

## Developing a Trip Distribution Model using the Interzonal Relative Attractiveness for the Seoul Metropolitan City

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**Abstract:** Transportation demand models estimate travel demands due to daily activities of persons. The gravity model is the representative approach of trip distribution drawn between the spatial interaction of trip making and travel costs. However, the standard gravity model shows the modeling limitation due to distance-based distribution in cases of polycentric city structure. Many transportation researchers insist that the gravity model should be improved by concerning new variables of areal characteristics or interzonal relative attractiveness. This research develops an estimation procedure for interzonal relative attractiveness as a new variable for explaining zonal spatial properties and interzonal spatial association using 1996 and 2002 interzonal commuting trips of the SM city. The research is extended to develop an improved trip distribution model containing the counterpropagation neural network with three hidden layers. The applicability of the improved model is evaluated by four criteria including  $\beta$ , E-norm, RMSE, and Theil value.

**Key Words:** *trip distribution model, interzonal relative attractiveness, Seoul metropolitan city, neural network, gravity model*

### 1. INTRODUCTION

Transportation demand models are models that conceptually estimate travel demands due to daily activities of persons in a society. Transportation demand models are classified based on various standards such as model approach, analysis units, analysis frameworks or variable characteristics. Kanafani (1983) largely divided transportation demand models into two groups: combined models and sequential models. The four-step approach for travel demands is the dominant sequential model in Korea. Growth factor techniques and gravity models are widely used models in trip distribution stage of the four-step approach.

The gravity model is the approach that estimates interzonal trips drawn between the spatial interaction of trip making (trip production and attraction), and the inverse function of travel costs such as travel time, distance, monetary out-of-pocket costs (Meyer and Miller, 1984). It is understood to be better than growth factor techniques simply using regional growth rates in

terms of conceptual and mathematical aspects. However, the standard gravity model shows its own limitation in transportation demand applications when we compare the real-world interzonal trips with the estimated trips from the gravity model. Many transportation researchers including Ortuzer and Willumsen (1994), and Stopher and Mayburg (1980) identified the limitation of the standard gravity model. They proposed the improvement of standard gravity model by considering the use of socio-economic factors in model framework.

The limitation of the standard gravity model is often shown in cases of cities with multi-center structure. The Seoul metropolitan city (SMC) is one of the representative poly-centric regions that have expanded by many residential development and redevelopment projects in urban fringe areas. SMC has formed several subcenters such as Kangnam, Jamsil, or Yeoju, serving adjacent residential areas. Consequently, commuting trips are headed to the multiple sub-centers of the SMC rather than simply distributed according to the inverse function of the costs between SMC zones. Thus, the gravity model should be improved by concerning new variables of areal characteristics or interzonal relative attractiveness in order to resolve the limitation of standard gravity model.

The objectives of this research are to 1) develop an estimation procedure for interzonal relative attractiveness as a new variable for explaining areal characteristics and interzonal association using 1996 and 2002 interzonal commuting trips of the SM city, and 2) develop an improved version of trip distribution model containing the estimated interzonal relative attractiveness in order to resolve the limitation of the standard gravity model.

## **2. LITERATURE REVIEW**

The difference between actual trips and estimated trips by the standard gravity model is often shown in polycentric cities, especially trips heading to city centers and subcenters. This trip difference is clearly observed in commuting trips among eight trip types of the SM city. Commuting trips from the Eunpyeong administrative district to other Seoul districts are the representative example of this trip mismatch. Multiple peaks except the Seoul city center are observed so that the difference between actual commuting trips and estimated trips by the gravity model is expected to be large. Thus, a new type of gravity model considering the interzonal relative attractiveness is required for the more accurate estimation of commuting trips in the SM city.

Many transportation researchers have pointed out the model limitation of the standard gravity model. Ortuzer and Willumsen (1994), and Stopher and Mayburg (1980) insisted the use of socio-economic factors in the gravity model in order to resolve the model deficiency of the standard gravity model. However, they neither provided applicable variables nor analyzed empirical cases. Lim (1980), Lim and Lee (1996), Kim (1998), Yu (2001), and Goncalves and Cursi (2001) provided improved versions of the gravity model by either containing socio-economic variables or calibrating trip distances.

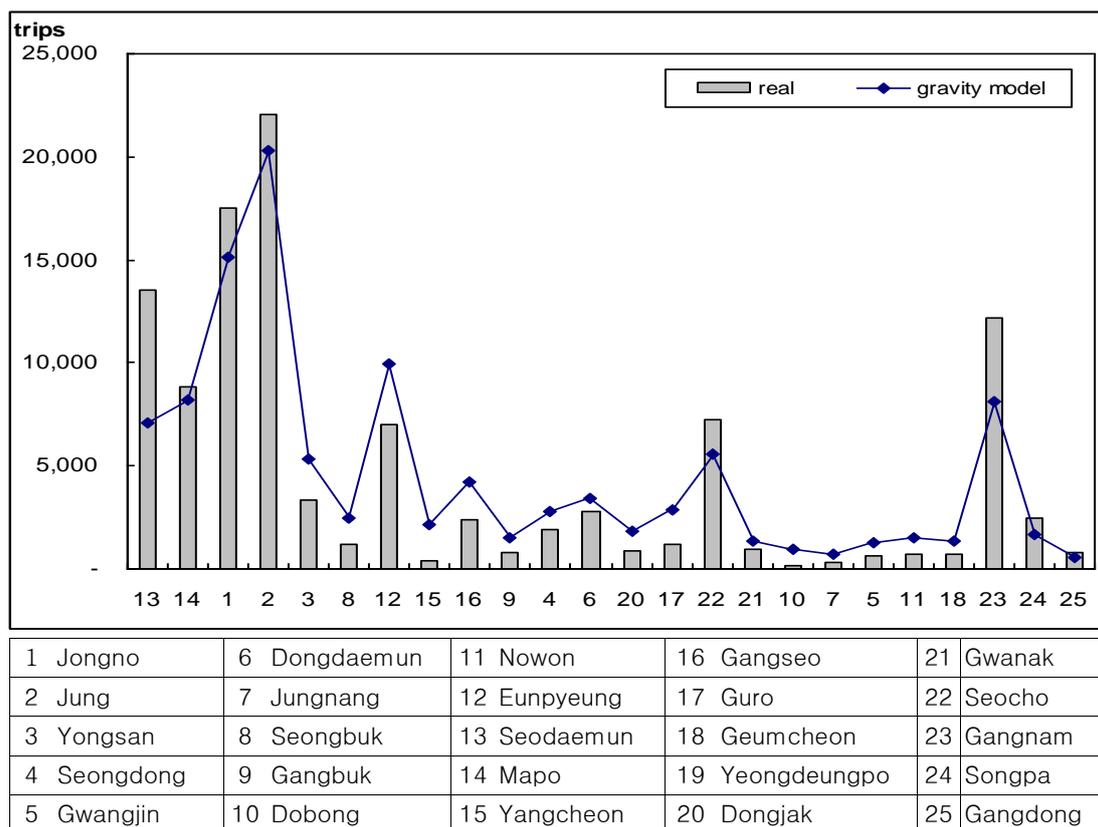


Figure 1 Commuting trip distribution from the Eunpyeong district to others by distance

Combining socio-economic variables with the standard gravity model is performed by Lim (1980), Lim and Lee (1996), and Yu (2001). Lim (1980) and Lim and Lee (1996) concerning the suggestion by Stopher and Meyburg (1981) improved the gravity model using regression models with socio-economic variables by assuming  $K_{ij}$  as the ratio between actual and estimated trips. However, Lim's approach did not provide relevant results because the linear function of regression model is hard to capture the complex socio-economic association among zones. Yu (2001) introduced the way of gravity model improvement by considering  $K_{ij}$  as the interzonal relative attractiveness, and applying an exponential function containing the difference between home-based employees and work-based employees. He also developed an adjustment factor  $\gamma$  for reducing the error between actual and estimated trips.

The second approach of calibrating trip distances is performed by Kim (1998) and Goncalves and Cursi (2001). Kim (1998) developed adjustment factors grouping trip distances. However, Kim's approach has a limitation of using the same adjustment factors for future trip estimation. Goncalves and Cursi (2001) improved the standard gravity model by considering travel costs and intervening opportunities of distances. However, they tried to calibrate the gravity model by distance adjustment rather than improve the model structure by applying new factors. Thus, Goncalves and Cursi's approach is subjective in applying intervening opportunities for future cases.

There has been a lack of evaluation in using the improved gravity models of the existing studies for future cases. The applicability of the improved models is understood if we evaluate the models for future cases. This research develops the model with the new concept of interzonal relative attractiveness applicable to future cases.

### 3. DESCRIPTION OF INTERZONAL RELATIVE ATTRACTIVENESS

#### 3.1 Interzonal Relative Attractiveness

This research defines a factor affecting areal characteristics and interzonal association as the interzonal relative attractiveness that can be used for the improved trip distribution model. There have been many types of trip distribution models including growth factor techniques, intervening opportunities models, disaggregate destination choice models, and gravity models. Among them, the intervening opportunities models have been limited use because they have never enjoyed generalized acceptance by cumbersome calibration (Meyer and Miller, 2001). This research develops a gravity model with an entropy maximization concept in order to improve the conventional gravity model. The typical version of gravity-opportunity model is hard to fully explain the interzonal association between two zones because the interzonal association of the gravity-opportunity model is exogenously given.

The interzonal relative attractiveness  $R_{ij}$  is regarded as the ratio between actual trips and estimated trips by the standard gravity model. When we introduce the interzonal relative attractiveness  $R_{ij}$  as a new variable in the gravity model, we need to develop a procedure for estimating  $R_{ij}$  as an endogenous variable in the model structure. This research introduces the functional relationship between the interzonal relative attractiveness  $R_{ij}$  and explanatory variables of zonal spatial properties and/or interzonal spatial association. This functional relationship between  $R_{ij}$  and such explanatory variables is described in equations 1, 2, and 3:

$$R_{ij} = f(X_1, X_2) \tag{1}$$

$$X_1 = (x_1^a, x_1^b, x_1^c, \dots) \tag{2}$$

$$X_2 = (x_2^a, x_2^b, x_2^c, \dots) \tag{3}$$

where  $R_{ij}$  = interzonal relative attractiveness,  
 $X_1$  = variables of zonal spatial properties  $(x_1^a, x_1^b, x_1^c, \dots)$ , and  
 $X_2$  = variables of interzonal spatial association  $(x_2^a, x_2^b, x_2^c, \dots)$ .

The interzonal relative attractiveness  $R_{ij}$  is classified into three groups shown in table 1.

Table 1 Three groups of the interzonal relative attractiveness  $R_{ij}$

Type	Description
$R_{ij} > 1$	. Underestimated by the standard gravity model . Interzonal trips should be added by the interzonal relative attractiveness.
$R_{ij} < 1$	. Overestimated by the standard gravity model . Interzonal trips should be subtracted by the interzonal relative attractiveness.
$R_{ij} = 1$	. Estimated trips by the gravity model are equal to actual trips. . Travel costs in the gravity model fully explain zonal spatial properties and interzonal spatial association. . This case is hard to observe in real-world cases. Endogenous errors of the standard gravity model are suspected to capture the difference between actual and estimated trips.

### 3.2 Zonal Spatial Properties

This research regards areal characteristics as explanatory socio-economic variables for the interzonal relative attractiveness  $R_{ij}$ . Variables explaining zonal spatial properties are non-directional, whereas the interzonal relative attractiveness is a directional variable. Thus, this research computes average values of the interzonal relative attractiveness  $R_{ij}$  in origin zones ( $R_i$ ) and destination zones ( $R_j$ ) because the interzonal relative attractiveness of origin zones ( $R_i$ ) and destination zones ( $R_j$ ) is in normal distribution pattern. The total number of zones is twenty-five because traffic zones are based on twenty-five administrative jurisdictions of the Seoul metropolitan city. The unit of trip matrix in this research is daily commuting trips of Seoul residents. The daily commuting trips of the two Seoul transportation census data sets based on home-survey methods in 1996 and 2002 are applied in this research. The baseline model is developed using the 1996 Seoul transportation census data.

Since socio-economic variables of population, home-based employee, and work-based employee are widely used for future forecasting in Korean transportation demand models, this research uses such socio-economic variables for future trip distribution estimation. The socio-economic variables used in this research are shown in table 2.

Table 2 Explanatory variables of zonal spatial properties

Types	Explanatory Variable	Computing Method
Origin Zone ( $R_i$ )	Home-based(HB) employee	$ratio\ of\ HB\ employee = \frac{HB\ employee\ at\ a\ zone}{total\ HB\ employee}$
	Age Factor of home-based employee	$ratio\ of\ aged\ HB\ employee = \frac{ratio\ of\ aged\ HB\ employee\ at\ a\ zone}{ratio\ of\ total\ aged\ HB\ employee}$
	Job-housing balance by origin zone	$J-H\ ratio = \frac{WB\ employee\ at\ a\ zone}{HB\ employee\ at\ a\ zone}$ $ratio\ of\ J-H\ Balance = \frac{J-H\ balance\ at\ a\ zone}{J-H\ balance\ of\ entire\ region}$
Destination Zone ( $R_j$ )	Work-based(WB) employee	$ratio\ of\ WB\ employee = \frac{WB\ employee\ at\ a\ zone}{total\ WB\ employee}$
	Job-housing balance by destination zone	$J-H\ ratio = \frac{WB\ employee\ at\ a\ zone}{HB\ employee\ at\ a\ zone}$ $ratio\ of\ J-H\ Balance = \frac{J-H\ balance\ at\ a\ zone}{J-H\ balance\ of\ entire\ region}$

### 3.3 Interzonal Spatial Association

Different distribution patterns of the interzonal relative attractiveness  $R_{ij}$  are observed in each SMC zone because the interzonal spatial association among zones represents different travel demands from various socio-economic factors. This research classifies the interzonal relative attractiveness of the SM city into five regional groups based on the 『Seoul Metropolitan City Base Plan』. Trip directions between regional groups are considered as interzonal spatial association. In addition to that, trip directions between city centers and suburban areas are

also studied as another interzonal spatial association among SMC zones.

Table 3 Average values of  $R_{ij}$  in cases of trip direction between regional groups

Regional Group	Trip direction	Average value of $R_{ij}$	Rank
1	Within regional group	1.01517	3
2	Northeast region↔Northwest region, Southeast region↔Southwest region	1.02764	2
3	Northeast region↔Southeast region, Northwest region↔Southwest region	0.81088	5
4	Northwest region↔Southeast region, Northeast region↔Southwest region	0.99601	4
5	Each region↔Downtown region	1.05655	1

Table 4 Average values of  $R_{ij}$  in cases of trip direction between city centers and suburban areas

Type	Trip direction	Average value of $R_{ij}$	Rank
1	Between city centers	0.99490	3
2	City center→Suburban area	1.00984	2
3	Suburban area→City center	1.01949	1
4	Suburban area→Suburban area	0.91913	4

#### 4. MODELING INTERZONAL RELATIVE ATTRACTIVENESS

##### 4.1 Applying Neural Networks to Interzonal Relative Attractiveness

The interzonal relative attractiveness distribution among SMC zones is observed to be very irregular. Thus, the linear modeling structure of the standard regression model is hard to capture this irregular trip association among zones. In addition, the interzonal relative attractiveness  $R_{ij}$  has a complex association with areal characteristics and interzonal factors. The neural network approach is proven to have a strong explanatory power in non-linear association of many empirical case studies. Thus, this research adopts the neural network approach for modeling interzonal relative attractiveness among SMC zones.

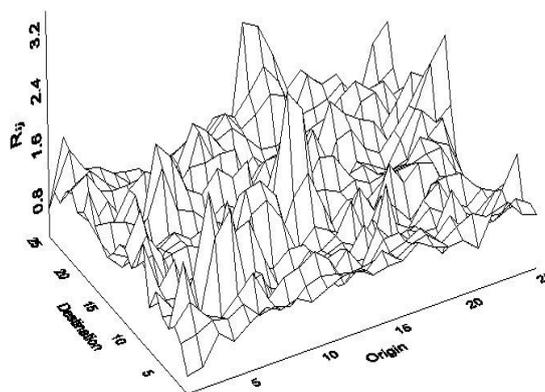


Figure 2 Distribution of interzonal relative attractiveness between origins and destinations

Artificial neural networks are referred to as modeling neural nets of human nervous system. They consist of a set of “nodes” and a set of “connections” connecting pairs of nodes within the framework of “parallel distributed processing systems (Mehrotra *et. al.*, 1997).” Each node in artificial neural networks performs some simple computations. Each connection conveys a signal from one node to another, referred to the “weight” indicating the extent to which the signal is amplified or diminished by a connection. Artificial neural networks learn from experience, generalize from previous examples to new ones, and abstract essential characteristics from a set of inputs containing irrelevant data. They self-adjust to produce consistent responses. Thus, artificial neural networks become the preferred technique for a large class of pattern-recognition tasks with non-linear association (Wasserman, 1989). This research uses the counterpropagation neural network with multilayer perceptron training algorithm.

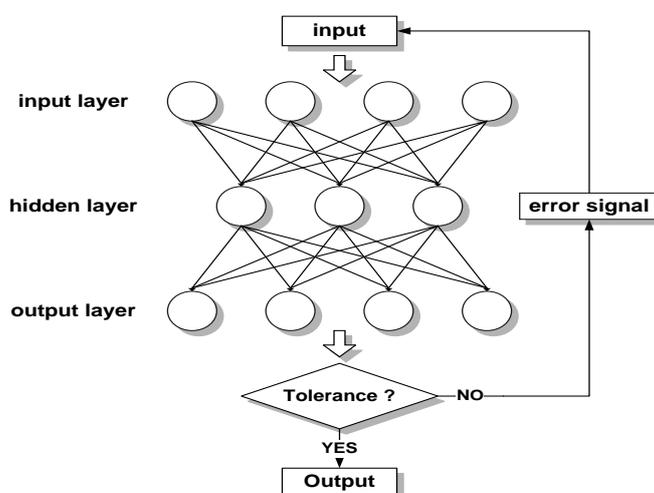


Figure 3 Architecture of counterpropagation neural network

#### 4.2 Determining Explanatory Variables

Artificial neural networks are not affected by multicollinearity problem in which two or more variables are very highly correlated with each other in the application of multiple regression models. Thus, this research applies all of the explanatory variables for the interzonal relative attractiveness that is described in chapter 3. The distribution of interzonal relative attractiveness  $R_{ij}$  is very complex so that this research adopts the idea of complex variable using a look-up table and multiple layers. Figure 4 shows the ideal framework of making complex variables using a look-up table and multiple layers.

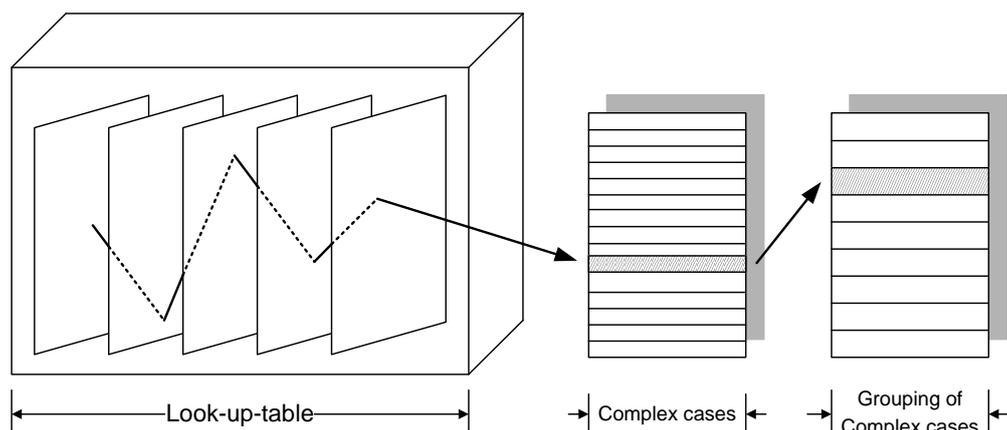


Figure 4 Ideal framework of Complex Variables Using a Look-up Table and Multiple Layers

The ordinal scale in a variable may produce same results, though estimated values from artificial neural networks are different. This research applies the interval variable scale to explanatory variables of areal characteristics in order to further classify results from this research’s neural network. Average values of groups in each category are used in missing values of weights in multiple layers.

This research first identifies 5,120 study cases based on six factors: four factors from trip-starting zones and two factors from trip-ending zones. The total number of 5,120 cases is computed by  $4(\text{relative size of employment}) \times 4(\text{relative size of elderly employment}) \times 4(\text{job-housing balance in trip-starting zone}) \times 5(\text{impact areal size in trip-ending zone}) \times 4(\text{relative size of employment}) \times 4(\text{job-housing balance in trip-ending zone})$ . The description of areal characteristic factors in trip-starting and trip-ending zones is provided in table 5. The total number of 428 cases among the 5,120 cases is identified to be applicable in this Seoul transportation census data set by applying the complex variable method using a look-up table and multiple layers in cases of zonal spatial properties. The remaining 4,692 cases have no data for further studies.

Table 5 Areal characteristic factors in trip-starting and trip-ending zones

Type	Areal characteristic factor(number of category)
Trip-starting Zone	Relative size of employment(4 groups), Relative size of elderly employee(4 groups), Job-housing balance in trip-starting zone(4 groups)
Trip-ending Zone	Impact areal size in trip-ending zone(5 groups), Relative size of employment(4 groups), Job-housing balance in trip-ending zone(4 groups)

The correlation coefficient of average values of each group’s  $R_{ij}$  and interzonal relative attractiveness  $R_{ij}$  is statistically significant with the high value of 0.87309. Average values of  $R_{ij}$  are not different among groups with the value of standard deviation 32.456. The average values of  $R_{ij}$  are within the interval of 0.19292~3.27243. This research determines an interval variable scale of eighteen groups with interval 0.1 in average values of  $R_{ij}$ . The correlation coefficient in the interval variable scale is 0.85388 a little less than the ordinal scale, but statistically significant in terms of statistical evaluation.

In addition, this research identifies 100 study cases based on three factors: directional trip-pattern factor (5 groups), interzonal trip pattern factor (4 groups), and trip-ending zonal factor (5 groups). The total number of 100 cases is computed by 5(directional trip-pattern) X 4(interzonal trip pattern) X 5(trip-ending zonal characteristics). The total number of 73 cases among the 100 cases is identified to be applicable in this Seoul transportation census data set by applying the complex variable method in cases of interzonal spatial association. The correlation coefficient of average values of each group's  $R_{ij}$  and interzonal relative attractiveness  $R_{ij}$  is 0.53754 less than that of areal characteristics case, but still statistically significant with the 99.9% confidence interval. Average values of  $R_{ij}$  are not different among groups with the value of standard deviation 19.9825. The average values of  $R_{ij}$  are within the interval of 0.55788~2.04408. This research determines an interval variable scale of sixteen groups with interval 0.1 in average values of  $R_{ij}$ . The correlation coefficient in the interval variable scale is 0.53298 very close to the ordinal scale.

### 4.3 Structuring a Neural Network

Every artificial neural network requires the determination of total number of hidden layers. This research applies a heuristic approach of increasing the number of hidden layers and observing the value of root mean square error (RMSE) to determine the optimal number of hidden layers. The maximum number of total hidden layers is set to be ten. The case of three hidden layers produces the lowest RMSE. Thus, this research applies the structure of three hidden layers. The value of RMSE is within the range of 0.18~0.19.

$$RMSE = \sqrt{\sum(\text{observed} - \text{estimated})^2 / \text{observed}} \quad (4)$$

The iteration number of our neural network model is evaluated using the 9.1 version of SAS program with ninety percent of training cases and the remaining test cases. The value of RMSE is converged in the iteration number of ninety-two. The average error of  $R_{ij}$  by our estimation model is computed to 0.0297. Since the average value of  $R_{ij}$  is 0.9821 in the SM city, the percentage of average error of  $R_{ij}$  is 0.0302 within the range of 5 percent confidence interval. The final average error of  $R_{ij}$  by our estimation model using synthetic data becomes 0.0432. The RMSE value for the entire estimation model is 0.1724. The Theil value of U is computed to 0.0830. Thus, the applicability of our neural network for  $R_{ij}$  estimation is proven to be strong.

$$U = \frac{\sqrt{\sum(\text{observed} - \text{estimated})^2 / \text{number of observed}}}{\sqrt{\sum(\text{observed})^2 / \text{number of observed} + \sum(\text{estimated})^2 / \text{number of estimated}}} \quad (5)$$

The applicability of our neural network model is further applied to estimating the 2002 interzonal relative attractiveness using training cases of the 1996 interzonal relative attractiveness for future trip estimation. The average error of  $R_{ij}$  for estimating the 2002 cases using the 1996 training data is computed to 0.6007. The Theil value of U is computed to 0.2377.

## 5. MODELING A TRIP DISTRIBUTION MODEL WITH THE INTERZONAL RELATIVE ATTRACTIVENESS VARIABLE

### 5.1 Combining a Trip Distribution Model with the Interzonal Relative Attractiveness

This research points out the weakness of the standard gravity model with empirical case studies in polycentric city structure such as the SM city. This research introduces an improved version of trip distribution model containing the interzonal relative attractiveness  $R_{ij}$  in order to resolve the limitation of the standard gravity model. The functional form of the trip distribution model containing the interzonal relative attractiveness  $R_{ij}$  is

$$T_{ij}^R = R_{ij} A_i O_i B_j D_j \text{EXP}(-\beta c_{ij}) \quad (6)$$

where  $T_{ij}^R$  = interzonal trip between zone  $i$  and zone  $j$ ,  
 $O_i$  = total number of trips produced in zone  $i$ ,  
 $D_j$  = total number of trips attracted in zone  $j$ ,  
 $C_{ij}$  = travel cost between zone  $i$  and zone  $j$ ,  
 $R_{ij}$  = interzonal relative attractiveness between zone  $i$  and zone  $j$ , and  
 $A_i$  and  $B_j$  = adjustment factors for calibrating the gravity model.

### 5.2 Analysis Results from the improved Trip Distribution Model

This research compares analysis results from the standard gravity model with those from the improved trip distribution model in order to evaluate the applicability of the improved trip distribution model containing the concept of interzonal relative attractiveness. The comparison results of the two models are shown in table 6. The Theil value of our improved model that provides the absolute evaluation of errors is almost half comparing with that of the standard gravity model. Other evaluation criteria of our improved model such as E-norm or RMSE are less than those of the standard model. This explains the better estimation of our improved model in non-linear association of interzonal trips.

Table 6 Comparison of estimation results from the standard model and the improved model

Evaluation Criteria	Standard gravity model	Improved gravity model with interzonal relative attractiveness
$\beta$	0.13181	0.13181
E-norm	0.11237E+10	0.03185E+10
RMSE	0.96769E+03	0.72861E+03
Theil value	0.1043	0.05551

This research further evaluates the applicability of the improved model by forecasting the 2002 case using the 1996 data set. Results from the improved model are compared with those from the standard model. The Theil value of our improved model is seventy percent of the standard model value. The forecasting case study provides less accurate values comparing with the estimation case in terms of E-norm, RMSE and Theil value. However, the improved model provides the better forecasting power than the standard model.

Table 7 Comparison of forecasting results from the standard model and the improved model

Evaluation Criteria	Standard gravity model	Improved gravity model with interzonal relative attractiveness
$\beta$	0.13181	0.13181
E-norm	0.14022E+10	0.06812E+10
RMSE	0.15313E+04	0.10673E+04
Theil value	0.13529	0.094621

## 6. CONCLUSION

This research develops a new version of trip distribution model with interzonal relative attractiveness in order to resolve the limitation of the standard gravity model in cases of polycentric city structure. Two research findings are identified in the case study of the Seoul metropolitan city. First, the interzonal relative attractiveness is in non-linear, complex form, explained by variables of zonal spatial properties and interzonal spatial association. Second, a neural computing approach such as counterpropagation neural network models is proven to have a strong power for minimizing errors in the non-linear, complex form of interzonal relative attractiveness. The heuristic approach provides that the counterpropagation neural network model with three hidden layers and interval variable scale is the best model in the SMC case.

This research combines a trip distribution model with the counterpropagation neural network model containing the interzonal relative attractiveness  $R_{ij}$ . Results from the improved model show the reduction of errors between actual and estimated values of interzonal trips, comparing to errors from the standard model. This estimation improvement of our model is also observed in the 2002 forecasting case using the 1996 data set.

Further studies are recommended in this subject. Different variables representing zonal spatial properties and/or interzonal spatial association can be used to improve the estimation power of the model. Other artificial intelligence techniques such as backpropagation neural network models or associative memory models are suggested for reducing errors. The study area can be expanded from the SM city to the SM region including the Incheon metropolitan city and the Gyeonggi province. Travel behaviors of other Korean metropolitan cities can be studied by the improved model of our research.

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