of opening of Yongin light rail, the supply level of the bus running through Dongbaek district was observed to be as 77,607 vehicle-km for 17 lines.

In this study, the result of this scenario is assumed to be the observed value of Yongin light rail demand.

c) Scenario 3

In scenario 3, the method suggested in this study which takes into account the bus supply level forecasting model was applied. In this scenario, the change of bus supply level due to the land development plan was considered. But, unlike scenario 2 which used observed bus network information of 2013, this scenario reflects the change of bus supply level by applying the cross-elasticity and post-processing the total rail demand.

The reliability of the proposed method was verified by comparing the demand of Yongin light rail in scenario 3 with the result of scenario 2.

As the result of the application of the bus supply level forecasting model, the bus supply level for the population of 93,565 person was estimated at 76,259 vehicle-km.

Table 4.19 Bus supply level prediction(Dongbaek district)

Analysis point in time	Forecasted population (person)	Bus supply level (observed) (vehicle-km)	Bus supply level (predicted) (vehicle-km)
2001 (agreement year)	-	**15,504**	-
2013 (opening year)	93,565	77,607	**76,259**

Rail demand reduction ratio was calculated by using the bus supply level in 2001 of 15,504 vehicle-km, the predicted bus supply

level in 2013 of 76,259 vehicle-km, and the cross-elasticity of -0.4 as suggested in chapter 3.

As a result, the rail demand reduction ratio for scenario 3, was calculated as 0.529. That is, the demand for rail in Dongbaek district will decrease by 47.1%, since the bus supply level increase in 2013 by 392% compared to 2001.

Table 4.20 Rail demand reduction ratio(Dongbaek district)

Analysis point in time	Bus supply level (vehicle-km)	Cross-elasticity of rail demand	Rail demand reduction ratio
2001 (agreement year)	15,504	-0.4	=exp[-0.4*{n(76,259)-ln(15,504)}] =0.529
2013 (opening year)	76,259		

4.3.5. Result of scenario analysis

By comparing the demand of Yongin light rail in scenario 1 with the result of scenario 2, the impact of bus supply level change on rail demand forecasting error was quantified. Also, The reliability of the proposed rail demand forecasting method was verified by comparing the demand of Yongin light rail in scenario 3 with the result of scenario 2.

EMME/3.0 Transportation modeling software package was used to perform demand forecasting, and the data of bus supply level for

2001 and 2013 was acquired based on the observed bus network information.

The 2013 bus network used in scenario 2 increased from 3 to 17 bus lines compare to the 2001 bus network used for scenario 1 and scenario 3. These increased routes mainly connect Gangnam and Yongin. Figure 4.4 shows the comparison result of bus lines of scenario 1(&3) and 2. The figures on links mean the number of increased bus lines in Scenario 2.

Figure 4.4 Comparison of bus line between scenario 1(&3) and scenario 2(Yongin Light Rail case)

The results of analyzing the demand for public transport in Dongbaek district and the demand for Yongin light rail are as shown in the following table.

Table 4.21 Results of scenario analysis(Yongin Light Rail)

(Units: trips per day)

Scenario number	Proportion of trip generation by mode at Dongbaek district		Demand for Yongin light rail	Ratio comparison
	Subway	Bus + Subway		
Scenario 1	8,839	3,593	311,102	117%
Scenario 2	7,772	4,177	26,527	100%
Scenario 3	4,674	5,703	27,384	103%

As a result of scenario analysis, the demand of Yongin light rail without consideration of bus supply level change(scenario 1) is about 17%p overestimated than the demand of Yongin light rail with consideration of bus supply level change(scenario 2). As expected, the increase in bus supply level due to the population increase in the land development plans have been an overestimation error factor for rail demand.

Next, the demand of Yongin light rail that the method proposed in this study was applied in analysis(scenario 3) is about 3%p overestimate than the result of scenario 2. It is expected that the method proposed in this study can reduce the demand forecasting error of new rail more than 10%p compared with the prior model.

Also, this result suggests that the accuracy of the proposed method using the cross-elasticity of rail demand and the change of bus supply level seems is within an acceptable range, showing only 3% of difference.

4.4. Gimpo metro line project

4.4.1. Overview of the project

Gimpo metro line project has not yet completed, so acquiring the data on the observed demand are not possible. However, most of the residents of Hangang new town have moved in, and the supply of buses had increased based on the population. Thus, it is possible to estimate the demand for Gimpo metro line based on current bus supply level by obtaining the latest bus route data.

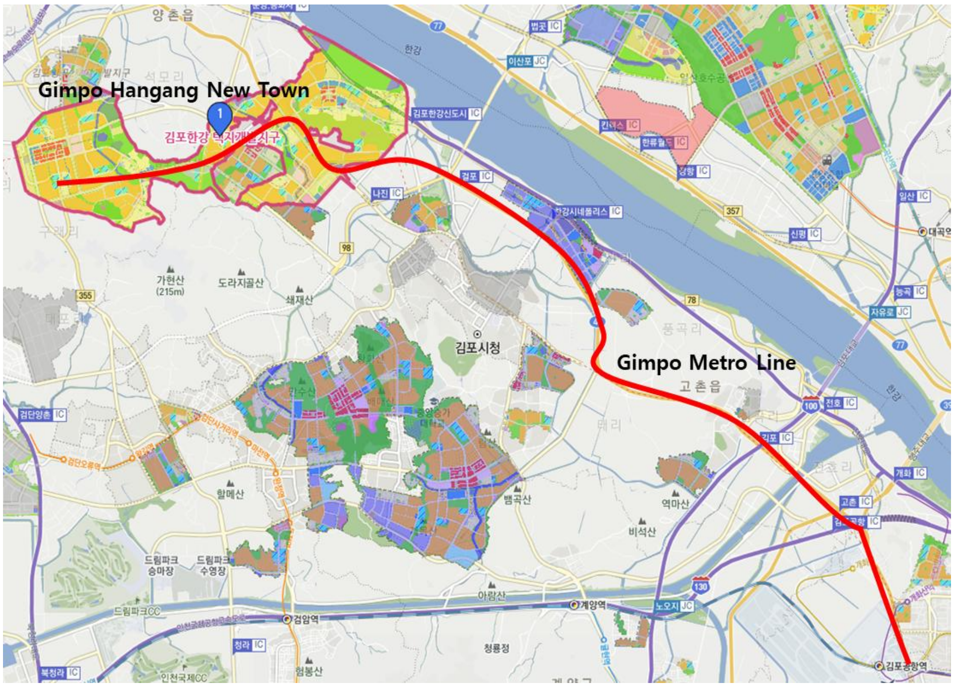
In this study, it is assumed that the change of bus supply level according to the land development plan was completed at present(2017). And the demand estimated with the bus supply level of present time was considered as the observed value of Gimpo metro line demand.

The Gimpo metro line project started in 2001 when KDI analyzed the pre-feasibility of the project. The master plan was established in 2009, and the construction began in 2014. At the analysis point of the master plan in time, the construction was expected to complete in 2012. But, the plan has been delayed, and expected to complete in 2018.

Table 4.22 Implementation process of Gimpo metro line project

Year	Implementation Process
2001.6	Pre-feasibility analysis was conducted by KDI(B/C=0.37~0.77)
2003.7	The project was included in "Metro-wide Transport Scheme for North of Seoul metropolitan area"
2006.12	Metro-wide Transport Improvement Scheme for Gimpo new town was authorized
2009.7	The master plan for Gimpo metro rail was established and the target completion year was set to 2012
2010.12	The master plan for Gimpo metro rail was adjusted
2011.9	The master plan for Gimpo metro rail was adjusted
2012.3	The adjusted master plan for Gimpo metro rail was authorized
2014.3	The construction began
2016.6	Contractor for consign operation was selected
2018.	Construction is expected to be completed

Figure 4.5 Location of Gimpo metro line and Hangang new town



Gimpo metro line was constructed with the purpose of dealing with the traffic demand of Gimpo Hangang new town. That is Hangang new town development project is located within the impact area of Gimpo metro line.

Hangang new town is located in Gimpo-si, Gyeonggi-do and is a large-scale residential development project with a total planned population of 153,760 person.

At the point of Gimpo metro line demand forecasting, the Hangang new town development project was expected to be completed in 2012. In fact, the project has been completed in 2017. But, the first partial completion occurred in December 2012, and more than 100% of the planned population have been inhabited in 2017. Therefore, it can be considered that the impact of the completion delay of Hangang new town on the degree of realization of the planned population will be insignificant.

Table 4.23 Hangang new town development project overview

Project period	2006.12.31~2017.11.30
Location	Gyeonggi-do Gimpo-si Gimpo2-dong(Janggi-dong , Unyang-dong, Gurae-dong, Masan - dong)
Completion year(predicted)	2012
1st partial completion year(observed)	2012.12(1st) / 2014.4(2nd) / 2014.12(3rd)
population(predicted)	153,760(person)
Population of 1st partial completion year(observed)	72,242(2012) / 119,998(2014) / 159,499(2017)

Source: Korea Land and Housing Corporation(http://www.jigu.go.kr)

The traffic demand from Hangang new town increased from 2012 when more than 70,000 person moved in since the land development project was partially completed. However, Gimpo metro line is expected to start running in 2018 resulting in a time lag of minimum six years between the increase of traffic demand and supply of rail.

Despite the drastic traffic demand increase, rail facilities were not supplied in a timely manner. As a result, the number of buses increased during the time lag.

Table 4.24 Analysis of transport condition(Gimpo metro line)

Trip generation point in time	Gimpo Hangang new town project was partially completed in 2012. Over 80,000 people have moved in, and traffic demand increased.
Rail opening point in time	The construction was expected to complete in 2012 at the point of analysis but delayed until in 2018.
Time lag	From 2012 to 2018, delay of minimum 6 years between the increase of traffic demand and the supply of rail is expected.

4.4.2. Analysis of bus supply level change

To carry out the analysis, the analysis point in time was set to 2012 when the master plan for Gimpo metro rail was adjusted for the last time.

The bus supply level of Hangang new town amounted to 64,329 vehicle-km for 15 lines at the analysis point in time. The bus supply in 2017, which is the time of completion of Hangang new town, increased to 127,877 vehicle-km for 31 lines.

For the application of the urban rail demand forecasting method proposed in this study, the bus supply level forecasting model based on the population level presented in Chapter 3 was used to predict the supply level of the bus in 2018 for Hangang new town.

The traffic analysis zones used for the population analysis are Gimpo2-dong in Gimpo-si, where the Hangang new town is located. The total population of these zones was estimated at 154,330 person in 2018. As the result of the application of the bus supply level forecasting model, the bus supply level for the population of 154,330 person was estimated at 124,734 vehicle-km.

The bus supply level of Hangang new town at the completion point in time had increased by about 99% compared to the bus supply level at the analysis point in time. It is reasonable to assume that there will be an impact on the rail demand due to the change in the level of bus supply.

When applying the bus supply level forecasting model proposed in this study, the predicted bus supply level amounts to 124,734 vehicle-km for Hangang new town, and the error rate to the observed bus supply level is about -2.5%. It can be concluded that the error of the bus supply level model is insignificant.

Table 4.25 Comparison of predicted and observed bus supply level(Gimpo new town)

Category	Point of analysis	Number of Bus lines*	Bus supply level (vehicle-km)**	Error rate(%)***
Survey data	2012 (analysis year)	15	64,329	
	2018 (expected opening year)	31	127,877	
Model prediction	2018 (expected opening year)	-	124,734	-2.5%

* : intra-city bus, Metropolitan bus, express city bus(intercity bus, community bus, express bus are not included)

** : bus supply level is the sum of the multiplication of route length and number of bus runs for each bus route

*** : $Error\ rate(\%) = \frac{(Model\ prediction - Survey\ data)}{Survey\ data} \times 100$

Source: Gyeonggi Transport Information center(http://gits.gg.go.kr)

4.4.3. Scenario analysis

To analyze the impact of the change of bus supply level on rail demand forecasting error and the reliability of the model suggested in this study, scenario analysis was conducted. Since the purpose of this study is to analyze the effect of bus supply level change, other sources of rail demand forecasting error were excluded from the scenario analysis. The target year of analysis was set to 2018 when the Gimpo metro line is expected to open.

The analysis scenarios consisted of three scenarios depending on whether the changes of bus supply level is reflected or not and the way these changes applied in the scenarios.

Table 4.26 Scenario description(Gimpo metro line)

Scenario number	Scenario 1	Scenario 2	Scenario 3
Model	Prior model	Prior model	Proposed model
Bus supply level change	-	Observed	Predicted
Bus supply level (vehicle-km)	64,329	127,877	124,734
Cross-elasticity of Rail Demand	-	-	-0.4

a) Scenario 1

In Scenario 1, rail demand forecasting method suggested in the existing preliminary feasibility guidelines was applied. In this scenario, the change of bus supply level according to the land development plan was not taken into consideration, and the bus supply level at the time of demand analysis was assumed to remain the same at the time of opening of the new rail facilities.

Therefore, at the time of opening of Gimpo metro line, the supply level of the bus running through Hangang new town was estimated at 64,329 vehicle-km for 15 lines, which is the same as the bus supply level at the time of the analysis.

Since the change of bus supply level was not considered in this scenario, the errors of rail demand forecasting are inherent. By comparing the result of scenario 1 with the result of scenario 2, the impact of bus supply level change on rail demand forecasting error can be quantified.

b) Scenario 2

Like scenario 1, rail demand forecasting method suggested in the existing preliminary feasibility guidelines was applied in scenario 2. But, the change of bus supply level according to the land development plan was taken into consideration. The data of bus supply level for 2018 was acquired based on the observed bus network information of 2017.

The bus supply level of this scenario is higher than the bus supply level of scenario 1 reflecting the increase in traffic demand due to the land development plan. At the time of completion of Hangang new town(2017), the supply level of the bus running through Hangang new town was observed to be as 127,877 vehicle-km for 31 lines.

In this study, the result of this scenario is assumed to be the observed value of Gimpo metro line demand.

c) Scenario 3

In scenario 3, the method suggested in this study which takes into account the bus supply level forecasting model was applied. In this scenario, the change of bus supply level due to the land development plan was considered. But, unlike scenario 2 which used observed bus network information of 2017, this scenario reflects the change of bus supply level by applying the cross-elasticity and post-processing the total rail demand.

The reliability of the proposed method was verified by comparing the demand of Gimpo metro line in scenario 3 with the result of scenario 2.

As the result the application of the bus supply level forecasting model, the bus supply level for the population of 154,330 person was estimated at 124,734 vehicle-km.

Table 4.27 Bus supply level prediction(Hangang new town)

Analysis point in time	Forecasted population (person)	Bus supply level (observed) (vehicle-km)	Bus supply level (predicted) (vehicle-km)
2012 (analysis year)	-	**64,329**	-
2018 (expected opening year)	154,330	127,877	**124,734**

Rail demand reduction ratio was calculated by using the bus supply level in 2012 of 64,329 vehicle-km, the predicted bus supply

level in 2018 of 124,734 vehicle-km, and the cross-elasticity of - 0.4 as suggested in chapter 3.

As a result, the rail demand reduction ratio for scenario 3, was calculated as 0.767. Thant is, the demand for rail in Pangyo new town will decrease by 23.3%, since the bus supply level increase in 2018 by 94% compared to 2012.

Table 4.28 Rail demand reduction ratio(Hangang new town)

Analysis point in time	Bus supply level (vehicle-km)	Cross-elasticity of rail demand	Rail demand reduction ratio
2012 (analysis year)	64,329	-0.4	=exp[-0.4*{n(124,734)-ln(64,329)}] =0.767
2018 (expected opening year)	124,734		

4.4.4. Result of scenario analysis

By comparing the demand of Gimpo metro line in scenario 1 with the result of scenario 2, the impact of bus supply level change on rail demand forecasting error was quantified. Also, The reliability of the proposed rail demand forecasting method was verified by comparing the demand of Gimpo metro line in scenario 3 with the result of scenario 2.

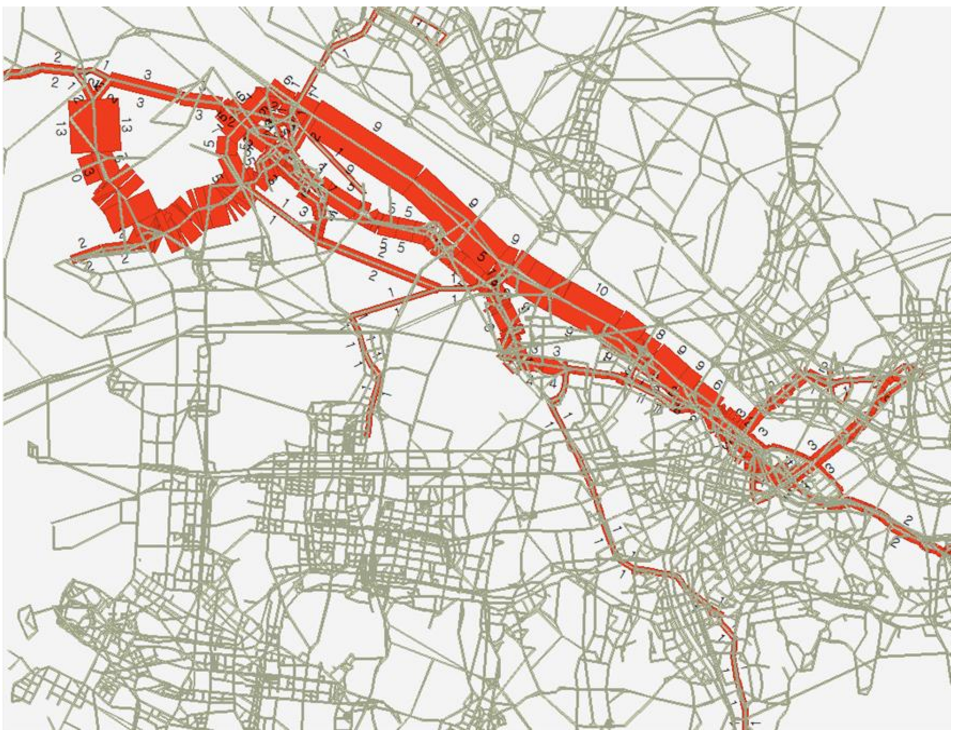
EMME/3.0 Transportation modeling software package was used to perform demand forecasting, and the data of bus supply level for

2012 and 2018 was acquired based on the observed bus network information.

The 2018 bus network used in scenario 2 increased from 15 to 31 bus lines compare to the 2012 bus network used for scenario 1 and scenario 3. These increased routes mainly connect Seoul Station, Yeouido, and Hangang new town and are similar to the route of shinbundang-line.

Figure 4.6 shows the comparison result of bus lines of scenario 1(&3) and 2. The figures on links mean the number of increased bus lines in Scenario 2.

Figure 4.6 Comparison of bus line between scenario 1(&3) and scenario 2(Gimpo metro line)



The results of analyzing the demand for public transport in Hangang new town and the demand for Gimpo metro line are as shown in the following table.

Table 4.29 Results of scenario analysis(Gimpo metro line)

(Units: trips per day)

Scenario number	Proportion of trip generation by mode at Hangang new town		Demand for Gimpo metro line	Ratio comparison
	Subway	Bus + Subway		
Scenario 1	42,967	15,371	105,072	123%
Scenario 2	40,474	16,099	85,749	100%
Scenario 3	32,955	11,789	85,782	100%

As a result of scenario analysis, the demand for Gimpo metro line without consideration of bus supply level change(scenario 1) is about 23%p overestimated than the demand for Gimpo metro line with consideration of bus supply level change(scenario 2). As expected, the increase in bus supply level due to the population increase in the land development plans have been an overestimation error factor for rail demand.

Next, the demand for Gimpo metro line that the method proposed in this study was applied in the analysis(scenario 3) is same as the result of scenario 2. It is expected that the method proposed in this study can reduce the demand forecasting error of new rail more than 20%p compared with the prior model.

Also, this result suggests that the accuracy of the proposed method using the cross-elasticity of rail demand and the change of bus supply level seems is within the acceptable range, showing no difference.

4.5. Byeollae-line Project

4.5.1. Overview of the project

Byeollae-line project which is the extension line of Seoul metro 8^{th} line has not yet completed, so acquiring the data on the observed demand are not possible. However, most of the residents of Byeollae and Galmae district have moved in, and the supply of buses had increased based on the population. Thus, it is possible to estimate the demand for Byeollae-line based on current bus supply level by obtaining the latest bus route data.

In this study, it is assumed that the change of bus supply level according to the land development plan was completed at present(2017). And the demand estimated with the bus supply level of present time was considered as the observed value of Byeollae-line demand.

The Byeollae-line project started in 2003 when the Metro-wide Transport Scheme for North of Seoul metropolitan area was established. The master plan for the project has been authorized in 2014 and the construction began in 2015. At the analysis point of the master plan in time, the construction was expected to complete in 2012. But, the plan has been delayed, and expected to complete in 2022.

Table 4.30 Implementation process of Byeollae-line project

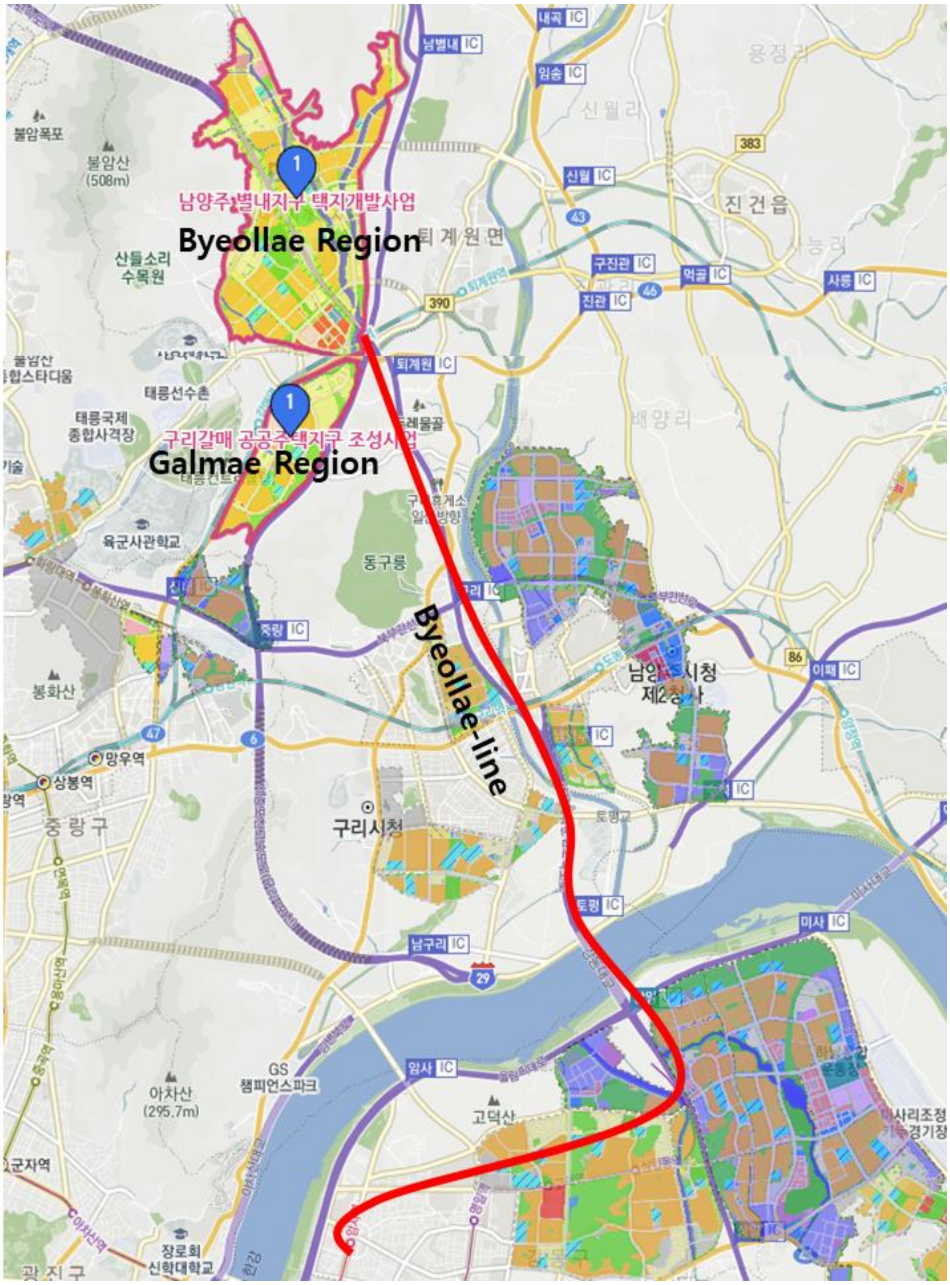
Year	Implementation Process
2003.11	The project was included in “Metro-wide Transport Scheme for North of Seoul metropolitan area”
2006.7	Metro-wide Transport Improvement Scheme for Byeollae development project was authorized
2006.11	Pre-feasibility analysis was conducted(B/C=0.91, AHP=0.508)
2010.5	The mast plan for Byeollae-line project was conducted(B/C=1.17)
2014.1	The mast plan for Byeollae-line project was adjusted(B/C=1.06) and the target completion year was set to 2012
2014.12	The adjusted master plan for Byeollae-line was authorized
2015.12	The construction began
2022.	Construction is expected to be completed

Byeollae-line was constructed with the purpose of dealing with the traffic demand of Byeollae and Galmae district. That is, Byeollae and Galmae development project is located within the impact area of Byeollae-line.

Byeollae district is located in Namyangju-si, Gyeonggi-do and is a large-scale residential development project with a total planned population of 67,135 person.

Galmae district is located in Guri-si, Gyeonggi-do and is a large-scale residential development project with a total planned population of 153,760 person.

Figure 4.7 Location of Byeollae-line and Byeollae/Galmae district



Within the impact area of Byeollae-line, there are several development districts such as Dasan-Jinjun district, Dasan-Jigeum district, Gaun district, and Misa district besides Byeollae district and Galmae district.

The development projects except for Byeollae and Galmae district are not yet completed, and the inhabitants have not yet moved in. So, it is not possible to confirm the increase of the bus supply level at present. Therefore, this study considers only Byeollae and Galmae district as the subject of analysis since their inhabitants have move in and bus supply had increased.

There is one thing to take noticed. Some of the bus routes running through Byeollae and Galmae district also pass through other land development district, and this may impacts the result of this study since the impacts on other land development district can be taken into account.

Table 4.31 Land development districts adjacent to Byeollae-line

Land development district	Project duration
Namyangju Byeollae	2004.12~2017.12
Guri Galmae	2009.12~2017.12
Namyangju Dasan-Jinjun	2009.12~2018.6
Namyangju Dasan-Jigeum	2010.7~2018.6
Namyangju Gaun	2003.6~2012.9
Hanam Misa	2009.6~2018.6

Byeollae-line was constructed with the purpose of dealing with the traffic demand of several land development plans in Guri and Namyangju. That is, several development projects are located within the impact area of Byeollae-line.

Byeollae district is located in Namyangju-si, Gyeonggi-do and is a large-scale residential development project with a total planned population of 67,135 person.

Galmae district is located in Guri-si, Gyeonggi-do and is also a residential development project with a total planned population of 26,516 person.

At the point of Byeollae-line demand forecasting, the Byeollae district project was expected to be completed in 2011. In fact, the project has been completed in 2017. Also, at the point of Byeollae-line demand forecasting, the Galmae district project was expected to be completed in 2015. In fact, the project has been completed in 2017.

The population of Byeollae and Galmae district amounts to 102,705 person in 2017. This population amounts to about 98% of the planned population. It can be assumed that the impact of the completion delay of Byeollae and Galmae development on the degree of realization of the planned population will be insignificant.

Table 4.32 Byeollae district development project overview

Project period	2005.12.21~2017.12.31
Location	Gyeonggi-do Namyangju-si Byeollae-myeon, Hwajeop-ri, Gwangjeon-ri, Deoksong
Completion year(predicted)	2011
Partial completion year(observed)	2012.12(1st) / 2014.3(2nd)
Population(predicted)	67,135(person)
Population of 1st partial completion year(observed)	55,434(2015) / 60,776(2016)

Source: Korea Land and Housing Corporation(http://www.jigu.go.kr)

Table 4.33 Galmae district development project overview

Project period	2009.12.3.~2017.12.31
Location	Gyeonggi-do Guri-si Galmae-dong
Completion year(predicted)	2015
1st partial completion year(observed)	2017.7
Population(predicted)	26,516(person)

Source: Korea Land and Housing Corporation(http://www.jigu.go.kr)

The traffic demand from Byeollae and Galmae district increased from 2012 when the land development project was partially completed. However, Byeollae-line is expected to start running in 2022 resulting in a time lag of minimum ten years between the increase of traffic demand and supply of rail.

Despite the drastic traffic demand increase, rail facilities were not supplied in a timely manner. As a result, the number of buses increased during the time lag.

Table 4.34 Analysis of transport condition(Byeollae-line)

Trip generation point in time	Byoellae development project was partially completed in 2012 and traffic demand increased.
Rail opening point in time	The construction was expected to complete in 2017 at the point of analysis but delayed until in 2022.
Time lag	From 2012 to 2022, delay of minimum 10 years between the increase of traffic demand and the supply of rail is expected.

4.5.2. Analysis of bus supply level change

The analysis point in time was set to 2011 which is the base year of analysis of the adjusted master plan of Gimpo metro line.

The bus supply level of Byeollae and Galmae district amounted to 26,237 vehicle-km for 5 lines at the analysis point in time. The bus supply in 2017, which is the time of completion of Byeollae and Galmae district, increased to 69,063 vehicle-km for 21 lines.

For the application of the urban rail demand forecasting method proposed in this study, the bus supply level forecasting model based on the population level presented in Chapter 3 was used to predict the supply level of the bus in 2022 for Byeollae and Galmae district.

The traffic analysis zones used for the population analysis are

Galmae-dong and Byeollae-myeon where the Byeollae and Galmae district is located. The total population of these zones was estimated at 102,705 person in 2022. As the result the application of the bus supply level forecasting model, the bus supply level for the population of 102,705 person was estimated at 83,705 vehicle-km.

The bus supply level of Byeollae and Galmae district at the completion point in time had increased by about 163% compared to the bus supply level at the analysis point in time. It is reasonable to assume that there will be an impact on the rail demand due to the change in the level of bus supply.

When applying the bus supply level forecasting model proposed in this study, the predicted bus supply level amounts to 83,705 vehicle-km for Byeollae and Galmae district, and the error rate to the observed bus supply level is about 21.2%.

Compared to other cases where the bus supply level error rate did not exceed 5%, a high error rate was observed in Byeollae-line case. It is assumed that increasing bus supply level take some time for administrative procedures. Since Byeollae and Galmae development was completed in December 2017, time to adjust the bus line was not enough. So, the error of the bus supply level forecasting model may be due to the short of time to adjust bus lines. So, the change of bus supply level on the actual bus network may not yet be completed.

Table 4.35 Comparison of predicted and observed bus supply level (Byeollae/ Galmae district)

Category	Point of analysis	Number of Bus lines*	Bus supply level (vehicle-km)**	Error rate(%)***
Survey data	2011 (analysis year)	5	26,237	
	2022 (expected opening year)	21	69,063	
Model prediction	2022 (expected opening year)	-	83,705	21.2%

* : intra-city bus, Metropolitan bus, express city bus(intercity bus, community bus, express bus are not included)

** : bus supply level is the sum of the multiplication of route length and number of bus runs for each bus route

*** : $Error\ rate(\%) = \frac{(Model\ prediction - Survey\ data)}{Survey\ data} \times 100$

Source: Gyeonggi Transport Information center(http://gits.gg.go.kr)

4.5.3. Scenario analysis

To analyze the impact of the change of bus supply level on rail demand forecasting error and the reliability of the model suggested in this study, scenario analysis was conducted. Since the purpose of this study is to analyze the effect of bus supply level change, other sources of rail demand forecasting error were excluded from the scenario analysis. The target year of analysis was set to 2022 when the Byeollae-line is expected to open.

The analysis scenarios consisted of three scenarios depending on whether the changes of bus supply level is reflected or not and the way these changes applied in the scenarios.

Table 4.36 Scenario description(Byeollae-line)

Scenario number	Scenario 1	Scenario 2	Scenario 3
Model	Prior model	Prior model	Proposed model
Bus supply level change	-	Observed	Predicted
Bus supply level (vehicle-km)	26,237	69,063	83,705
Cross-elasticity of Rail Demand	-	-	-0.4

a) Scenario 1

In Scenario 1, rail demand forecasting method suggested in the existing preliminary feasibility guidelines was applied. In this scenario, the change of bus supply level according to the land development plan was not taken into consideration, and the bus supply level at the time of demand analysis was assumed to remain the same at the time of opening of the new rail facilities.

Therefore, at the time of opening of Byeollae-line, the supply level of the bus running through Byeollae and Galmae district was estimated at 26,237 vehicle-km for 5 lines, which is the same as the bus supply level at the time of the analysis.

Since the change of bus supply level was not considered in this scenario, the errors of rail demand forecasting are inherent. By comparing the result of scenario 1 with the result of scenario 2, the impact of bus supply level change on rail demand forecasting error can be quantified.

b) Scenario 2

Like scenario 1, rail demand forecasting method suggested in the existing preliminary feasibility guidelines was applied in scenario 2. But, the change of bus supply level according to the land development plan was taken into consideration. The data of bus supply level for 2022 was acquired based on the observed bus network information of 2017.

The bus supply level of this scenario is higher than the bus supply level of scenario 1 reflecting the increase in traffic demand due to the land development plan. At the time of completion of Byeollae and Galmae district(2017), the supply level of the bus running through Byeollae and Galmae district was observed to be as 69,063 vehicle-km for 21 lines.

In this study, the result of this scenario is assumed to be the observed value of Byeollae-line demand.

c) Scenario 3

In scenario 3, the method suggested in this study which takes into account the bus supply level forecasting model was applied. In this scenario, the change of bus supply level due to the land development plan was considered. But, unlike scenario 2 which used observed bus network information of 2017, this scenario reflects the change of bus supply level by applying the cross-elasticity and post-processing the total rail demand.

The reliability of the proposed method was verified by comparing the demand of Byeollae-line in scenario 3 with the result of scenario 2.

As the result of the application of the bus supply level forecasting model, the bus supply level for the population of 102,705 person was estimated at 83,705 vehicle-km.

Table 4.37 Bus supply level estimation(Byeollae/Galmae district)

Analysis point in time	Forecasted population (person)	Bus supply level (observed) (vehicle-km)	Bus supply level (predicted) (vehicle-km)
2011 (analysis year)	-	**26,237**	-
2022 (expected opening year)	102,705	69,063	**83,705**

Rail demand reduction ratio was calculated by using the bus supply level in 2011 of 26,237 vehicle-km, the predicted bus supply level in 2022 of 83,705 vehicle-km, and the cross-elasticity of -0.4 as suggested in chapter 3.

As a result, the rail demand reduction ratio for scenario 3, was calculated as 0.629. That is, the demand for rail in Byeollae and

Galmae district will decrease by 37.1%, since the bus supply level increase in 2022 by 219% compared to 2011.

Table 4.38 Rail demand reduction ratio(Byeollae/Galmae district)

Analysis point in time	Bus supply level (vehicle-km)	Cross-elasticity of rail demand	Rail demand reduction ratio
2011 (analysis year)	26,237	-0.4	=exp[-0.4*{n(83,705)-ln(26,237)}] =0.629
2022 (expected opening year)	83,705		

4.5.4. Result of scenario analysis

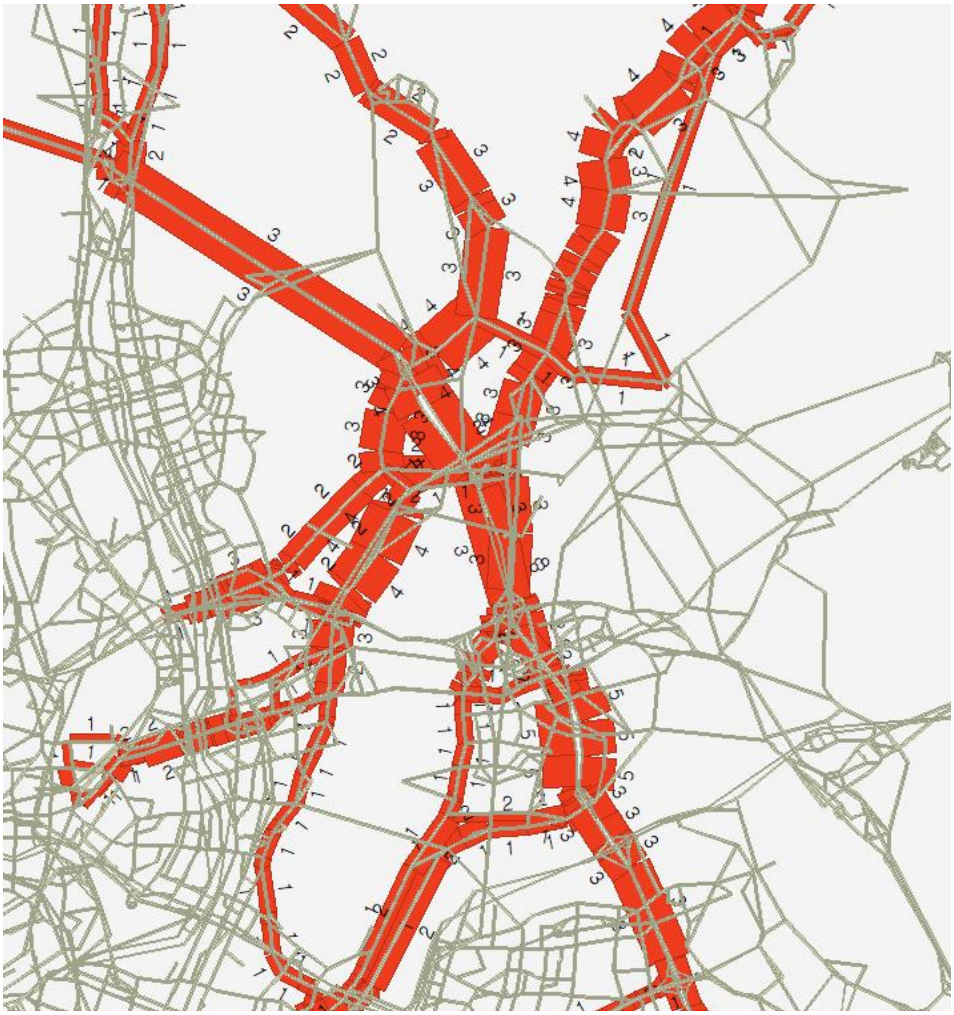
By comparing the demand of Byeollae-line in scenario 1 with the result of scenario 2, the impact of bus supply level change on rail demand forecasting error was quantified. Also, The reliability of the proposed rail demand forecasting method was verified by comparing the demand of Byeollae-line in scenario 3 with the result of scenario 2.

EMME/3.0 Transportation modeling software package was used to perform demand forecasting, and the data of bus supply level for 2011 and 2022 was acquired based on the observed bus network information.

The 2017 bus network used in scenario 2 increased from 5 to 21 bus lines compare to the 2012 bus network used for scenario 1 and scenario 3. These increased routes mainly connect Uijeongbu, Namyangju, Cheongnyangni, and Gangnam and are similar to the route of Byeollae-line.

Figure 4.8 shows the comparison result of bus lines of scenario 1(&3) and 2. The figures on links mean the number of increased bus lines in Scenario 2.

Figure 4.8 Comparison of bus line between scenario 1(&3) and scenario 2 (Byeollae-line)



The results of analyzing the demand for public transport in Byeollae and Galmae district and the demand for Byeollae-line are as shown in the following table.

Table 4.39 Results of scenario analysis(Byeollae-line)

(Units: trips per day)

Scenario number	Proportion of trip generation by mode at Byeollae/Galmae district		Demand for Byeollae-line	Ratio comparison
	Subway	Bus + Subway		
Scenario 1	40,271	41,980	80,327	141%
Scenario 2	36,756	44,567	57,089	100%
Scenario 3	30,178	30,475	66,778	117%

As a result of scenario analysis, the demand of Byeollae-line without consideration of bus supply level change(scenario 1) is about 41%p overestimated than the demand of Byeollae-line with consideration of bus supply level change(scenario 2). As expected, the increase in bus supply level due to the population increase in the land development plans have been an overestimation error factor for rail demand.

Next, the demand of Byeollae-line that the method proposed in this study was applied in the analysis(scenario 3) is about 17%p overestimated than the result of scenario 2.

Even though the method proposed in this study reduced the demand forecasting error of new rail about 24%p compared with the prior model, it showed large percent difference to the result of scenario 2. Also, the percent difference of scenario 1 to the result of scenario 2 was much larger to the results of other case studies.

The source of this relatively large error of Byeollae-line case is that some of the bus routes running through Byeollae and Galmae district, also, pass through other land development district. Among 21 bus lines running through Byeollae and Galmae district, 13 bus lines pass through other land development districts as well.

The overlapped bus lines may cause the forecast error in the other land development districts which were excluded in the analysis of this study. And the effects of overlapped bus line caused the significantly large error.

From this result, it can be assumed that if there are several neighboring land development plans within the impact area of the new rail project, the buses running through these districts may be overlapped. The more the buses are overlapped, or the more the adjacent land development plans are, the bigger the demand forecast errors of new rail project will be.

Therefore, in the process of urban rail demand forecasting, if there are several uncompleted land development plans within the impact area, the estimation of bus supply level change should be conducted with much caution.

Chapter 5. Conclusion

5.1. Summary and conclusion

For large-scale transport facilities, various sources of errors and uncertainties in the demand estimation process are causing the errors in estimating traffic demand, resulting in controversy over the inaccuracy of the traffic demand forecasting. In particular, the demand for transportation was overestimated for private investment projects, which put a burden on the government's national finance by providing huge operational subsidies to private businesses.

Previous studies suggest that the problem of misleading forecasts on the road is less severe and less one-sided than for rail. For road projects, the traffic estimates are highly, systematically and significantly inflated. The same result was observed in the forecast of domestic road and rail projects.

This study focused on the unexpected increase of the bus supply level and the modal share prediction errors caused by the unexpected bus supply change in the process of mode split. If a new rail line is planned for an area where large land developments are expected, the level of bus supply at the time of development planning and level of bus supply at the time of development completion would be different, and this may cause forecasting error.

The results of the survey on the changes in bus supply levels before and after the large-scale developments in the Seoul metropolitan area showed that the number of bus lines increased by 54% to 467%. In a situation that the supply level of bus in land development district increases more than four times, if the change of bus supply level was not considered in rail demand forecasting, the competitiveness of rail will be overestimated, as a result, cause forecast error.

Therefore, this study developed a bus supply level forecastinging model and suggested a method to apply the model in the rail demand forecasting process. To consider the effect of change of future bus supply level, post-processing analysis which re-estimates rail demand by using cross-elasticity and the percent difference between bus supply level of the existing model and proposed model.

The post-process analysis is conducted by estimating the future population of the land development district, estimating the bus supply level based on the future population and calculating the bus supply level change, and re-estimating the rail demand using cross-elasticity concerning the change of bus supply level.

To consider the utility change in an aspect of temporally and spatially, the vehicle-km was selected as the index of bus supply level. In this study, to develop a bus supply forecasting model a regression analysis using cross-sectional data on bus supply level was conducted. The only explanatory variable of the bus supply levels is population, and as the population of the research area increased, the supply level of bus also increased. Changes in the level of bus supply change the utility of passengers, and consequently, cause changes in modal share.

The cross-elasticity was analyzed using cross-sectional data of bus supply in Siheung-si, Gyeonggi province. And log arc elasticity was adopted in the analysis of cross-elasticity. As the result of analysis, the cross-elasticity of rail demand regarding the bus supply level was calculated as -0.398.

Using the proposed model, four cases of previous urban rail demand forecasting studies were re-reviewed. The demand estimates result from the scenarios applying the existing model and the proposed model, and the observed rail demand were compared. Through this scenario analysis, the error due to the change of the bus supply level was quantified, and the reliability of the proposed model was verified.

In Shinbundang-line, Yongin light rail, Gimpo metro line and Byollae-line case studies, it was confirmed that the supply level of buses increased after the land development project completion, and the rail demand forecasts tend to overestimate. The impacts of bus supply level change on the rail demand forecasts ranged from 16% to 41%. In this proposed model, the error was less than 5% except for the case of Byollae-line.

In Byollae-line case, the results of both of the existing model and proposed model showed large percent difference to the observed demand. The source of this relatively large error of Byeollae-line case is supposed that there are several land development projects nearby, and buses running through these districts may be overlapped.

From this result, it can be assumed that if there are several neighboring land development plans within the impact area of the new rail project, the buses running through these districts may be overlapped. The more the buses are overlapped, or the more the adjacent land development plans are, the bigger the demand forecast errors of new rail project will be. Estimation of the supply level change of overlapping bus lines should be conducted with much caution.

This study suggests the unexpected change of bus supply level as a major source of rail demand forecasting error, which has been failed to be considered in the previous studies and guidelines.

This study is distinct from the previous study regarding the impact of changes of bus supply levels on urban rail demand forecast was quantified, and a bus supply level prediction model was developed and applied to improve the reliability of demand forecasting.

5.2. Further research

This study suggests the unexpected change of bus supply level as a major source of urban rail demand forecasting error, which has been failed to be considered in the previous studies and guidelines in depth. Also, this study is distinct from the previous study regarding the impact of changes of bus supply levels on urban rail demand forecast was quantified, and a bus supply level prediction model was developed and applied to improve the reliability of demand forecasting.

Still, due to the lack of reliable data on bus supply level, only cross-sectional data were used in the development of bus supply level forecasting model. This limitation is, also, observed in the calculation of cross-elasticity of urban rail concerning the bus supply level change. Due to the lack of data, the transferable indices on cross-elasticities according to the size of the change, time, the region could not be calculated.

Also, to consider the effect of change of future bus supply level, it is assumed that designing the bus lines in advance and applying these schemes to future transportation network will be more appropriate. But, there are no reliable guidelines or manuals on bus supply level until yet. If future bus operation schemes for land development districts can be planned, or reliable guidelines on bus line planning are suggested, by applying these bus operation scheme on the transportation analysis network, the reliability of the urban rail demand forecasting model can be improved.

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Appendix A. The statistical data used in bus supply forecasting model development

Region	Number of bus lines	Average route length per line	Average number of frequency per line	Total vehicle-km*	Population
Gapyeong-gun	42	48	10	57,294	62,448
Goyang-si	74	73	64	654,661	1,039,684
Gwacheon-si	33	71	65	267,305	63,778
Gwangmyeong-si	36	56	73	242,824	339,484
Gwangju-si	578	38	10	768,051	327,723
Guri-si	66	68	49	421,494	193,763
Gunpo-si,	37	58	87	325,663	284,890
Gimpo-si	49	69	55	380,229	363,443
Namyangju-si	106	54	35	458,235	662,154
Dongducheon-si	127	35	6	50,845	98,277
Bucheon-si	68	36	95	434,241	851,380
Seongnam-si	158	68	55	1,087,978	974,580
Suwon-si	173	60	47	961,269	1,194,041
Siheung-si	67	54	48	340,408	402,888
Ansan-si	75	50	40	325,886	689,859
Anseong-si	145	37	14	182,775	182,896
Anyang-si	76	53	83	595,521	597,414
Yangju-si	76	45	24	176,137	205,513
Yangpyeong-gun	81	41	3	23,563	111,367
Yeoju-si	223	35	3	54,879	111,563
Yeoncheon-gun	91	44	4	34,456	45,907
Osan-si	34	53	41	174,666	208,656
Yongin-si	212	52	30	806,931	991,126
Uiwang-si	59	68	73	494,306	156,763
Uijeongbu-si	62	66	39	282,593	438,457
Icheon-si	221	29	3	62,314	210,359
Paju-si	66	62	33	318,292	430,781
Pyeongtaek-si	112	41	20	215,627	470,832
Pocheon-si	65	55	16	147,176	154,763
Hanam-si	40	59	51	216,843	211,101
Hwaseong-si	202	51	28	690,841	640,890

* : One bus route run through at least two zones which are origin and destination. To refect this, in this study, the total bus supply was calculated as twice the surveyed.

Source: Gyeonggi Transport Information center(http://gits.gg.go.kr)

Appendix B. The statistical data used in cross-elasticity analysis

$Date$	$\ln(S)$	$\ln(vehicle-km)$	$\ln(Q_{SUB})$
2012_07	11.62964126	11.10256339	10.58769326
2012_08	11.67453398	11.10256339	10.58114113
2012_09	11.72230269	11.10256339	10.78420775
2012_10	-	11.10256339	10.85838777
2012_11	11.70856626	11.10256339	10.82755861
2012_12	11.64504962	11.10256339	10.75650039
2013_01	11.55319371	11.10256339	10.64041776
2013_02	11.57840417	11.10256339	10.67581883
2013_03	11.64451497	11.10256339	10.93115749
2013_04	11.64028913	11.10256339	10.96548484
2013_05	11.44229912	11.10256339	11.02089258
2013_06	11.67144089	11.10256339	10.91430209
2013_07	11.64569782	11.10256339	10.76722715
2013_08	11.55522796	11.10256339	10.77871298
2013_09	11.6397255	11.10256339	10.91597413
2013_10	11.66607564	11.10256339	11.01678026
2013_11	11.66689899	11.10256339	10.96499719
2013_12	11.63877367	11.10256339	10.88359417
2014_01	11.57666992	11.10256339	10.73287717
2014_02	11.90687115	11.13772279	10.79989695
2014_03	11.94377888	11.13772279	11.03751421
2014_04	11.96277741	11.13772279	11.0687294
2014_05	12.01691377	11.13772279	11.08732513
2014_06	11.98938322	11.13772279	10.97440371
2014_07	-	11.13772279	10.87095822
2014_08	11.97924732	11.16007178	10.8478609
2014_09	11.9811713	11.16007178	11.04243158
2014_10	11.98921554	11.16007178	11.07729958
2014_11	11.96195441	11.16007178	11.01350236
2014_12	11.64398004	11.16007178	10.66765598
2015_01	11.89385195	11.18214102	10.53810137

Appendix B.(Continued).

date	$\ln(S)$	$\ln(vehicle-km)$	$\ln(Q_{SUB})$
2015_02	11.92649101	11.18214102	10.77637931
2015_03	11.9765274	11.18214102	11.05719777
2015_04	12.02566526	11.18214102	11.24437913
2015_05	12.05646413	11.18214102	11.0789175
2015_06	11.92904033	11.18214102	10.90152907
2015_07	11.91862388	11.18214102	10.84778813
2015_08	12.02015864	11.16840493	10.85476361
2015_09	12.03672457	11.16840493	11.03200271
2015_10	12.01868226	11.16840493	11.0691272
2015_11	12.02101936	11.16840493	11.22652701
2015_12	11.96390554	11.16840493	10.94828101
2016_01	11.88886564	11.16840493	10.77300718
2016_02	11.8982899	11.16840493	10.80651275
2016_03	12.01143759	11.16840493	11.10152958
2016_04	12.00396258	11.16840493	11.10995424
2016_05	12.01313089	11.16840493	11.12516971
2016_06	11.95305606	11.16840493	11.05731693
2016_07	12.00445205	11.16840493	10.92151994
2016_08	11.95195429	11.16840493	10.92199884
2016_09	11.98150308	11.18433806	11.05918776
2016_10	11.98057633	11.18433806	11.09531154
2016_11	11.98022544	11.18433806	11.06396918
2016_12	12.0054975	11.18433806	10.97545168
2017_01	11.87150859	11.18433806	10.83524833
2017_02	11.94444811	11.18433806	10.90460842
2017_03	12.0294011	11.18433806	11.11956216
2017_04	12.20426601	11.31557149	11.12170147
2017_05	12.21549809	11.32249109	11.12708318
2017_06	12.20585262	11.32249109	11.06984779
2017_07	12.2018638	11.37003614	10.90369714
2017_08	12.17957979	11.37003614	10.91753357

Source: Gyeonggi Transport Information center(http://gits.gg.go.kr)

초 록

철도사업의 수요예측 오차는 도로사업의 수요예측 오차보다 더 크고 과다추정이 큰 확률로 관측되는 비임의성을 띄고 있다. 본 연구에서는, 철도사업에서 더 크고, 비임의적인 오차가 발생하는 원인으로, 타교통 수단, 특히 버스의 공급 수준 증가에 주목하였다. 대규모 토지개발로 인구가 증가할 것으로 예상되는 지역에 신설 철도노선이 계획되는 경우, 개발계획 수립 시점의 버스 공급수준과 개발계획 완료시점의 버스 공급수준은 상이할 것으로 예상할 수 있으며, 이로 인해 철도수요는 과대추정되어 예측 오차가 발생하게 된다.

따라서 본 연구에서는 버스의 공급 수준 변화가 도시철도 수요 예측에 미치는 영향을 분석하고, 철도 수요예측 과정에서 이로 인한 영향을 고려할 수 있는 방법을 제안하였다. 이를 통해 버스의 공급 수준 변화가 도시철도 수요에 미치는 영향을 정량적으로 분석하고, 향후 도시철도의 수요 예측 오차를 개선할 수 있을 것으로 기대할 수 있다.

분석을 위해 개발계획 지구의 인구에 따른 버스의 공급 수준을 예측하는 모형을 구축하고, 버스 공급수준 변화에 따른 도시철도의 교차탄력성을 산출하였다. 도시철도의 수요를 예측하는 과정에서 버스 공급수준 변화를 반영하기 위해, 산출된 버스 공급 수준 변화량과 교차탄력성을 이용한 철도수요 후처리 과정(post-processing)을 거치는 방법을 제안하였다.

제안된 버스 공급수준 예측 모형과 이를 이용한 철도수요 재산정 방법을 이용해, 기존 도시철도 수요 예측 사례를 시나리오 분석하였다. 신분당선, 용인경전철, 김포도시철도, 서울 8호선 연장 별내선의 사례를 대상으로 버스의 공급 증가가 철도의 수요예측에 미치는 영향을 분석한 결

과, 버스의 공급 증가가 미치는 오차 영향은 16% 많게는 41%까지 나타났다. 또한 본 연구에서 제안한 모형의 오차 정도는 별내선의 사례를 제외하고는 5% 이내로 나타나 높은 예측력을 확인하였다.

다만, 별내선의 경우 분석 대상지에 여러 개발계획이 존재하고, 버스 노선이 중복되는 등의 영향으로 상대적으로 큰 오차가 발생하였다. 이를 통해, 신규 도시철도 노선의 영향권 내에 진행 중인 개발계획의 크기가 클수록, 계획의 수가 많을수록, 버스 노선의 중복 정도가 크게 나타날수록, 오차 역시 크게 나타날 것으로 예상할 수 있다.

본 연구에서는 기존 연구들이 철도사업 수요예측 오차 발생원인으로 제시하는데 그쳤던 버스 공급수준 변화가 철도수요에 미치는 영향을 주요 오차원인으로 제시하며, 철도사업의 수요예측 시 버스의 공급수준 변화를 체계적, 정량적으로 분석하였다. 이를 통해 버스의 공급수준 변화가 과거 철도사업의 수요예측에 미친 영향을 여러 도시철도 사례분석을 통해 실증적으로 분석하고, 향후 철도사업의 수요 예측 시 버스의 공습수준 변화 예측 모형의 적용을 통해 향후 철도사업의 수요예측 오차 개선 방안을 제시한다는 점에서 기존의 연구들과 차별성을 지닌다.