SEEMINGLY UNRELATED REGRESSION MODEL FOR ANALYSING TRAVEL TIME VARIATION: A CASE STUDY OF HANSHIN EXPRESSWAY

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1. Introduction

Travel Time variation frequently occurs in urban arterial road networks as a result of demand and supply variations as well as some external factors such as adverse weather and natural disasters. Study on travel time variation is useful for measuring travel time reliability. The knowledge about relation between sources of uncertainties and travel time is not only enough, but also quantitative evaluation between these will be very much useful to the system planers as well as system managers to take decision on how to improve travel time reliability.

Travel time reliability has attracted many researchers in the study of transport network reliability because of its importance as compared with other network reliability measures such as connectivity reliability, capacity reliability etc. This reliability can be used in policy assessment as a new evaluation technique and also may be used as a new travel time related information to the users (Asakura 2006). In the literature travel time reliability and travel time variations has been used as interchangeably (Lomax et. al 2003).

The objective of this paper is to analyze the day to day travel time variation with respect to traffic volume as a demand side factor, road accidents as supply side factor and intensity of rainfall as an external effect. For this, seemingly unrelated regression (SURE, Zellener 1962) model was considered for the evaluation of the effect of these factors on travel time variation. SURE is an extension of regression models to systems of equations having contemporaneous correlations across the multiple equations.

2. Review on Travel Time Variability

Federal Highway Administration (FHWA) has identified seven sources of events which are cause of travel time variation. Further they have categorized into three main events such as traffic influence events (includes traffic incidents, work zones and weather), traffic demand events(includes fluctuations in normal traffic and special events) and physical highways features (includes traffic control devices and bottle necks) (FHWA Report 2004). Asakura (2006) further categorized the sources of travel time fluctuations into three factors which are from demand side factor such as day to day traffic variation, supply side factors such as road closure due to accidents and external factors such as adverse weather effects and natural disaster. Ruimin Li (2004), examined travel time variability under the influence of time of a day, day of a week, weather effect and traffic accident for this he used multiple linear regression model.

Keywords: Travel Time Variability, Seemingly Unrelated Regression, Urban Expressway

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In another study, Florida department of transportation (Florida DOT) developed empirical travel time variability models as a function of frequency of incidents, work zones and weather conditions. For this, they have considered regression analysis for different combinations scenarios of uncertainty sources. (FLDOT Report, 2007).

All these models are estimated equations separately, also unable to estimate the error correlation among various equations (contemporaneous correlation). There has been no such study that considers impact of factors from supply side, demand side and external effects on travel time. Therefore in this study an effort has been made to consider contemporaneous correlation among the system of equations, for this SURE model was considered. The implementation approach methodology for the present study has been discussed in the following section.

3. Methodology for Travel Time Variability Analysis

In this study travel time variation was evaluated with respect to traffic volume as a demand side factor, road accidents as supply side factor and intensity of rainfall as an external effect. Figure 1 shows the structural framework between travel time fluctuation and sources of travel time fluctuation which were considered in this study. Travel time can be expressed as directly influenced by incoming flow of the Ikeda line section, traffic accident and rain fall. Further, rain fall also has indirect effect on travel time through traffic flow and traffic accident. The functional relationship for typical m^{th} day observation can be written in usual algebraic notation has explained at Equation 1 to 3.

$$y_m = \beta_0 + \beta_1 x_{1m} + \beta_2 x_{2m} + \beta_3 x_{3M} + \varepsilon_{1m} \text{ ...... Eqn.1}$$

$$x_{1m} = \alpha_0 + \alpha_1 x_{2m} + \alpha_2 x_{3m} + \varepsilon_{2m} \text{ ... ... Eqn.2}$$

$$x_{2m} = \gamma_0 + \gamma_1 x_{2m} + \gamma_2 x_{3m} + \varepsilon_{2m} \text{ ... ... Eqn.3}$$

Where x_{1m} = is hourly traffic flow of day m (in Veh/hr)

x_{2m} = Intensity of rain fall of day m (in mm/hr)

y_m = travel time of day m (in seconds)

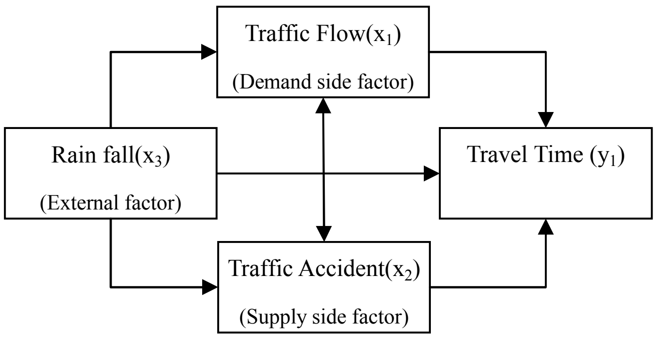

Figure 1: Structure of travel time fluctuation

When, system having multiple equations there could be residual error correlation among the equation. This kind of phenomena is known as contemporaneous correlation. In the presence of contemporaneous correlation, independent equation solution models such as multiple regression models will suffer from simultaneous bias. Therefore the jointly estimated equation models are more efficient in this situation.(Zellner 1962). The above three equation can be written as a stacked model and presented at equation 4.

$$\begin{bmatrix} y \\ x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} X_1 & 0 & 0 \\ 0 & X_2 & 0 \\ 0 & 0 & X_3 \end{bmatrix} \begin{bmatrix} \beta \\ \alpha \\ \gamma \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix} \text{ .... Eqn. 4}$$

$$\text{where } X_1 = \begin{bmatrix} 1 & x_{11} & x_{21} & x_{31} \\ .. & .. & .. & .. \\ 1 & x_{1M} & x_{2M} & x_{3M} \end{bmatrix} \quad X_2 = \begin{bmatrix} 1 & x_{21} & x_{31} \\ .. & .. & .. \\ 1 & x_{2M} & x_{3M} \end{bmatrix} \quad X_3 = \begin{bmatrix} 1 & x_{11} & x_{31} \\ .. & .. & .. \\ 1 & x_{1M} & x_{3M} \end{bmatrix}$$

Using obvious notation we can rewrite equation 4 as, $Y = X\beta + \varepsilon$ ... ... Eqn. 5

The coefficients from all the three model equations can be estimated by using the generalized least square estimator (GLS). The GLS estimator has best linear unbiased estimator for β and has lower variance than the least square estimator because it takes into account the contemporaneous correlation between the disturbances in different equations

$$\beta = \left(X' W^{-1} X\right)^{-1} X' W^{-1} Y = \left[X'\left(\Sigma^{-1} \otimes I_M\right) X\right]^{-1} X\left(\Sigma^{-1} \otimes I_M\right) Y \text{ .... Eqn. 6}$$

where $W = \begin{bmatrix} \sigma_{11} I_M & \sigma_{11} I_M & \sigma_{11} I_M \\ \sigma_{11} I_M & \sigma_{11} I_M & \sigma_{11} I_M \\ \sigma_{11} I_M & \sigma_{11} I_M & \sigma_{11} I_M \end{bmatrix} = \sum \otimes I_M$ Eqn.7

The unknown variance and covariance matrix ($\sum$) can be estimated by using residual error obtained by OLS method and $\otimes$ is the knecker operator indicates each element of $\sum$ is multiplied by an Identity matrix I_M .The entire procedure discussed as above was implemented with the help of MATLAB statistical tool box.

4. Application to Travel Time Variability Analysis

4.1 Data collection and travel time estimation

Data used in this study was collected on Ikeda line section of Hanshin Expressway, Japan. For this study a 11km section of Ikeda line starting from air port entrance (13.1 kilometer post) to Fukushima exist (2.1Kilometer post) has been considered. Supersonic vehicle detectors were placed to observe the traffic volume and time occupancy ratio at every 5 minutes interval. From this data spot speed of the traffic flow was estimated. Further, travel time of the section is calculated as the length of the section divided by the spot speed. Route level travel time was estimated by considering time slice method (Asakura 2006, Higatani et.al 2007). Travel time at 8am departure time for every day at airport entrance side has been calculated by using the time slice method for the year2003 (1st April 2003 to 31st March 2004). Besides hourly traffic volume data between7 am to 8am, incident data such as number of accidents, vehicle breakdown, road work and falling objects from vehicles were collected from Hanshin expressway highway corporation for this section. Incidents which occurred in early hours from 0:00 to 8:00AM were assumed to effect the travel time variation and all incidents that happened between those hours were considered. The intensity of hourly rain fall during the period of 7am to 8am was collected from Japan Meteorological Agency (JMA), Osaka region.

4.2 Travel time variation analysis

On Ikeda line wide variation of travel time was observed on working days (239 days) this is varies between 593 seconds to 3952 seconds(about 8 times). Whereas on nonworking days the travel time varies between 387 seconds to 984 seconds (about 2.5 times). This wide variation of travel time during working days on Ikeda line is mainly due to traffic flow variation, traffic accidents and intensity of rain fall. Road works generally carried out on non working days on Hanshin expressway network. Therefore in this study main concern is the working days data.

Initially, multiple regression analysis by considering ordinary least square estimation (OLS) has been carried out separately for all the three equations for working days data. The model parameters, standard error and t-sat value for all the individual equations are presented at table2. The error covariances among the three equations were estimated by considering the error residual obtained by OLS method. The non diagonal values of the error covariance matrix (Table1) are not zero therefore there is an existence of contemporaneous correlation among the three equations. After that SURE approach was adopted and the results of both OLS and SURE models were presented at Table 2.

Table 1: Error covariance matrix ($\sum$)

187200.00	0.00	0.00
0.00	34175.00	10.44
0.00	10.44	0.06

From Table 2, It can be observed that between equation 2 and 3 there is significant gain in SURE model coefficients. From results it can be identified that, if there is an traffic accident, traffic flow will be reduced by 188vehicles in that hour according to MLR model results whereas from SUR model traffic flow will be reduced by 356 vehicles. This explains that MLR models were under estimate the effect of uncertainties. Also the relative reduction of standard error in SURE model is less than the MLR model. This further indicates that coefficients obtained by SURE model are more appropriate than the MLR model coefficients.

Table 2: Model coefficients estimated by OLS and SURE models

Variable	MLR model			SURE Model		
	Estimated coefficient	Standard error	t-stat	Estimated coefficient	Standard error	t-stat
$y_m = \beta_0 + \beta_1 x_{1m} + \beta_2 x_{2m} + \beta_3 x_{3M} + \varepsilon_{1m}$ …… Eqn.1						
Intercept (β_0)	-1778.737	384.142	-4.630	-1778.755	380.916	-4.670
Traffic volume (Veh/Hr) (β_1)	1.383	0.153	9.056	1.383	0.151	9.133
Traffic accidents (Yes/ No) (β_2)	455.631	119.936	3.799	455.640	118.929	3.831
Rain fall (mm/hr) (β_3)	10.710	15.976	0.670	10.710	15.841	0.676
$x_{1m} = \alpha_0 + \alpha_1 x_{2m} + \alpha_2 x_{3m} + \varepsilon_{2m}$ … … Eqn.2						
Intercept (α_0)	2508.724	12.546	199.966	2519.437	12.445	202.445
Accidents (Yes/no) (α_1)	-188.547	49.642	-3.798	-356.487	47.968	-7.432
Rain Fall (mm/hr) (α_2)	-6.592	6.798	-0.970	-7.327	6.755	-1.085
$x_{2m} = \gamma_0 + \gamma_1 x_{2m} + \gamma_2 x_{3m} + \varepsilon_{2m}$ … … Eqn.3						
Intercept (γ_0)	0.827	0.201	4.104	1.506	0.195	7.736
Rain Fall(mm/Hr) (γ_1)	-0.006	0.009	-0.709	-0.008	0.009	-0.895
Volume (veh/hr) (γ_2)	-0.0003	0.000	-3.798	-0.001	0.000	-7.432

5. Conclusions

- ❖ SURE models are efficient than the MLR models in modeling travel time variation under the influence of system of uncertainties
- ❖ Standard error obtained by the SURE models is less than the MLR method this emphasizes that model coefficients obtained by this method are more appropriate than MLR models.
- ❖ MLR and SURE models of functional relation 3 explains that, due to increase in rain fall and traffic volume the number of accident are reduced, actually this may not happen. This is mainly because of insufficient data in this category. Further this has to be investigated by considering more number of incident data.

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