Study on Calibrating the Volume Delay Functions of the Travel Demand Model on Expressways Using a Genetic Algorithm

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Abstract: This study work estimates the optimal αs and βs of VDFs after building expressway O-D matrix and network for travel demand model. The optimal values of αs and βs are found using GA by adjusting the values in a way to maximize the correlation coefficient between assigned traffic volumes and actual traffic counts. The final α and β of Type 1 VDF are 0.251 and 1.866 respectively. The values for Type 2 VDF are found as 0.361 and 1.708. The travel demand mode using the optimized VDF shows correlation coefficient of 0.9545.

Keywords: Volume Delay Function, Transportation Demand Model, Calibration, Expressway

1. INTRODUCTION

1.1 Background and Purpose

The travel demand forecasting is the process to predict travel demands that will use a transport facility under study in the future. The transportation facility may be an existing highways or a potential expressway. The travel demand forecasting is conducted using diverse transportation demand models. Among the models, the traditional 4-step models is most commonly used. In the 4-step model, the selection of input data and parameters, (e.g., those of volume delay functions) has a decisive effect on the results of travel demand forecasting. Therefore, it is very important to use reliable input data and parameters in modelling.

In Korea, in order to gain the credibility in travel demand forecasting process, the Center for Korea Transportation Database (KTDB) has provided basic input data and parameters related with the travel demand forecasting process based on the 4-step model. In other words, the center supplies highway networks and vehicular Origin-Destination (O-D) tables (hereafter, KTDB) which were generated through trip generation, trip distribution, and modal split.

Transportation planners just need to conduct traffic assignments using KTDB and Emme4, TransCAD, etc. Based on the user equilibrium assumption in which the generalized costs estimated using volume density functions(VDF) play the most important role in route decision process(KDI, 2008).
Due to the importance of VDF in the travel demand forecasting process in Korea, the center for KTDB provides a basic set of VDF functions for all types of highways. This study work presents a systemic methodology to calibrate the essential parameters such as $\alpha$ and $\beta$ of the set of VDF using a stochastic optimization coupled with a genetic algorithm and the Emme4 program, which is a macro model for travel demand forecasting.

1.2 Study Scopes and Methodology

In order to develop the calibration methodology, this study work uses a 3,913km-long expressway network and O-D matrices. It is noted that the expressway network used in this study includes only expressways operated by the Korea Expressway Corporation. The expressway network and O-D matrices may provide the best development environment for the calibration method with the following reasons. First, the Korea Expressway Corporation (KEC) operates the Toll Collection System (TCS) which records the entry and exit tollgates with associated times for individual vehicles using the expressways. TCS can generate the daily and perfect O-D matrices for five vehicle types, which are determined according to vehicle sizes. Second, on every third Thursday of October, KEC conducts traffic counts covering the entire links, which may be an expressway segment between junctions (JC) or its combination. Thus, the traffic counts may work as input for the measures of effectiveness (MOE) for the calibration.

The center for KTDB provides the highway network including the entire expressways. The most recent network was provided by the center in 2011. This study work extracted the expressway network from the year 2011 highway network. In the year 2011 highway network, the center for KTDB provide two VDFs for expressway; the VDF for 4-lane expressway and 6 and more lane expressway, which are called as Type 1 VDF and Type 2 VDF, hereafter.

The component of VDF functions for expressways related with calibration consists of free-flow travel time, capacity, $\alpha$, $\beta$ and the weight for toll. Among those, the free-flow travel time and capacity is link specific parameter. In addition the weight for toll is identical for all expressway link. Thus, this study work focuses on $\alpha$s and $\beta$s for the two VFDs.

The calibration methodology was developed using a stochastic optimization approach. In the approach, the genetic algorithm (GA) seeks for the better values of $\alpha$s and $\beta$s within a set of ranges allowed by the center for KTDB. Based on the values of $\alpha$s and $\beta$s found by GA, Emme4 assigns, traffic volume for each expressway link. Finally a selected MOE provides an error measures. The entire process was coded using Matlab. The following figure 1 shows the entire process for this study.

2. Literature Review

2.1 Volume Delay Function

The most famous VDF is the one introduced by the bureau of Public Road. The VDF is referred to as the BPR function. The BPR function estimated the travel time of a highway section using free-flow travel time, $v/c$ ratio, $\alpha$ and $\beta$ as shown in Eq.1 (BPR, 1964).

$$TT = FFT(1 + \alpha(v/c)^\beta) \quad (1)$$

where,

- $TT$: predicted travel time,
- $FFT$: free-flow travel time,
- $v$: traffic volume,
- $c$: capacity, and
- $\alpha$, $\beta$: parameters.
The BPR function was developed using the data collected from uncongested expressways. Thus, the function works better for uninterrupted highways than interrupted urban streets (MnDOT, 2007). The center for KTDB basically provide the same form of VDFs to the BPR function. In the case of expressways, the weigh for tolls was added in the function.

### 2.2 Prior Studies

The center for KTDB is a Korea Transport Institute (KOTI)-affiliated Organization. Therefore, the KOTI conducted lots of efforts to finding appropriate parameters of VDFs. In 2007, the KOTI estimated VDF parameters (i.e., $\alpha$ and $\beta$) which could minimize the differences between assigned traffic volume and traffic counts.

In this study, the research team applied an iterative approach. For example, in the first step, the team found $\beta'$ using a golden section method after assuming fixed $\alpha^0$ as initial value. In the next step, the team adversely found $\alpha'$ after fixing the value of $\beta$ at $\beta'$. By
iterating such an approach, optimal $\alpha^*$ and $\beta^*$ were estimated (KOTI, 2007).

In 2009, a data-driven approach was applied in order to find the optimal parameters for VDF. In the study, after selecting test sites, traffic volumes, speeds, capacities were surveyed. It is noted that the free-flow speeds were determined using posted speed limits. Based on surveyed relationships between traffic volume and actual travel times, the appropriate $\alpha$ and $\beta$ were estimated (KOTI, 2009).

In 2013, an optimization approach was utilized. For optimization, a harmony search was used. This approach is much similar to that a used in this study. The estimated values for $\alpha$s and $\beta$s are presented in Table 1 (KOTI, 2013).

<table>
<thead>
<tr>
<th>Classification</th>
<th>No. of Lanes</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>Free-flow speed(km/h)</th>
<th>Capacity (veh/h/ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KOTI (2004)</td>
<td>Less than 3 lanes</td>
<td>0.645</td>
<td>2.047</td>
<td>117</td>
<td>2200</td>
</tr>
<tr>
<td></td>
<td>3 lanes or more</td>
<td>0.601</td>
<td>2.378</td>
<td>119</td>
<td>2200</td>
</tr>
<tr>
<td>KOTI (2007)</td>
<td>Less than 3 lanes</td>
<td>1.459</td>
<td>1.943</td>
<td>117</td>
<td>2200</td>
</tr>
<tr>
<td></td>
<td>3 lanes or more</td>
<td>3.210</td>
<td>5.936</td>
<td>119</td>
<td>2200</td>
</tr>
<tr>
<td>KOTI (2009)</td>
<td>Less than 3 lanes</td>
<td>0.611</td>
<td>2.772</td>
<td>117</td>
<td>1700</td>
</tr>
<tr>
<td></td>
<td>3 lanes or more</td>
<td>0.526</td>
<td>2.707</td>
<td>119</td>
<td>1900</td>
</tr>
<tr>
<td>KOTI (2013)</td>
<td>Less than 3 lanes</td>
<td>0.3500</td>
<td>2.0</td>
<td>120</td>
<td>2056</td>
</tr>
<tr>
<td></td>
<td>3 lanes or more</td>
<td>0.3251</td>
<td>2.1</td>
<td>112</td>
<td>2139</td>
</tr>
</tbody>
</table>

3. Building an Expressway Travel Demand Model

The O-D Matrix for the expressway travel demand model was estimated using 24-hour TCS Data from 7a.m. October 20, 2011 to 7a.m. October 21, 2011. During the same time frame, a traffic survey was conducted at the entire expressway links. The traffic counts were utilized to compare assigned traffic volume based on optimized $\alpha$s and $\beta$s of VDFs.

The expressway network for transportation demand modelling was extracted from the KTDB network as shown Figure 2. The network uses basically two types of VDFs; VDF for four-lane expressways (Type 1 VDS), and the VDF for expressways with more than six lanes (Type 2 VDS). However, the expressway networks includes a few private financed expressways. In the case of the private financed expressways, the same values of $\alpha$ and $\beta$ are used. But the weigh for tolls are different. It is noted that the weighs of toll were provided in KTDB. The initial parameters applied in the network built in this study were presented in Table 2.
<table>
<thead>
<tr>
<th>No.</th>
<th>Expressways in charge of KEC</th>
<th>α</th>
<th>β</th>
<th>Free-flow speed (km/h)</th>
<th>Capacity (veh/h/ln)</th>
<th>Weight for Tolls</th>
<th>VDF Type</th>
<th>No. of Lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Expressways in charge of KEC</td>
<td>0.611</td>
<td>2.772</td>
<td>90</td>
<td>1700</td>
<td>0.0795</td>
<td>Type1</td>
<td>Less than 3 lanes</td>
</tr>
<tr>
<td>2</td>
<td>Cheonan-Nonsan Expressway</td>
<td>0.526</td>
<td>2.707</td>
<td>107</td>
<td>1900</td>
<td>0.1590</td>
<td>Type2</td>
<td>3 lanes or more</td>
</tr>
<tr>
<td>3</td>
<td>Cheonan-Nonsan Expressway</td>
<td>0.611</td>
<td>2.772</td>
<td>90</td>
<td>1700</td>
<td>0.2024</td>
<td>Type1</td>
<td>Less than 3 lanes</td>
</tr>
<tr>
<td>4</td>
<td>Daegu-Busan Expressway</td>
<td>0.611</td>
<td>2.772</td>
<td>90</td>
<td>1700</td>
<td>0.2220</td>
<td>Type1</td>
<td>Less than 3 lanes</td>
</tr>
<tr>
<td>5</td>
<td>Busan-Ulsan Expressway</td>
<td>0.526</td>
<td>2.707</td>
<td>107</td>
<td>1900</td>
<td>0.2912</td>
<td>Type2</td>
<td>3 lanes or more</td>
</tr>
<tr>
<td>6</td>
<td>Seoul-Chuncheon Expressway</td>
<td>0.611</td>
<td>2.772</td>
<td>90</td>
<td>1700</td>
<td>0.2014</td>
<td>Type1</td>
<td>Less than 3 lanes</td>
</tr>
<tr>
<td>7</td>
<td>Seoul-Chuncheon Expressway</td>
<td>0.526</td>
<td>2.707</td>
<td>107</td>
<td>1900</td>
<td>0.4027</td>
<td>Type2</td>
<td>3 lanes or more</td>
</tr>
<tr>
<td>8</td>
<td>Other Expressway</td>
<td>0.611</td>
<td>2.772</td>
<td>90</td>
<td>1700</td>
<td>0.2190</td>
<td>Type1</td>
<td>Less than 3 lanes</td>
</tr>
<tr>
<td>9</td>
<td>Other Expressway</td>
<td>0.526</td>
<td>2.707</td>
<td>107</td>
<td>1900</td>
<td>0.4380</td>
<td>Type2</td>
<td>3 lanes or more</td>
</tr>
</tbody>
</table>

Figure 2. Network for Travel Demand Forecasting

4. Search for Optimal Parameters for VDF

4.1 Selection of MOE

As a MOE for the optimization using GA, this study work selected the correlation coefficient (R). The value of MAPE (mean absolute percent error) present the difference between traffic counts and assigned traffic volume. The GA tries to minimize the value by adjusting values for αs and βs of Type1 and 2 VDFs.

The correlation coefficient is a quantity that represent the quality of a least squares fitting to the original data. The value of R ranges from -1 to +1. When the value is close to +1 the two data set have a positive correlation.
Correlation Coefficient = \[ \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \] (2)

where,
- \( X_i \): assigned traffic volume,
- \( Y_i \): observed traffic volume,
- \( \bar{X} \): mean of assigned traffic volume, and
- \( \bar{Y} \): mean of observed traffic volume.

Figure 3 shows the X-Y plot based on traffic counts and assigned traffic volume which are estimated using VDF parameters shown in Table 2. The calculated R is 0.9506.

Figure 3. Relationship between Assigned and Observed Traffic Volumes

4.2 Optimization Using GA

Among diverse optimization tool, this study work uses the GA. The GA has been utilized in many transportation-related optimization problems. In many applications, the GA has shown potential performances (Yun, 2011; Yun and Park, 2012). Before using the GA, the search ranges for \( \alpha \)s and \( \beta \)s should be determined. To this end, the minimum and maximum values for \( \alpha \)s and \( \beta \)s provided in KTDB were applied. The ranges are presented in Table 3.
For running GA, there is a need to set up the parameters for optimized and a stop condition. The GA parameters includes a population size, maximum generation, the probability of crossover and mutation as shown in below. As the stop condition, if there is no enhancement in the best MOE during two generations after the fifth generations, the GA optimization will be stopped. The values for αs and βs of Types 1 and 2 VDF, are found as shown in Table 4. As a result of optimization, α and β for Type 1 VDF are optimized as 0.251 and 1.866 respectively. Those for Type 2 VDF are 0.361 and 1.708.

When the optimized parameters are applied in the travel demand model, the value of R is revealed as 0.9545. This value is improved 0.39%. Table 4 presents the final optimized values as well as initial values for αs and βs.

Table 4. Optimization Results

<table>
<thead>
<tr>
<th>Classifications</th>
<th>α</th>
<th>β</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>KTDB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1 VDF (Less than 3 lanes)</td>
<td>0.611</td>
<td>2.772</td>
<td>0.9506</td>
</tr>
<tr>
<td>Type 2 VDF (3 lanes or more)</td>
<td>0.526</td>
<td>2.707</td>
<td></td>
</tr>
<tr>
<td>GA Optimization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1 VDF (Less than 3 lanes)</td>
<td>0.251</td>
<td>1.866</td>
<td>0.9545</td>
</tr>
<tr>
<td>Type 2 VDF (3 lanes or more)</td>
<td>0.361</td>
<td>1.708</td>
<td></td>
</tr>
</tbody>
</table>
Finally, the optimized VDF are verified by drawing a plot the two VDFs with optimized αs and βs as shown Figure 4.

Figure 4. Types 1 and 2 VDFs

As presented in Figure 4, Type 1 VDF standing for four-lane expressways shows more travel times than Type 2 VDF at the same levels of traffic volumes. This phenomenon seems to be natural. Because expressways with six or more lanes will experience less traffic congestion that four-lane expressways at the same traffic volume.

5. Conclusions

This study work estimates the optimal αs and βs of VDFs after building expressway O-D matrix and network for travel demand model. The optimal values of αs and βs are found using GA by adjusting the values in a way to maximize the correlation coefficient between assigned traffic volumes and traffic counts. The final α and β of Type 1 VDF are 0.251 and 1.866 respectively. The values for Type 2 VDF are found as 0.361 and 1.708. The travel demand mode using the optimized VDF shows correlation coefficient of 0.9545.

This study presents an efficient way to optimize parameters for VDFs used in travel demand models. However, there are following limitations. First, among diverse parameters for VDF, only α and β are examined in depth. Later, there is a need to investigate other parameters. Second, the development environment includes only expressway O-D and network due to the ease of data collection. In the future, this approach should be tested in more complex situation including other types of highways.

Acknowledgments

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