Forecasting Net Induced Travel Demand for Optional Trip Purpose by Trip Production Model with Accessibility

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Abstract: Predicting net induced demand can be helpful for better feasibility study before investigating transportation infrastructure. The net induced demand can be defined as newly generated trips, but not shifted trips, by some improvements in transportation systems. This study only focused on the net induced demand rather than any other concepts belong to the general term “induced demand”. The net induced demand is quite related to the trip generation model because it refers to purely increased trips in frequency due to transportation improvement that would not be occurred without the improvement.
The study analyzed trip production models with accessibility measure for each traffic analysis zone. Multiple linear regressions were adopted as the production models in the study. The study’s basic hypothesis on trip generation was that number of generated trips per day will be statistically different at different level of accessibility for each production zone. In the estimated regression model, the study considered that the parameter for accessibility, as an independent variable, can be interpreted as unit change of the net induced demand by changes of a unit of accessibility measure. This study tried to show empirically that the number of production trips was varied depending on level of accessibility for a specific traffic analysis zone with real data of household survey. The study used the 2010 household travel survey data of Daegu Metropolitan Area in South Korea with 68,398 traveler’s data. As the results, the regression analysis showed that accessibility for a specific zone significantly affected net induced demand especially for optional trip purpose. The study also showed the way how estimating quantitatively the increased net induced demand with an example.

Keywords: net induced demand, production model, accessibility, linear regression, optional trip purpose

1. INTRODUCTION

It is important to know the demand and traffic patterns before constructing transportation infrastructures. Therefore, in many countries, economic feasibility study is required before investing large-scale transportation facilities by governments. The economic feasibility study usually analyzes the effects of any planned new transportation facilities on traveler's choice in trip frequencies, destination, mode and route. Then, the public benefits are compared with the public cost such as B/C analysis. In this feasibility study, the magnitude of transportation demand affects a lot on analysis results which may lead apposite decision-making in investing transportation facilities. In South Korea, there is a standardized manual for economical feasibility study about transportation demand analysis and B/C analysis. The manual only focused on shifted demand in mode and/or route choice while analyzing transportation demand due to new transportation facilities. Many practitioners in transportation area have felt limitation to forecast realistic transportation demand without induced demand in Korea. Therefore, this study tried to reflect such induced demand within transportation demand analysis. Especially, the study focused on net induced demand, newly generated trips, in aspect of trip frequency itself rather than any demands shifted from any previous travel choice due to improvements of transportation services. We believed that accessibility measure can represent somewhat magnitude of net induced demand if it is empirically proved that number of trip production per day and per household varies depending on traffic analysis zones (TAZs) with different level of accessibility. Therefore, this study tried to build trip production model including an accessibility measure. Multiple regression models were used for trip production models, which can easily adopted in real practice of economic feasibility study with the standardized manual in Korea.

By using the multiple regression models as trip production models, the study tried to prove empirically that the generated average trip frequencies per household and per day are varied according to the level of accessibility for a specific TAZ. Such variation depending on accessibility level indicates that better accessibility to attractive places for an activity tends to cause more generated trips in frequency. The differences in trip production rate implies that, if the accessibility for a zone can be improved by better transportation services, peoples resided at better accessibility will get better opportunities for their activities and make more trips to achieve the activities. The net induced demand was latent trips which were not fulfilled actually at the lower level of accessibility. To analyze the variations depending accessibility, data of Deagu Metropolitan Area, fourth largest city in South Korea, was used for an empirical study. The sample data of household travel survey was performed by KOTI (Korea Transport Institute) in 2010. The KOTI also estimated the origin-destination (OD) matrix and production-attraction (PA) matrix by expanding the sample data for population scale in 2011. With the data, this study calibrated production models with both of disaggregate data and aggregate data such as household-based regression production model and zonal-based regression production model, respectively.

The production regression models were calibrated by trip purpose. The trip purposes can be classified largely by mandatory trips and optional trips. The mandatory trip purpose includes Home-based work trips and Home-based school trips, and the optional trips are such as Home-based shop trips, home-based other trips and various Non-home-based trips. The mandatory trips usually do not vary in numbers by level of accessibility, because the trips should be made no matter what level of accessibility. However, the accessibility will affect spatial locations of mandatory trips by leading relocation of their residential places in long-term aspect, but the accessibility will not affect total number of mandatory trips in the system. This study only focused on optional trip purpose; home-based shop trips and home-based other trips, because such optional trips were significantly varied according to level of accessibility. This means that

the net induced demands mostly stemmed from such optional trips rather than mandatory trips when transportation systems were improved.
In order to analyze trip production with accessibility independent variable, the study needed to define accessibility measure. The measure was as function of threshold travel time distance to attractive places from home, attractiveness of a specific TAZ for each activity, and impedance values in gravity model used in this study. Such measure was calculated from highway network and PA matrix data built by KOTI in Korea for Daegu Metropolitan area. Including such accessibility measure, the final calibrated production model contains number of persons and number of cars for home-based shop trip purpose, and number of persons, number of babies, number of cars for home-based other purpose in case of household-based model. In case of zonal-based model, the production model were composed by number of households in the zone and accessibility measure for home-base shop trips, and population at the zone and accessibility measure for home-based other trips. All parameters for accessibility measure were statistically significant for shopping trips and other purpose trips in both of disaggregate and aggregate models. By using these estimated production models, the study showed the way how to forecast amount of net induced demand with an example case.

Such quantifiable methods are necessary especially for countries that require mandatory feasibility analysis with strict standard procedures and conventions such as South Korean and UK explained in Mackie (1996). The authors expect that the suggested method, quantification of impacts of net induced demand, will be helpful for more realistic forecasting of transportation demand in South Korea and also in other countries.

2. REVIEW OF PREVIOUS STUDIES

Many studies estimated changes in Vehicle Mile Traveled (VMT) or Vehicle Kilometer Traveled (VKT) after improvements of transportation systems. In some studies among them, the amount of changes in vehicle traveled distance was analyzed by using traffic demand elasticity, which is the increase in vehicle travel associated with a change in level of transportation services at a specific facility or a certain area-wide basis as described in FHWA (2011) and Barr (2000). Noland et al. (2002) also broadly defined the term of induced travel as the increase in VMT attributable to any transportation infrastructure project that increases capacity which is usually measured by unit of lane-miles(or lane-kilometers) in highway case. The studies with VMT (or VKT) tried to explain usually phenomena or impacts on traffic volume, vehicle traveled distance or environment before and after improving transportation services with macroscopic view such as the studies of Fulton *et al*. (2000), Cervero et al. (2002), Cervero (2003) and Fröhlich (2003). They did not analyze specifically causal relationship between changes of travel behavior and changes in transportation systems. They mostly tried to find relationship of traveled volume and distance directly with amount of improved transportation facilities mostly by using time series data. Therefore, they did not concern much about travel behavioral causality itself, but overall results of amount changes in VMT at a certain corridor or at a certain region. This will give macroscopic view and guidance of future policies related to induced demand and investments of new transportation facilities by relatively brief analysis. However, it is hard to measure actual amount of the induced travel demand zone by zone or mode by mode or link by link in order to incorporate the effects of induced demand into economic feasibility study at a schematic planning stage as explained by DeCorla-Souza et al. (1999) and FHWA (2011).

The other approach in previous studies used actual changes in number of person trips (or vehicle trips) at a specific location such as at a specific TAZ or links in transportation network by using four-step demand analysis models. Most of the studies used various mathematical forms of production models to count induced travel demand. Thilland Kim (2005) and Weis et al. (2009) tried to explain induced travel demand with disaggregate or aggregate level of data at stage of trip generation analysis. Thilland Kim (2005) viewed induced demand as the altered demand which comes from changes of traveler's behavior in any of several ways such as switching departure time, destination, mode and route, or modifying the rate at which one engages in new trips. They modeled trip generation separately for each of four trip type; Home-Based Work (HBW), Home-Based Shopping (HBSP), Home-Based School (HBSC), and Home-Based Other (HBO) trips. They used a stepwise Poisson regression approach to explain the generated trip count at zonal level or trip rate at household level with gravity accessibility measure at location i accounting impedance and attractiveness from i to other locations. They concluded that accessibility is not only a statistically significant predictor of trip generation, but that it is rather influential in inducing demand for travel. Weis et al. (2009) also tried to explain the effects of transportation generalized costs including accessibility measure on traffic generation by using a structural equations model with panel data in case of Swiss. They adopted five endogenous variables in their structural equations model; out-of-home activity, number of trips, number of trips per home-to-home tour and total duration spent out of home and total trips distance. They also incorporated accessibility measure into their structural equations model. They used the inclusive value (or log-sum term) in location destination and mode choice model as the accessibility measure with a negative exponential impedance function.

Litman and Colman (2001) tried to distinguish various concepts of induced demand with generated traffic, diverted traffic and induced vehicle travel. They defined that "generated traffic" consists of "diverted traffic" and "induced vehicle travel". The diverted traffic was defined as trips shifted in time, route and destination while the induced vehicle travel was defined as trips shifted from other modes, longer trips and new vehicle trips. They also explained such that "generated traffic" consists of diverted travel (shifts in time and route) and induced travel (increased total motor vehicle travel). Additionally, latent demand and triple convergence was also defined in their paper. The "latent demand" was defined as additional trips that would be made if travel conditions improved (less congested, higher design speeds, lower vehicle costs or tolls). The "triple convergence" was defined as increased peak-period vehicle traffic volumes that result when roadway capacity increases, due to shifts from other routes, times and modes. In other aspect, Lee *et al.* (1999) distinguished the concept of induced demand by applying the short-run and long-run concepts.

3. CLASSIFICATION OF INDUCED DEMAND

Traffic volume increases have been often observed in reality after improvements of accessibility by constructing and widening roads or introducing new transit lines. Such increased traffic volumes by improving transportation systems are generally called as induced travel demand as a general term. However, definition of induced travel demand is slightly different by articles. As Lee *et al.*(1999) described, even though the concept of induced demand was frequently used in articles, the term is still ambiguous. Therefore, it is necessary to define clearly the concept of induced travel demand. In order to clear understanding the concept, it was needed to classify various concepts explained in several previous studies.

This ambiguity may come from less clarity of definition about measurement of demand and travel behavioral causality related to the induced demand. In general, previous studies can be largely categorized by two approaches. This study called the one as “abstract-measure approach” and the other one as “behavior-causality approach”. The previous studies belong to the abstract-measure approach usually tried to find macroscopic impacts of changes in transportation facility capacities on overall changes in total traveled vehicle-distance such as VMT or VKT. We called this concept of induced demand as “induced traffic”. We used the word “traffic” instead of ‘trip” or “travel”, because it measures demand in vehicle trips rather than person trips. Some studies related to the induced traffic have used some mathematical equations that predict VMT as function of speed, lane miles, travel time, capacity and so on.

Table 1.Classification and terminologies related to induced travel demand

Classification	Terminology	Analysis Methods	Object of study
abstract-measure approach	Induced Traffic in abstract term	$VMT = f(Speed, Lane\,Mile, Travel\,Time)$ $\varepsilon = \frac{\Delta VMT_t^{t+1} / VMT_t}{\Delta LM_t^{t+1} / LM_t}, \quad LM_t = lane\,miles\,at\,t$	Corridor or area
Behavior-causality approach	Net Induced Travel Demand	Trip Generation Model (Changes in trip frequencies)	Newly generated trips from latent travel demand
	Shift Induced Travel Demand	Trip Distribution Model (Changes in destination choice)	Shifted trips, so these do not affect total amount of trips
		Mode Choice Model (Changes in transportation mode choice)	
		Trip Assignment Model (Changes in route choice)	
	Long-term Induced Travel Demand	Land-use/Transportation Interaction Model (Changes in Land-use)	Long-term changes in location of residence or industry

On the other hand, studies related to behavior-causality approach usually focus on finding traveler’s behavioral changes at disaggregate level due to changes in transportation supply attributes. The travel behavior can be choice of trip frequency, destination, mode, route, and departure time. The behavior-causality approach is considered to be better to understand traveler’s behavior and make possible detail analysis in aspect of spatial traffic patterns and traveler’s choice behaviors. Therefore, the approach can be used for analysis with very disaggregate level in aspect spatial dimension and traveling subject, and it can be also applied for infrastructure investments for various modes as like the study of Yao and Morikawa (2005), while abstract-measure approach is usually applied to highway cases. This approach can be more classified into three such as net induced travel demand, shift induced travel demand and long-term induced travel demand depending stage of traveler's choice behavior. Such classification suggested by this study was summarized in Table 1.

The net induced demand refers to the amount of increased number of trips in generated trip frequencies after transportation improvements. Therefore, it will affect total number of generated trip itself. The net induced travel demand can be analyzed with accessibility measure for specific traffic zone at the stage of trip generation analysis as in the studies of Thilland Kim (2005) and Weis et al. (2009).

The shift induced demand refers to the converted number of trips from behavioral changes in choice of destinations, modes and routes, which may increase trips on a specific corridors or areas, but will not affect total number of trips in a system. In order to estimate the net induced demand, it needs to find out the amount of latent travel demand which are not occurred presently, but will be newly generated after the accessibility improvement. The shift induce demand can be estimated by using trip distribution models, mode choice models and trip assignment models in the 4-step traditional transportation demand forecasting process, which will make possible to get spatially different impacts of the induced demands explicitly that could not be gotten from analyses by abstract-measure approach.

The long-term induced demand can be defined as increased trips at a specific area by changes in land-use of residence or industries due to transportation improvements. Long-term induced travel demand originates from changes in residential locations and industrial locations, which may affect trip length, location of origin and/or destination. Even though analysis for the long-term induced demand seems to be not easy, any land-use and transportation interactive model can be used to estimate them.

4. METHODOLOGY AND DATA USED IN THE STUDY

This study only focused on the "net induced travel demand" for a specific TAZ. Because transportation accessibility was considered as a major key factor affecting on invoking latent travel demand into actual net induced demand in several previous studies such as Handy et al. (1997), Dong *et al*. (2006), and Litman (2008), accessibility measure was always included in production models which calibrated in this study if it is statistically significant. To count the newly generated trips, the concept of trip production was used instead of origin or destination concept. The production is defined by trips at home end of a Home-based trip or as trips at the origin of Non-home-based trips explained in Ortuzar et al. (2011). This concept represents much better total amount of generated trips at a specific resident places and it is also much more behavioral oriented concept. This study used multiple linear regression models as trip production model. The parameters in the linear regression model was estimated by OLS(ordinary least squared) estimation method, which are commonly used in practice over the world. The authors considered that the simple model is relatively satisfactory when considering the imbedded assumptions of linear-type demand function with traveler's travel behavior especially in practical application. Practices in real world often need to overcome limitations in data, time and budget, so simple model is more preferable if there are no critical problems in statistical theories.

The study used the data of Daegu Metropolitan Area. We used the 2010 household travel survey data of Daegu Metropolitan Area in Gyeongbuk province at located Southeast part of South Korea. The Daegu city is fourth largest city in population. The survey was performed for one target date on Wednesday of October in 2010 by KOTI and national government. The survey should be performed regularly every 5 years by Korean law. The number of traffic analysis zone (TAZ) was 143 zones except external zones. The total number of households in this area was 856,915 households, and the 22,575 sample data (sample rate 2.63 %) was valid data after abandoning defected survey data. The sample data has attributes of 68,398 travelers and information about 148,543 trips. The household travel survey data including characteristics of a household and attributes of its member of the family, and travel information such as trip purpose, departure time, arrival time, used transport mode, fare or cost of the trip and so on. The study used the raw data of household travel survey data and the expanded PA trips to build trip production model with accessibility measurements.

Before building trip production model, it is necessary to decide accessibility measure. After review several types of accessibility measures and limitation of Deagu data, we decided to adopt gravity-based accessibility measure because it was only possible to be calculated with the data. The gravity-based measurement has following functional form like Eq.(1).

$$AC_i^p = \sum_j A_j^p \, F(t_{ij}) \ , \quad \forall \ i \tag{1}$$

where,

AC_i^p : Accessibility measurement for trip purpose p at a specific traffic zone i,

A_j^p : Quantitative measurement for attractiveness for the activity generating trip Purpose p at zone j,

$F(t_{ij})$: Impedance as a function of generalized cost between zone i and j,

t_{ij} : Generalized cost (eg. travel time) from i to j.

Before calculating the accessibility measurement of the Eq. (1), the boundary of traffic zones from residential zone i to all of attraction zone j need to be defined, which will be included in the set of attraction zone j for the summation. The distance to take travel time from a residential zone to the boundary of attraction places was called as threshold travel time distance. The study analyzed the trip length distribution (TLD) to find reasonable the threshold travel time distance for each trip purpose, and then it fitted the data with gamma probability density function. With the fitted function, the study found the threshold travel time distance that most of traveler not going far more than the travel time distance for a specific activity purpose, for example, 95 percentile of trips happened within the travel time.

The other required variable to calculate the accessibility is quantitative attractiveness of a specific attraction zone j. The study used the total attraction trips for a specific traffic zone from the expanded P-A trips, which was estimated by Korea Transport Institute in 2011. In addition, the threshold travel time distances for each trip purpose were defined by using trip length distribution analysis in order to clarify the boundary of attractive zones for certain activity. In order to find relationship between trip attraction and socio-economic variables in a zone, the study collected the data about building usage and floor area, number of employees for each industry category for each attraction zone in the Daegu city from the architectural administration system of the Ministry of Land, Transport and Maritime Affairs in Korean Government, so called Se-um-ter. Then, attractiveness of a zone was also estimated with 46,913 building data and employee data by using regression analysis, which was used for calculated accessibility measurements. The regression model was used for estimating the accessibility measurement instead of the number of attraction trips itself, because the changes in some land-use at a specific zone can be reflected with the model, but the attraction trip itself can not reflect correctly. After finishing building the accessibility measurement data for all of production zones, the study tried to find regression models for each optional trip.

The study tried also to fit three types of impedance functions $F(c_{ij})$ with PA trip data, simulated and perceived travel time in highway network, which are needed to calculate the accessibility measurement. We tried to find the best-fitting function with the observed spatial trip distribution patterns for each trip purpose among three possible impedance functions. The three impedance functions for gravity model are inverse power function, exponential function and modified gamma function. Only travel time between two zones was used as generalized cost, c_{ij}, but two kinds of travel time was tested for statistically better fitting, which are simulated travel time at user equilibrium status after traffic assignment analysis and average traveler's perceived travel time actually answered at survey by travelers. The simulated travel time from origin zone to destination zone for each OD pair in highway network was gotten after analyzing highway traffic assignment. The used travel times are shortest path travel times at equilibrium status. The perceived travel time were calculated by averaging all of trips between origin and destination from household travel survey data which were actually perceived by survey respondents at Daegu Metropolitan Area.

We decided to use modified gamma function with travel time at equilibrium status for the most of trip purposes after the analyses. The modified gamma power function as an impedance function in gravity model is as following;

$$F^{p}(t_{ij}^{*}) = \alpha_{p}\ t_{ij}^{\beta_{p}} \exp(\gamma_{p}\ t_{ij}) \quad \forall\ i,\ j,\ p \tag{2}$$

where,

$F^{p}(\ )$: Impedance function for trip purpose p,

t_{ij}^{*} : Travel time from i to j at network equilibrium status,

α_{p}, β_{p}, γ_{p} : Estimated parameters for trip purpose p.

After finishing building the accessibility measurement data for all of production zones, the study tried to find regression models for each optional trip purpose which represented travelers' behaviors significantly. As an example, a linear production model for Home-based shopping (HBShop) trips could be estimated as following regression model;

$$P_{hh|i}^{Shop} = \beta_{0}^{Shop} + \beta_{1}^{Shop} INC_{hh|i} + \beta_{2}^{Shop}\ NPER_{hh|i} + \beta_{3}^{Shop}\ NCAR_{hh|i} + \beta_{4}^{Shop}\ AC_{i}^{Shop} + \varepsilon_{hh|i}^{Shop} \tag{3}$$

where,

$P_{hh|i}^{Shop}$: Number of trip production for shopping by household hh residing at i,

$INC_{hh1|i}$: Income of household hh residing at zone i,

$NPER_{hh|i}$: Number of persons in household hh residing at zone i,

$NCAR_{hh|i}$: Number of cars owned by household hh residing at zone i,
Acc_i^{Shop} : Value of accessibility measure at the zone i for shopping,
β_k^{Shop} : Value of kth parameter in regression model for shopping purpose trips.

Related to net induced travel demand, the parameter β_4^{Shop} for AC_i^{Shop} can be interpreted as amount of increased shopping trips per household by improvement of one unit of accessibility at zone i. The regression reflects relationship between spatially different accessibility and spatially different number of production trips per household. It means that average number of produced shopping trips could be differently observed over the space in the cross-sectional data according to different magnitudes of accessibility at each zone. Of course, such spatial variation in number of generated trips may be affected by several factors as in the regression Eq. (3). However, the effects by improvements of transportation systems (accessibility) can be independently analyzed by adding the independent variable AC_i^{Shop} which can separate the effect from other factors' effects. Therefore, the net induced travel demand can be estimated as following;

$$NID_{i|t+1}^{Shop} = NH_i \; (\beta_4^{Shop} \; AC_{i|t+1}^{Shop} - \beta_4^{Shop} \; AC_{i|t}^{Shop}) = NH_i \; (\beta_4^{Shop} \; \Delta AC_{i|t+1}^{Shop}) \tag{4}$$

where,

$NID_{i|t+1}^{Shop}$: Number of net induced shopping trips newly generated by improvement of transportation services from time t to t+1 at TAZ i,
NH_i : Number of households at TAZ i,
$AC_{i|t+1}^{Shop}$ (or $AC_{i|t}^{Shop}$) : Value of shopping accessibility measure at TAZ after (or before) improvement of transportation systems at time t+1 (or t),
$\Delta AC_{i|t+1}^{Shop}$: Changes of shopping accessibility measure from time t to t+1.

As showed in the Eq. (4), the net induced travel demand can be directly analyzed by using the multiple linear regression models, which can show how some improvements in transportation services would affect differently on induced demands throughout TAZs with quantitatively explicit numbers.

5. ANALYSIS RESULTS AND INTERPRETATIONS

The study analyzed the effects of accessibility on trip production for six trip purposes in the Daegu Metropolitan Area ; Home-based Work (HBW), Home-based School (HBSch), Home-based Tutor-school (HBTut), Home-based Shopping (HBShop), Home-based Others (HBO) and Nonhome-based (NHB) trips. Others except HBTut are commonly used categories of trip purpose for many previous studies. The HBTut trips are very distinctive one comparing other countries in America, Europe, even in Asia, which cannot be ignored in aspect of number in Korea. The HBTutare the trips to go to various private tutorial academies at evening time after school time in order to preparing examination for college entrance.

Even though all kind of trip purposes were analyzed to find the effects of accessibility at a zone on number of trip frequency, the statistical test showed that the significance of the accessibility was meaningless in case of mandatory trip as expected. In case of NHB trip, the interpretation of analysis results was also ambiguous because the places of the departure are different from place that the concerned households reside at. Therefore, the study excluded to explain about mandatory trip and NHB trip purposes. This study only focused on optional trip purpose such shopping trip and other purpose trip such as recreational trip, social trip, personal-business trip and so on.

The trip length distribution (TLD) for optional trip purpose was analyzed to get threshold travel time distance by fitting the TLD data with gamma probability density function (PDF) with whole trips in the metropolitan area as shown in Figure 1 for shopping trip case as an example. With the fitted gamma PDF function, the threshold travel time was calculated at the 95 percentage point of the cumulative probability. The threshold travel time were 41.5 minutes for home-based shopping purpose trip (HBShop) and 45.0 minutes for home-based other purpose trip (HBO).

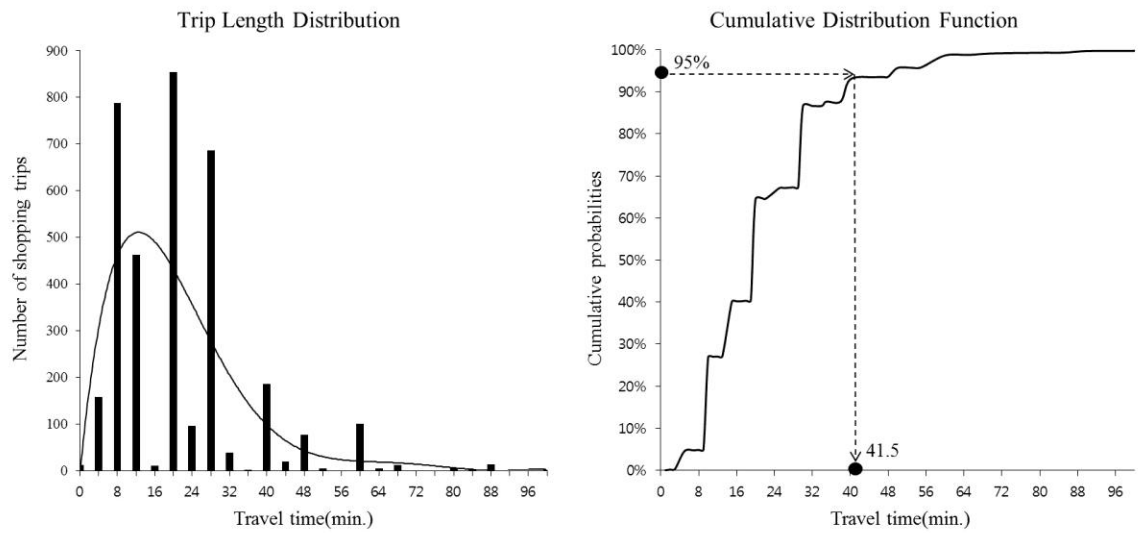

Figure 1.TLD and CDF for shopping trips

The attractiveness of a specific attraction zone j in the Eq. (1) was calculated by the attraction regression model calibrated with attraction trips from PA table and building and employee data for each zone. As an example, the attraction model for HBO is described only here as following;

$$A_i^{HBO} = \beta_0^{HBO} + \beta_1^{HBO}\,REMP_i + \beta_2^{HBO}\,NSEMP_i + \beta_3^{HBO}\,NBEMP_i + \beta_4^{HBO}\,MEMP_i + \beta_5^{HBO}\,SEMP_i + \varepsilon_i^{HBO} \quad (5)$$

Where A_i^{HBO} = Attractiveness of zone i for HBO trip purpose

$REMP_i^{HBO}$ = Number of employees at recreational business in zone i

$NSEMP_i^{HBO}$ = Number of employees at neighborhood business in zone i

$NBEMP_i^{HBO}$ = Building floor area (m^2) of neighborhood business in zone i

$MEMP_i^{HBO}$ = Building floor area (m^2) of medical buildings in zone i
$SEMP_i^{HBO}$ = Number of employees at service business in zone i

The attraction regression models were estimated with adjusted R^2 =0.39 for shopping trip and adjusted R^2 =0.73 for HBO and all of its parameters were statistically significant at the level of 95 percent. The final calibrated attraction model for HBShop contained number of employees in retail and wholesale business and number of employees in self-employed business. The attraction model for HBO consisted of employee number in entertainment business (β=0.152), employ number in neighborhood business (β=0.002), floor area of buildings for neighborhood business (β=0.004), floor area for medical building (β=0.004), and employee number in service business (β=0.025).

To complete building accessibility measurements for each production zone, impedance function in gravity model needed to be calibrated with PA trips and travel time data by log-linear regression analysis. The study tried to estimate parameters in the impedance function with two kinds of travel time. One is simulated travel time which is calculated after the network equilibrium assignment analysis. The other is the average perceived travel time calculated from the data of household travel survey. The study also tried to fit three types of impedance functions $F(c_{ij})$; Inverse power function, exponential function and modified gamma function. The modified gamma function of the Eq. (2) fitted better for the P-A trips with gravity model than other impedance functions for all of trip purpose cases. The estimated parameter values in impedance function were summarized in Table 2.In case of shopping trips, the perceived travel time explains slightly better spatial trip distribution than the simulated travel time. Otherwise, the simulated travel time explained better than the average perceived travel time in case of home-based other trips. The perceived travel time could not be forecasted after improvements of transportation systems in future, but the simulated one can be forecasted by network analysis. Therefore, the study used the simulated travel time to keep consistency between calibration with base-year data and forecasting for future year after improvements.

Table 2.Estimated α, β, γ values in modified gamma Impedance Function

Trip Purpose	Travel time	α	β	γ	R^2
HBShop	Simulated time	-4.914	-0.953	0.293	0.183
	Perceived time	4.979	-4.238	0.084	0.193
HBO	Simulated time	-8.350	-0.888	0.016	0.264
	Perceived time	-4.320	-1.960	0.023	0.164

The accessibility measurement data for each production zone can be calculated with the threshold travel time distance, attraction model and impedance function in the Eq. (1). The calculated accessibility measurements were depicted in the map with boundary of traffic zones such as in Figure 2, and the zones within 10 highest ranked accessibilities were checked whether or not the analysis results seemed to be logically reasonable when comparing with real land-use and travel pattern phenomena. In case of accessibility of a production zone for shopping activity, the Figure 2 gives very understandable results, because the most of the10 zones have large shopping centers or large-scale outlet malls or central business area where shopping places are located densely. Therefore, the accessibility measurements were considered as the reasonable explain variable to be used in the production model for analysis of induced travel demand.

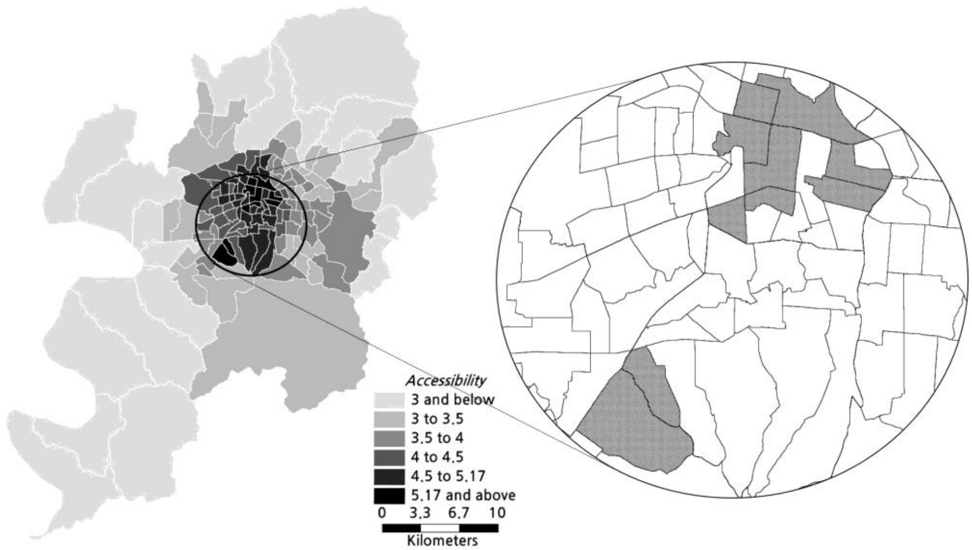

Figure 2.10 highest accessibility zones for shopping activity in Daegu

With the accessibility variables and other explain variables for production model, the study analyzed correlation coefficients between variables to see magnitudes of linear relationship between variables, and it did step-wise linear regression analysis to get some idea before building trip production model. Then it tried to find the best fitting models which are statistically significant and logically and intuitively acceptable by trial-and-error process. The production model was estimated in two ways, one with household-based regression and the other with zonal-based regression as a disaggregate model and as an aggregated model, respectively. As mentioned in Ortuzar et al. (2011), disaggregated regression models are theoretically better than aggregated model because zone size itself explains amount of productions rather than causal relation with key explain variables. However, this study analyzed both because of practical reason such as data limitation of disaggregate data in real practices.

The results of the linear regression analysis for HBShop and HBO were summarized in Table 3 as below;

Table 3. Production regression model for optional trip purposes

Model type	HBShop			HBO		
	Variables	Parameter	t-value	Variables	Parameter	t-value
Household-based Regression	$NPER_{hh\|i}$	0.011	4.848	$NPER_{hh\|i}$	0.303	28.524
	$NCAR_{hh\|i}$	0.011	4.422	$NBABY_{hh\|i}$	-0.395	-13.916
	AC_i^p	0.027	15.680	$NCAR_{hh\|i}$	0.173	14.828
				AC_i^p	0.485	20.573
	Adjusted R^2	0.135		Adjusted R^2	0.514	
Zonal-based Regression	NHH_i	0.129	10.895	$POP_{\|i}$	0.503	20.390
	AC_i^p	1.072	2.088		25.448	2.523
	Adjusted R^2	0.806		Adjusted R^2	0.925	

Notes:

- AC_i^p is accessibility measurement at the traffic zone i for trip purpose p,
- NHH_i is the number of households at zone i,
- $NBABY_{hh|i}$ is the number of children less than the age for pre-school in household hh residing at zone i,
- $NCAR_{hh|i}$ is the number of cars per household hh residing at zone i,
- $NPER_{hh|i}$ is the number of persons in household hh residing at zone i,
- $POP_{|i}$ is the number of population except children less than the age for pre-school in zone i.

The estimation result of regression analysis for HBShop trip purpose was not very satisfactory in overall statistics such as R-squared, but all parameters of independent variables including accessibility measurement are very statistically significant. The less satisfactory results might be came from irregularity of the shopping travel pattern comparing with other trip purposes having more regular trip pattern such as mandatory trips. Especially, the parameter for accessibility measurement of residential zone is extremely significant, which means the accessibility affects very likely on number of shopping trip frequencies. In case of Home-based other purpose trips (HBO), the analysis results were very satisfactory in aspect of statistics for overall and each independent variables including accessibility measurement. Therefore, the authors concluded that the frequencies of the optional trips are clearly affected by increase of accessibility due to transportation improvements, and that the accessibility measurement can be applied to forecast the net induced demand for the economic feasibility study before decision-making for implementing transportation investments.

Because the scale variations of accessibility measurements are different between HBShop and HBO in magnitude, we cannot directly conclude which trip purpose seems to be more sensitive in trip production of accessibility with the values of the parameters. Therefore, the standardized coefficients for accessibility variables in the regression models for HBShop and HBO are compared as in Table 4. The standardized coefficients for HBO are relatively smaller than ones of HBShop, even though the original coefficient of accessibility for HBO is bigger than HBShop's coefficient value. This means that changes in standard deviation of accessibility measure for HBShop will affect more deviations of trip production than cases of HBO. Therefore, we can conclude that induced demand for HBShop trips could be more significantly affected by improvement of accessibility than HBO.

Table 4.StandardizedCoefficients for Accessibility

Standardized β	HBShop		HBO	
	Household-based	Zonal-based	Household-based	Zonal-based
β_k^p Accessibility	0.242	0.148	0.239	0.108

The study also showed that the accessibility affect number of trip frequency differently depending on trip purpose. For example, the effect can be different between mandatory trips and optional trips, and it can be also different between HBShop and HBO even among optional trips. The net induced travel demand can be estimated for various optional trip purposes by using the Eq. (4) after analyzing the simple linear regression with accessibility independent variable. For example, let assume that accessibility measurement of a specific zone, such as zone code number 18 in Daegu case, is 3.015 that is relatively lower value when comparing with the highest accessibility measurement which is 5.734 for zone number 1 in Daegu. If we assume that there is some improvement in accessibility of zone 18 from 3.015 to 4.001 due to new highway construction near by the zone, the increased number of shopping trips per each household can be calculated by using the Eq. (4). The increased trips are caused by the net induced travel demand, which is invoked due to better opportunities for shopping with improvements in accessibility. In this example case, the average net induced travel demand for shopping trips per each household will become 0.0266 trips as shown in Eq. (6).

$$\beta_5^{shop} \; \Delta AC_i^{shop} \;=\; 0.027 \times (AC_{after}^{Shop} - AC_{before}^{Shop}) \;=\; 0.027 \times \; (4.001 - 3.015) = 0.0266 \qquad (6)$$

IF 3,000 households reside in the zone 18, the total net induced travel demand for shopping will become about 80 trips as shown in Eq. (7).

$$NID_{i|t+1}^{Shop} \;=\; NH_i \; (\beta_5^{Shop} \; \Delta AC_{i|t+1}^{Shop}) = 3{,}000 \times 0.0266 = 79.8 \qquad (7)$$

As shown in the example case, the number of net induced demand can be specifically forecasted for each zone by using the trip production model with accessibility. The demand is newly generated by households living at a certain zone due to increases in opportunity for various activities by improving accessibility. Therefore, the estimated net induced demand can make possible that such social benefit can be reflected in the process of economic feasibility analysis, which was not considered in many countries including South Korea.

6. CONCLUSION

Some countries, like South Korea, mandatorily require economic feasibility study before large-scale transportation investments for reasonable decision-making and also for precluding unrighteous political pressure. Therefore, the amount of forecasted traffic volumes are doing very important role in decision-making process of governments. However, net induced travel demand has not considered in economic feasibility study for investing transportation facilities in Korea. This study suggested the way to count induced travel demand.

The study also tried to define the concepts of induced travel demand clearly. The concepts are classified into four distinguishable induced demands such as induced traffic, net induced travel demand, shift induced travel demand and long-term induced travel demand. The induced demands were classified depending on different aspect of behavioral changes such as changes in purely generated number or changes in travel options or changes in aggregated travel measurement. The net induced travel demand was defined as newly generated trips from latent demand purely in aspect of trip frequency increase, but not coming from any converted trips by changing destinations, modes and routes. The study only focused on the net induced travel demand.

The simple linear regression model was used to estimate household's trip production for various trip purposes. In other to reflect the net induced demand into the model, accessibility measure was added into the model. Accessibility was interpreted as a major factor affecting on invoking latent travel demand into net induced demand. The study tried to show empirically that number of generated trips in a household can be varied depending on the zonal accessibility with 68,398 traveler's sample data from2010 household travel survey in Daegu Metropolitan Area, South Korea. The study analyzed the effects of accessibility on trip production for each trip purposes in the Daegu Metropolitan Area by using simple linear regression model.

As the results of analysis for shopping trip purpose, the parameter of accessibility at a residential zone is extremely significant, which means the accessibility affects very likely on number of shopping trip frequencies. In case of Home-based other purpose trips, the analysis results were very satisfactory in aspect of statistics for overall and each independent variables including accessibility measurement. Therefore, the authors concluded that the frequencies of the optional trips are clearly affected by increase of accessibility due to transportation improvements. The study also showed that the accessibility affect number of trip frequency differently depending on trip purpose. Therefore, the accessibility measurement can be applied to forecast the net induced demand for each trip purpose when evaluating economic feasibility before decision-making for implementing transportation investments. The study also explained the way how the linear production model with accessibility can be used to estimate the net induced travel demand with an example case.

REFERENCES

Barr, L. C., Testing for the Significance of Induced Highway Travel Demand in Metropolitan Areas, In Transportation Research Record : Journal of Transportation Research Board, No. 1706, 2000, pp. 1-8

Cervero, R. and M. Hansen, Induced Travel Demand and Induced Road Investment: A Simultaneous Equation Analysis, Journal of Transport Economics and Policy, Volume 36, Part 3, September 2002, pp. 469-490

Cervero, Road Expansion, Urban Growth, and Induced Travel: A path Analysis, Journal of

American Planning Association,, Vol. 69, No. 2 Spring, 2003, pp. 145-163,

DeCorla-Souza, P. and H. Cohen, Estimating induced travel for evaluation of metropolitan highway expansion, Transportation , Volume 26, No. 3, 1999, pp. 249-262

Dong, X, M. E. Ben-Akiva, J. L. Bowman, and J. L. Walker, Moving from trip-based to activity-based measures of accessibility, Transportation Research Part A Vol. 40, 2006, pp. 163–180

FHWA, Induced Travel: Frequently Asked Questions, US Department of Transportation, Federal Highway Administration, http://www.fhwa.dot.gov/planning/itfaq.htm#q1, Accessed July, 30, 2011

Fröhlich, P., Induced Traffic: Review of the explanatory models, The 3rd Swiss Transport Research Conference (STRC), Monte Verità / Ascona, March 19-21, 2003

Fulton, L. M., R. B. Noland, D. J. Meszler and J. V. Thomas, A Statistical Analysis of Induced Travel Effects in the U.S. Mid-Atlantic Region, Journal of Transportation and Statistics, Vol. 3, No. 1, 2000, pp.1-14

Handy, S.L., and D. A. Niemeier, Measuring accessibility: an exploration of issues and alternatives. Environment and Planning A, Vol. 29, 1997, pp. 1175–1194

Hills, P.J., What is induced traffic?, Transportation, Vol. 23, No. 1, 1996, pp. 5-16

Lee, B.B. Jr., L. A. Klein, and G. Camus, Induced Traffic and Induced Demand, In Transportation Research Record : Journal of Transportation Research Board, No. 1659, Tranportation Research Board of the National Academies, Washington, D.C., 1999, pp. 68-75.

Litman and Colman, Generated Traffic: Implications for Transport Planning, The ITE Journal, Vol. 71, No. 4, 2001, pp. 38-47

Litman, Evaluating Accessibility for Transportation Planning Measuring People's Ability To Reach Desired Goods and Activities, 87th Transportation Research Board Annual Meeting, January 2008

Mackie, Induced Traffic and Economic Appraisal, Transportation, Vol. 23, No. 1, 1996, pp. 103-119

Noland, R. B. and L. L. Lem, A review of the evidence for induced travel and changes in transportation and environmental policy in the US and the UK, Transportation Research Part D: Transport and Environment, Vol. 7, Issue. 1, 2002, pp. 1-26

Ortuzar, J. and Willumsen, L. G., Modelling Transport, 4th Edition, John Wiley & Sons, Ltd., 2011

Thill, J. C., and M. Kim, Trip making, induced travel demand, and accessibility, Journal of Geographical Systems, Volume 7, No. 2, 2005, pp. 229-248

Weis, C. and K. W. Axhausen, Induced Travel Demand: Evidence from a Pseudo Panel Data Based Structural Equations Model, Research in Transportation Economics, Vol. 25, No.1, 2009, pp. 8-18

Yao, E., and T. Morikawa, A study of an integrated intercity travel demand model, Transportation Research Part A, Vol. 39, 2005, pp. 367–381