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Estimation of Value of Time for a Congested Network – A case study of the National Highway, Karachi

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Abstract

Traffic congestion in mega cities is a common phenomenon for developing countries. Numerous studies on congestion cost estimation, that aim to quantify their monetary losses, have been conducted. Value of Time (VOT) assessment through utility maximizing theory and choice models are abundantly applied in transport literature. However, estimating VOT on congested network is not widely applied yet. To recognize the difference under normal and congested network, the current study focuses on VOT estimation for work trips in an extremely congested network.The focus of this research is to conduct a VOT estimation of the National Highway, Karachi. It connects Karachi city with Port Qasim Industrial area and the rest of the country. A large amount of freight transport to and from the port is also observed on this road. The National highway, being the only link to commute to this industrial area, is therefore under excessive traffic congestion.A stated preference (SP) survey was conducted at various industries located in this stretch. The respondents were asked about current travel practices and their (stated) preferences based on hypothetical -though realistic- travel attributes. A choice set of four alternative modes based on the currently used mode was presented to each individual. A Multinomial Logistics Regression (MNL) Model was developed for data analysis.As perceived, the results revealed a strong impact of travel time and travel cost on the (dis)utility of travel. These results can be utilized by policy makers to reduce congestion, monetary and time losses through efficient transport planning.

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Keywords: Value of Time (VOT); Traffic congestion; Stated Preference (SP) survey

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1. Introduction and Research Background

The focus of this research is to conduct a Value Of Time (VOT) estimation for a congested network in a developing country. The National Highway which connects Karachi city with the Port Qasim industrial area, has been selected for this study. This study emphasis on the work trips, as a major share of travelers uses this highway to reach their work place. Traffic congestion and delays on this stretch were quantified to be around 30,000 US$ per day[1].

The concept of VOT was introduced by Becker when he proposed the conversion of time into money by assigning more time to work[2]. Since then, a lot of research has been carried out that ascertains the impact of commuting purpose in estimating value of travel time. Many researchers including Belenky[3], Xumei[4], Kamga[5], Jiang[6] and Lei[7] worked on differentiating value of travel time between trip purposes. As per intuition, the highest value of travel time is associated with work/ business trips.

For this research, VOT estimations are made for 'passenger transport' only. Freight transport also passes through the stretch, but its VOT assessment is not part of this paper. The VOT is assessed for private car users and other transport mode users separately. Although it has been previously emphasized by researchers to analyze VOT for *each* mode separately[8], there are various reasons for this stand-out approach, the main one being that there is only a small percentage of public transport users. In addition, the bus is the only available mode of "public transport" in this area. Clustering "bus" with "bike" is needed for sound analysis. Moreover, "Company Van" was eliminated from the analysis as its travel cost estimation is an arguable matter in itself due to travel reimbursements. Travel reimbursements vary for each company (such as 25%, 50%, 100% etc.). This particular way of grouping revealed the difference between the VOT of car users and users of other modes.

This paper comprises of four sections. The next section explains the study area followed by data collection and methodology. The results and discussion is described in section 4. The last section of this paper is conclusion.

2. Study Area

The National Highway is a 20km stretch which connects Port Qasim Industrial Area to main arterial 'Shahrah-e-Faisal'. It comprises of nine intersections from the 'Star Gate' intersection to the 'Pakistan Steel' intersection. Each section is a two-way two-lane road with a median strip. The average volume per hour is higher than the road capacity[1] as this network is available for passenger and cargo transport and therefore is under excessive load. More than 100 medium and high scale industries are located in the Port Qasim area. A highly heterogeneous vehicular mix uses this stretch, including private vehicles, para-transit and public transport modes. Moreover, only motorized transport can be used to reach the work areas as it is far away from the residential areas. In the case of freight transport, heavy trailers traverse all day. There is also an oil depot situated in this area, which sets movement of tank trucks in the same stream which adds to stated quandary of traffic congestion. The Figure 1 below shows the Google imagery of the study area.

Figure 1. Google Image of National Highway Stretch.

3. Data Collection and Methodology

Data for the VOT estimation was collected through a Stated Preference (SP) survey. This survey was conducted at various industries located in the Port Qasim Industrial Area, where employees commute daily on the National Highway. A paper based questionnaire was developed where respondents were given hypothetical mode options to choose from.

The survey form comprised of two sections. The First section focused on socioeconomic data such as age, gender and income status. Furthermore, travel attributes such as origin, destination, mode, travel expenses and journey time were collected. Journey time was further divided into average, shortest and longest time. Some descriptive questions such as the most common reason for delays and their solutions were asked. There were some secondary questions as well, such as fuel type, number of daily trips, distance travelled and monthly travel expenses.

The Second section of this survey was related to SP data. The options from which the respondent could choose were provided based on his current mode. For example, private-car users were given the choice of bike (in case of ownership), three-wheeler, van and public transport. The travel time and cost parameters in the survey options were realistically formulated, satisfying constraints such as the maximum achievable speed.

The parameters for the alternative mode options are defined as a predefined offset from the reported time and cost. Hence, the values for time and cost for choices vary with respect to their current (revealed) values. This offset criteria ensured that the alternative parameter values remain stochastic. All the respondents, were given same hypothetical choices to choose form, except their current mode, which was eliminated from alternative choice set. In total, there were 5 travel modes (car, public transport, bike, three-wheeler and van). This resulted in four hypothetical choices for each respondent, with the fifth (eliminated mode) being their current mode.

Other common parameters such as comfort and safety were not included in the survey. As the average speed is identical for each mode (based on congestion and queue formation), it was hard to discriminate comfort level. Therefore, the attributes for the hypothetical choices were only travel time and travel cost. These were a function of the reported travel time and travel cost. Table 1 below shows the hypothetical choices and the values provided to respondents.

Table 1. Time and Cost for Alternative modes.

Current Mode	Alternative Choice	Travel time [minutes]	Travel cost [Rs] (100Rs = 1US$)
Car	Public Transport	20	-50
	Three-Wheeler	Same	30
	Van	20	-30
	Bike	-10	-30
Public Transport	Car	-20	50
	Three-Wheeler	-20	70
	Van	-10	50
	Bike	-20	30
Van	Car	-20	-30
	Public Transport	Same	-80
	Three-Wheeler	-20	Same
	Bike	-30	-60
Bike	Car	10	30
	Public Transport	25	-20
	Three-Wheeler	10	60
	Van	30	60

The respondents were selected through clustered sampling based on the income group. Figure 2 shows the number of respondents in the dataset with respect to their income group. It should be noted that that the distribution of income among the respondents (the sample) matches the income distribution of the real population. This was made possible by asking company’s representatives for equal representation of respondents from each income group.

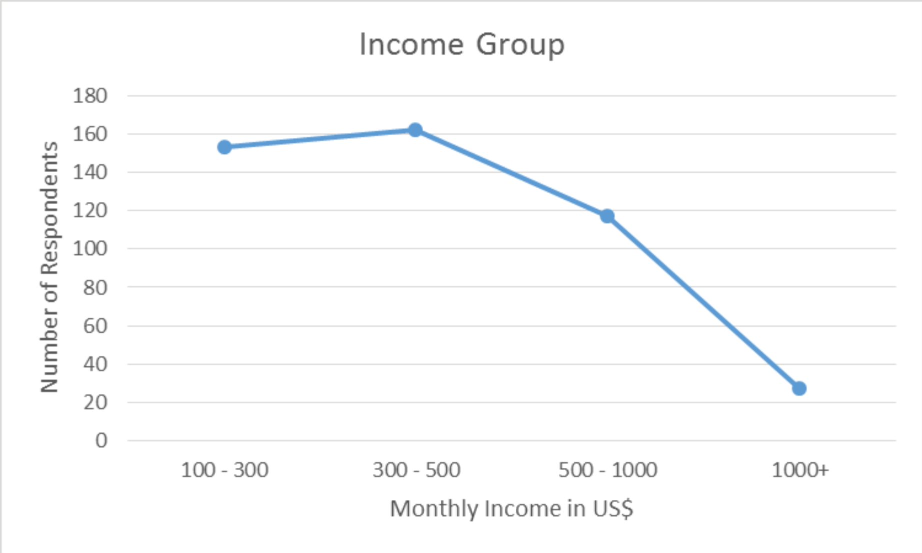

Figure 2. Sample size of Respondents.

Table 2 shows the alternative (stated) mode selection in function of the actual travel mode. Currently, three-wheeler was not used at all although it was chosen by many respondents as an alternative mode, especially by those travelling by public transport. A majority of those travelling by private car chose the company van as their alternative. furthermore, van passengers mainly opted for a car and a small percentage of them preferred to use a bike. Those travelling by public transport only opted for a three-wheeler or company van as these commuters do not typically own a private vehicle.

Table 2. Percentage shift from Current to Stated Mode.

	Bike	Bus	Car	Three-Wheeler	Van	Total
Bike	0	17	17	16	50	100
Bus	-	-	-	40	60	100
Car	8	8	0	19	65	100
Van	11	5	84	-	-	100

3.1. Multinomial Logit Regression Model

A Multinomial Logit Regression Model (MNL) was implemented through utility theory by maximizing log-likelihood. The equation 1 was used for estimating utility.

$$U_i = \beta_0 + \beta_1.TT_i + \beta_2.TC_i \quad (1)$$

Where,
U_i = Utility of mode i (i={Car, Bus, Bike, Van, Public Transport, Three-Wheeler}),
TT_i= Travel time for mode i,
TC_i= Travel cost for mode i,
B_0= Intercept,
β_1= Coefficient of travel time [1/min] and
β_2= Coefficient of travel cost [1/Rs].

Travel cost and time for alternative mode were calculated using the current mode attributes and the properties of the stated preference. The utility was calculated for each individual and alternative. From the utility, probabilities of choosing the current mode were derived for each individual. Lastly, the aggregate log-likelihood (ln) was maximized through the solver extension in MS Excel by optimizing the utility function coefficients.

Travel time increases during congestion and peak hours whereas Travel Time Reliability (TTR) is decreased[9]. Therefore, travel time and cost for alternative modes were provided stochastic nature (variation) through multiplication with a random variable. This variation in travel time served two purposes. Firstly, it deals with the repetition of identical answers from respondents (having same travel times) because their trip origins were nearby or even from same location. Secondly it assisted in determining the sensitivity of VOT estimated with change in travel time. This variation in travel time was kept under the limits of variations obtained from the answers of shortest and longest journey time faced (asked in section 1 of questionnaire survey). Separate MNL models were applied for car users and other mode users.

The obtained coefficients of Travel Cost and Travel Time were divided to estimate the VOT, as mentioned in the equation 2 below.

$$VOT = \frac{\beta_1}{\beta_2} \quad (2)$$

4. Results and Discussion

The following values were deduced through the use of the solver add-in available in MS Excel. Table 3 below shows the average estimated coefficient for travel time and cost after various simulations with different random variations as detailed previously. A negative sign denotes a disutility with an increase in both cost and travel time. However, it is primarily dependent on time. The constant or intercept is very small and can be considered as insignificant.

4.1 For car users

Table 3. Coefficient for MNL Model of Private Car Users.

Coefficient	Value
Constant	-5.6995 E-08
Time Coefficient [/min]	-0.1377
Cost Coefficient [/Rs]	-0.0223
Value of time [Rs/h]	370.4932 Rs/h
Value of time [US$/h]	3.6677 US$/h

A log-likelihood ratio test with null-hypothesis a 50%/50% probability (no parameters estimated) shows that the estimated parameters are significantly different from zero.

Based on these coefficients the estimated VOT is calculated to be **371.31 Rs/h**, which is equivalent to **3.6677 US$/h**. Although it is intended for only work trips in a private car, this VOT is higher than in previous studies conducted in similar locations in recent years.

4.2 For other users

Table 4 shows the coefficients for commuters other than car users. Based on these coefficients, the VOT is calculated to be **98.67 Rs/h**, which is equivalent **to 0.9752 US$/h**. This value is quite low when compared to the VOT of car users. However, it is still above the average VOT for similar regions.

Table 4. Coefficient for MNL Model of other users.

Coefficient	Value
Constant	-4.026 x E-08
Time Coefficient [/min]	-1.8938
Cost Coefficient [/Rs]	-1.1521
Value of time [Rs/h]	98.6268 Rs/h
Value of time [US$/h]	0.9752 US$/h

The values obtained are not highly sensitive to random variation when travel time is randomly altered by maximum 15 minutes. This can be seen in Table 5 where VOT results for 10 different simulations are shown. The VOT remains between 81.9546 Rs/h and 116.1628 Rs/h (equivalent to 0.7773 US$/h and 1.2698 US$/h respectively).

Table 5. VOT results for different simulations.

S. No	βTT [/min]	βCC [/Rs]	VOT [Rs/h]	VOT [US$/h]
1	-1.7492	-1.1868	88.4328	0.8744
2	-2.0056	-1.3034	92.3247	0.9128
3	-1.8016	-1.1843	91.2742	0.9025
4	-1.8797	-1.0403	108.4130	1.0719
5	-1.7688	-1.0979	96.6645	0.9558
6	-1.421	-1.0845	78.6169	0.7773
7	-1.9834	-1.1913	99.8942	0.9877
8	-1.8181	-1.1799	92.4536	0.9141
9	-1.965	-1.0732	109.8584	1.0862
10	-2.5235	-1.179	128.4224	1.2697
			Average =	**0.9752**

Table 6 below shows estimated country-wide VOT values as a comparison. The VOT varies from region to region but remains below the one dollar mark for all. Amongst them, the lowest VOT is of Pakistan. This study was conducted in Karachi city (same as current study). However, that study covered the whole city of Karachi which holds huge demographic variation; from some posh areas to many slum districts with reasonably different travel behaviour. Therefore, as an overall estimation, a VOT of 0.41 US$/h is quite reasonable. Similarly, Ahmed revealed diverse VOT values for Bangladesh for rural areas Ahmed[10].

Table 6. VOT for similar regions.

Country	VOT [US$/h]	VOT [€/h]
India	0.75	0.60
Srilanka	0.56	0.45
Bangladesh	0.72	0.58
Pakistan	0.41 (JICA)	0.32

Interestingly, previous studies such as the one of Gwilliam[11] have revealed huge intermodal differences in VOT. He further stated that Value of Travel time Savings (VTTS) in congested conditions and other unpleasant situations is higher than under normal conditions in the UK and the Netherlands. Further on, he compared the VOT for the countries as shown in Table 7. Most countries in this list have socioeconomic features similar to Pakistan. The percentage difference between highest and lowest VOT for each country has been calculated, and as a result enormous differences can be observed in intermodal VOT. The percentage difference of VOT for the current study can is slightly less as compared to the neighbouring country India.

Table 7 also shows VOT estimations which are higher than the currently calculated VOT values, but the detailed context of these estimations is not available.

Table 7. VOT (US$) comparison between Modes.

S. No.	Country	Car	Pickup	Bus	Truck	%Diff. in high and low VOT
1	Honduras	0.80	1.00	0.14	-	614%
2	Chile	5.97	8.31	30.89	4.48	590%
3	Srilanka	0.82	-	0.16	0.16	413%
4	Indonesia	2.06	2.06	0.42	-	390%
5	India	1.00	0.44	1.80	1.04	309%
6	Uruguay	1.10	1.10	0.29	-	279%
7	Pakistan (Current Study)	3.66	-	0.97	-	277%
8	Kenya	0.51	0.65	0.98	1.93	278%
9	Brazil	4.46	-	1.28	-	248%
10	Thailand	1.50	-	0.50	-	200%
11	China	0.33	0.12	0.33	0.33	175%
12	Bangladesh	0.91	0.91	0.35	-	160%
13	Hungary	2.80	-	-	6.63	137%
14	Tunisia	1.07	-	0.48	-	123%
15	Lebanon	1.72	2.59	1.24	-	109%
16	Spain	-	42.29	21.14	-	100%
17	Venezuela	2.72	2.14	1.66	-	64%
18	St. Lucia	1.14	1.49	0.91	1.10	64%
19	Korea	2.57	-	1.70	-	51%
20	Algeria	-	-	2.96	3.37	14%

5. Conclusion

This study, up to the best of our knowledge, is the first of its kind yet undertaken in Pakistan. It estimated VOT in a congested network through utility maximizing approach. This paper reported VOT for work trips under highly congested transport network to be much higher as compared to VOT under normal conditions. VOT estimated for car and other transport mode users was found to be 3.6677 US$/h and 0.9752 US$/h respectively. This study also includes the sensitivity analysis to assess the credibility of VOT estimated and it corroborates to be significantly acceptable. It also compared the difference in VOT amongst users of different transport modes and found it to be consistent with intermodal VOT differences of other study area.

The higher estimations of VOT can be justified with numerous insights. First, this VOT is solely estimated for work commutes. Secondly, only motorized transport can be used to reach the work areas as it is separated from the residential areas. Thirdly, a huge amount of congestion increased the value of unit time saved.

This research provided an important planning insight where project cost and benefits are imperative criteria in determining its feasibility. The results reveal an urgent need for congestion counter measures. In this regard several ‘low cost’ techniques can be applied to reduce the travel time, such as scheduling freight transport in non-business hours. A toll implementation on low occupancy vehicles, in favour of carpooling, can also assist in reducing congestion. Additionally, this paper identified the gap of VOT estimation for congested transport networks in developing countries; research that is not yet abundantly available in literature.

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