Toll Estimation as a Function of Time-Dependent Link Cost, Vehicle Category and Distance–A Case Study for Karachi

Mir S. Ali and Muhammad Adnan
NED University of Engineering and Technology, Karachi, Pakistan
Email: {mshabbar, adnanres}@neduet.edu.pk

Syed F. A. Baqueri
Transportation Research Institute (IMOB), Hasselt University, Diepenbeek, Belgium
Email: syed.fazalabbasbaqueri@uhasselt.be

***Abstract*—Currently, Time-based speed data are collected through the fixed detectors or loop based detectors fixed at road. These conventional methods were applicable scarcely on arterials or some major inter-city roads as their shifting is an arduous job every now and then. Simultaneously the livelier up rise of the Intelligent Transportation System (ITS) and its integration with the state-of-the-art GPS technology in the transportation sector has given a fresh dimension to it. It stretches the data collection from rather a point to the whole route and hence an opening to an in-depth examination of speed, travel time, delay, identification of bottlenecks and other essential traffic attributes connected to colossal progression of cost estimation. This paper utilizes the tracker data logged on a server specifically designated to record time based position and speed of vehicle. The success of this advanced approach lies in the association of log route modification with respect to the GPS coordinates. The delay functions are used to calculate the extra cost on road users due to superfluous load of vehicles. It explains the variations in this cost with time. This paper also demonstrates a function to internalize this cost on commuters through a toll stimulus. The results identify time based link cost and further provide way to optimize the travel cost through internalization of external cost on the whole network. As a coda this method provides an effective use of GPS within the transportation ensuing in the more apt functioning of the transportation system and eventually abating the monetary losses. It sets basis for toll estimation as a function of additional cost put by the road user. It will also assist in-car-navigation system, once available.**

***Index Terms*—time-dependent link cost, congestion pricing**

I. Introduction

National highway, a 20km long highway two-lane two way, is the only link which connects Karachi city with Port Qasim and further ahead to the rest of province. The Landhi Industrial Area (LATI) and Bin Qasim Industrial Area (BQATI) comprised of above 100 industries solely. This being said, it is under persistent traffic load of which freight transport constitute a major share. The traffic congestion cost estimation at national highway had already been reported in [1]. However, it is important to study the traffic behaviour at micro level in order to counter act the up surging cost.

The purpose of this study is to alleviate the additional cost imposed for efficient and proper transport management. It aims to plan a dynamic toll based on additional cost calculated at a certain location and transport mode.

The next section of this paper highlight the work done by various researchers in this domain. Section three explains the study area of this research and its reason followed by the data collection and processing. The fifth section of this paper comments on the results. The sixth section highlights the future work which can be done as a follow-up to this project and the last section in this paper is results and conclusion.

II. Literature Review

Road traffic growth rate is faster than roads to facilitate it [2] hence a reason for exponentially increasing congestion. Congestion therefore, is an incessant issue in case no positive measures are implemented. It has many side effects of loss in business, productivity and job growth [3]. With these reasons it has enlarged attention academically and practically both [4]. In the last decade a large number of cities such as Stockholm and Oslo in Norway and particularly London in UK implemented congestion pricing where a lot of them faced political conflicts. Litman Enormously covered London congestion charging scheme with many positive effects on city's transport and business [5].

There is huge literature available for congestion pricing however works on toll variations and pricing is quite low [6]. Over past years, a lot of research have been conducted for estimating shortest path methods with the assumption that travel time is deterministic [7] however in reality it remains stochastic. Many transport pricing strategies follow 'system optimum' principle of economics literature whereas it is far from reality as it oversees many transport flow philosophies.

Manuscript received October 12, 2015; revised June 8, 2016.

doi: 10.18178/jtle.4.2.154-159

There are many best practices worldwide for time-dependent congestion charging such as "London Congestion Charging" which varies with day and time of day [8], Stockholm [9] and Valetta [10]. Besides, there are a lot of studies calculating toll as a time dependent variable [11]. W. Vickrey also studied congestion charging as time dependent in theory and practical networks [12]. The total system delay can be maintained at optimal level with pricing strategies [13]. De Palma [14] used a dynamic simulator to compare various congestion charging. Kristofferson also used dynamic simulator SILVESTER for comparing present congestion charging in Stockholm with time carrying toll [15]. This model also divide time into 5 minute interval for microscopic analysis. Similarly there are a number of studies stating the negative impacts of dynamic congestion such as small savings with a huge amount of switching routes [16].

This study aims to estimate congestion toll according to time of day and commuter mode. There are examples available where toll was forced on selective modes and vice versa such as congestion tax exemption for 'energy efficient vehicles' [16]. Many researchers discussed 'third-degree' differentiated pricing where each commuter pays a different toll based on travel attributes [17] and [4]. However, to the best of our knowledge, it the only study in Karachi city where a toll has been calculated as a function of volume, time, travel distance and even transport mode.

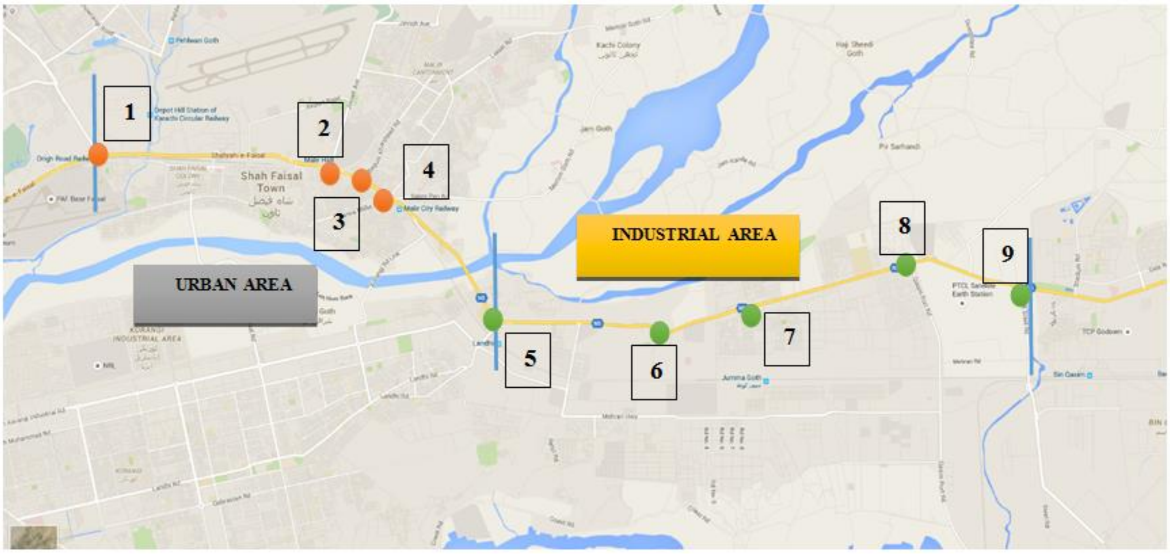

Figure 1. Google image of study area.

III. Study Area

The study area, as mentioned earlier and showed in Fig. 1, was National Highway. The 20 km stretch of National Highway selected was from Airport to Pakistan Steel intersection. The volume data was collected at 9 intersections within study area whereas delay was measured between each intersection as shown in Table I. The first four intersections were classified as Urban while last four intersections were marked as industrial intersections due to activity zones in their locality and largely traffic mix.

TABLE I. Link Length on National Highway

MID BLOCK	Km
STAR GATE – MALIR HALT	2.1
MALIR HALT – MALIR KALA BOARD	0.9
KALA BOARD – MALIR 15	0.7
MALIR 15 - Q.ABAD	3.7
Q.ABAD-YB	1.9
YB – FAST	3.9
FAST – BIN QASIM	4
BIN QASIM – PAKISTAN STEEL	2.8

IV. Data Collection and Processing

The traffic volume data was collected through an instrumented vehicle indigenously developed by NED University of Engineering and Technology with video cameras installed on it. Data collection time period was organized mainly to capture the business and port activities. The data was analyzed through Trazer software in 15 minutes intervals. The delay survey was conducted through floating vehicle method where the study vehicle was equipped with Real Time GPS Tracker. The Tracker supports real time data transfer capability with a lag of not more than 5 seconds.

Based on the delay (accumulated time when vehicle speed was below highway designed speed) [1] additional cost was calculated for each midblock segment. This cost was sub divided into various heads such as Opportunity Cost (OC), Vehicle Operating Cost (VOC) and Wear and Tear cost. VOC was calculated through fuel usage under delay conditions. It was separately estimated for each vehicle type through test surveys under designed conditions. The Table II shows per minute cost (in Rs/h) of fuel for each vehicle type under 'delay' conditions.

By incorporating these figures, Fig. 2 shows the total extra cost on road users for each link separately. Extra cost is the area between blue (cost based on optimized traffic flow) and red (current cost) line which is further used for analysis.

The vertical lines in graph represent total loss in a certain time interval. The graph for the 7th midblock i.e. between Fast University and Port Qasim shows minimum extra cost. This is the largest midblock in the study and therefore provide stability in traffic movement with minimum delay time. Likewise 3rd midblock imposes the most extra cost to commuters while highest cost in free flow condition is for 4th midblock. This difference is a huge amount as it exceeds twice the original cost in many cases. This midblock is further analyzed for minimization of cost. Last section also has low losses due to less amount of traffic because major industries are situated before this intersection.

A sharp change in evident in evening reflecting to peak hour right when the office hours ends.

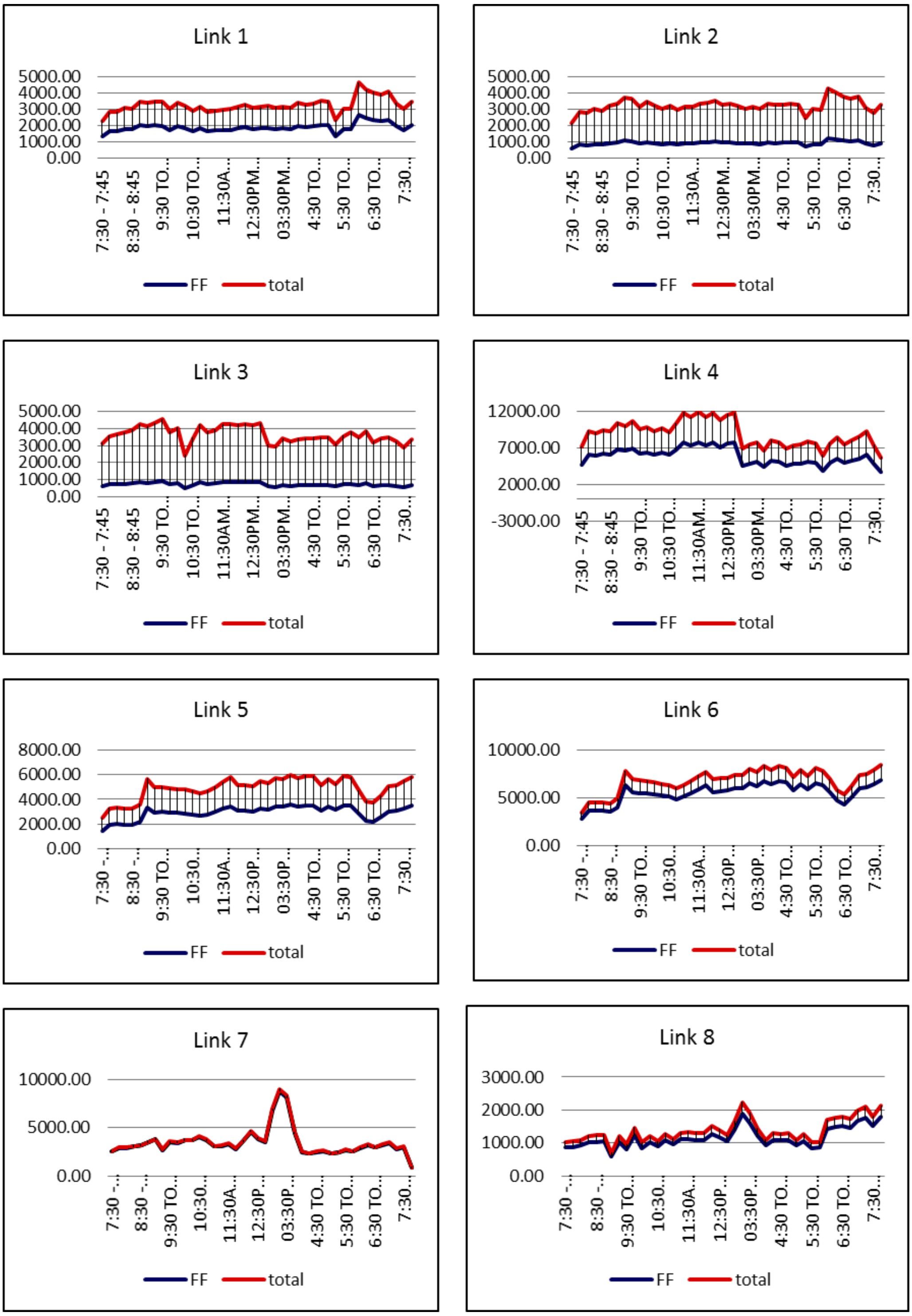

Figure 2. Time based cost at each link for designed and current scenario.

TABLE II. FUEL COST PER MINUTE IN DELAY

Mode	Cars	Bikes	Bus/minibus/van	Suzuki	3-wheelers	Container
Cost	1.75	0.7	5.6	1.75	1	7.5

A. *In-depth Study of Malir Halt - Kalaboard Midblock*

This section was chosen for further analysis due to the highest variation in cost as compared to other sections.

The Table III below shows the percentage increase in cost section depicted from the Table II.

TABLE III. PERCENTAGE INCREASE IN ADDITIONAL COST AT EACH LINK

Midblock	% increase in Cost
1	172
2	343
3	**503**
4	153
5	167
6	123
7	102
8	119

It proves that none of the section at National Highway is working at designed condition but quite below it.

To minimize this cost a toll was calculated at this intersection. This toll was introduced with 'impartiality' among all alternatives. This neutrality is described below. The toll was imposed on private and para transit vehicle and freight transport separately however public transport is excluded. To distribute the cost on this link amongst all modes function stated below was developed.

$$\text{Toll} = \sum_i^m \frac{R_i \times W_i}{V_i} \tag{1}$$

where,

R_i= Rank of mode i according to volume in ascending order,

W_i = weightage of mode i and

V_i = volume of specific Mode i.

This weightage was given according to the stated preference survey for choice and is justified intuitionally as the mode with highest 'rank' was given maximum weightage. This weight has a stochastic nature as it depends on the additional loss for each time interval and type of vehicle with highest volume. Moreover, with the input of additional loss it aims to recover only 'additional cost' which a commuter puts on overall transport system. This should be noted, that this cost is a direct outcome of volume therefore it is profound on volume. In case, there is no vehicle of its category then there is no toll.

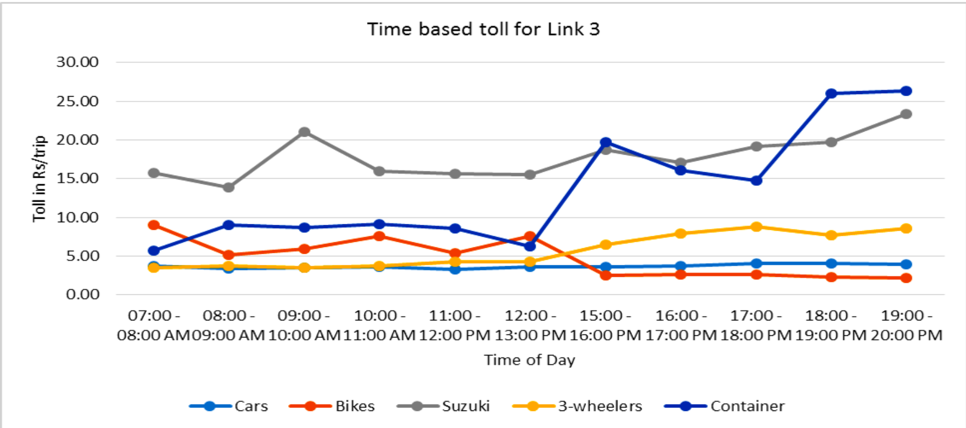

Figure 3. Time based toll variations.

V. RESULTS AND DISCUSSION

Fig. 3 below shows the toll per vehicle for each mode for each time interval. It can be easily notified that the amount is easily justified for one time travel through the section. The length of this section is 0.7 km. The toll for freight transport is higher than private vehicles whereas for para transit it is approximately close as of private vehicle. Highest toll calculated is for tank trucks (also referred as containers) in evening time. The congestion caused by tank trucks are absolutely greater than private vehicles and in evening time where they move in queue the effects are stretched. Therefore this sum is fairly reasonable.

The amount of toll for private vehicles slightly decrease in evening phase and for freight transport it is higher in afternoon. There is high movement of trailers in evening time to and fro port area therefore, this toll is higher in evening phase. This trend is observed for every intersection as cargo is mainly transported at night from industries for many motives. Similarly, in the office hours more movement of private vehicles is seen as reflected from their congestion pricing dynamics. Overall, the combined maximum toll income is also perceived in evening time after 5pm as all office timings are finished and this trend continues till seven in the evening. For Pickups (here referred as Suzuki) the toll amount is relatively higher than other modes and this trend is similar all over the network.

Likewise, this toll was calculated for other intersections in order to produce it for the whole network. Toll shows many variations with vehicle mode and time interval however when imposed over the whole network it is highest for the 4th block. The last two sections are purely industrial sections of National Highway and therefore a minimal toll can be witnessed there in the late hours of the day. Fig. 4 shows the accumulated toll for trip through entire network for all vehicle types during evening (18:00 - 19:00) time interval. Any commuter entering into the network after the first intersection or leaving before the last intersection would have to pay only for the covered sections. In other words, congestion toll is charged only for in-between entry and exit points where a commuter drives. Therefore, making it a function of time of day, mode and distance travelled.

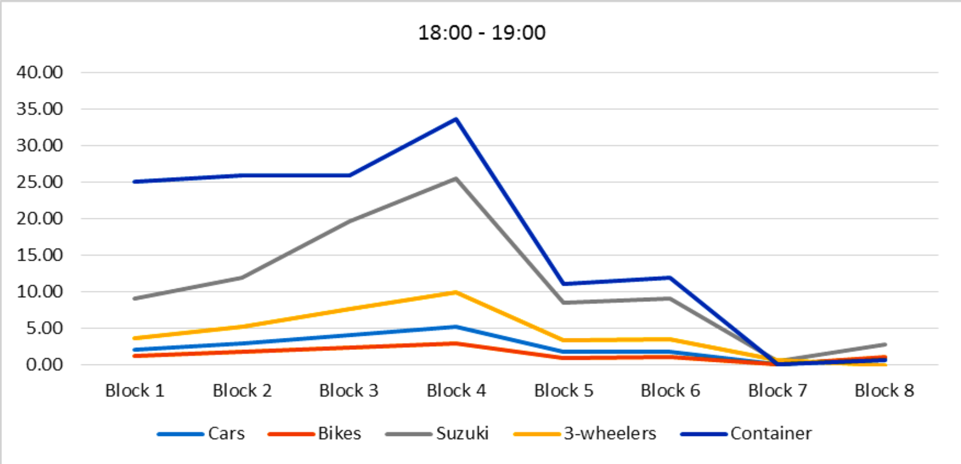

Figure 4. Toll for complete network between 18:00 – 19:00.

With the incorporation of this Toll price, the total link cost (time based) is minimized to optimum level. In addition, this toll is not applied to public transport which travels on the same link and unsegregated. It can be considered as an incentive to opt for public transport in favour of other modes. This phenomenon is applied in practices where priority mode is not charged such as in London and Stockholm [18].

VI. Future Work

This study was conducted at National Highway, however there are many other arterial roads under excessive traffic loads. These sort of studies should be conducted for efficient Urban Traffic Management. Currently, two flyovers are under construction at Malir Halt (Intersection 2) and Kalaboard (Intersection 3) respectively. Once they are under operation, traffic survey should be setup again to investigate the current traffic movements then. This data collected can be used as the base data for before and after studies. On a secondary basis, this study does not take into account Value of Time (VOT) of commuters as it cannot be directly observed however, with the advancements of technologies VOT can also be incorporated as a function of congestion pricing.

Acknowledgement

We would like to acknowledge Indus Motors Company Limited who funded for the Traffic Congestion research project with the collaboration of Department of Urban and Infrastructure Engineering, NED University, Karachi. Besides, we would like to also thank city officials who assisted us at data collection site and undergraduate students who did the video data processing.

References

[1] M. S. Ali, M. Adnan, S. M. Noman, and S. F. A. Baqueri, "Estimation of traffic congestion cost-a case study of a major arterial in Karachi," in *Proc. Fourth International Symposium on Infrastructure Engineering in Developing Countries, Karachi, Procedia Engineering*, December 2013, pp. 37-44.

[2] P. Goodwin, "The economic costs," Discussion Paper, May 2004.

[3] Metropolitan Planning Council, Moving at the speed of traffic congestion, August 2008.

[4] Q. Meng, Z. Liu, and S. Wang, "Optimal distance tolls under congestion pricing and continuously," *Transportation Research Part E: Logistics and Transportation Review*, vol. 48, no. 5, pp. 937-957, 2012.

[5] T. Litman, "London congestion pricing implications for other cities," November 24, 2011.

[6] W. Parry, "Pricing urban congestion," November, 2008.

[7] P. E. Hart, N. J. Nilsson, and B. Raphael, "A formal basis for the heuristic determination of minimum cost paths," *IEEE Transactions on Systems Science and Cybernetics*, vol. 4, no. 2, pp. 100-107, 1968.

[8] J. Leape, "The London congestion charge," *The Journal of Economic Perspectives*, vol. 20, no. 4, pp. 157–176, 2006.

[9] J. Eliasson, L. Hultkrantz, L. Nerhagen, and L. S. Rosqvist, "The Stockholm congestion charging trial 2006: Overview of effects," *Transportation Research Part A: Policy and Practice*, vol. 43, no. 3, pp. 240-250, 2009.

[10] M. Attard and M. Enoch, "Policy transfer and the introduction of road pricing in Valetta, Malta," *Transport Policy*, vol. 18, no. 3, pp. 544-553, 2011.

[11] X. Q. Li, W. Y. Szeto, and M. O'Mahony "Modeling time-dependent tolls under transport, land use, and environment considerations," *Applications of Advanced Technology in Transportation*, pp. 852-857, 2006.

[12] W. Vickrey, "Congestion theory and transport investment," *The American Economic Review*, pp. 251-260, 1969.

[13] J. A. Laval, H. W. Cho, J. C. Muñoz, and Y. Yin, "Real-time congestion pricing strategies for toll facilities," *Transportation Research Part B: Methodological*, vol. 71, pp. 19-31, 2014.

[14] A. D. Palma, M. Kilani, and R. Lindsey, "Congestion pricing on a road network: a study using the dynamic equilibrium simulator METROPOLIS," *Transportation Research Part A: Policy and Practice*, vol. 39, no. 7, pp. 588-611, 2005,
[15] I. Kristoffersson, "Impacts of time-varying cordon pricing: Validation and application of mesoscopic model for Stockholm," *Transport Policy*, vol. 28, pp. 51-60, 2013.
[16] I. Kristoffersson and L. Engelson, "Estimating preferred departure times of road users in a large urban network," in *Proc. European Transport Conference*, Leeuwenhorst Conference Centre/The Netherlands, 2008.
[17] J. Whitehead, J. P. Franklin, and S. Washington, "The impact of a congestion pricing exemption on the demand," *Transportation Research Part A: Policy and Practice*, vol. 70, pp. 24-40, 2014.
[18] M. Zangui, Y. Yin, S. Lawphongpanich, and S. Chen, "Differentiated congestion pricing of urban transportation," *Transportation Research Part C: Emerging Technologies*, vol. 36, pp. 434-445, 2013.
[19] J. O. Jansson, "Public transport policy for central-city travel in the light of recent experiences in congestion charging," *Research in Transportation Economics*, vol. 22, no. 1, pp. 179-187, 2008.

Prof. Dr. Mir Shabbar Ali completed his PhD Degree in Transportation Engineering from University of Birmingham, UK. He is currently Chairman and Prof. at Department of Urban and Infrastructure Engineering, NED University of Engineering and Technology, Pakistan. He has successfully completed projects on transport mobility and Road Safety. He is a life time member of Institute of Engineers Pakistan since 1996. His research interests include Transportation Planning, Travel Demand Modelling. He has over 25 refereed Conference and Journal publications.

Dr. Muhammad Adnan recently completed his Postdoc from National University Singapore (NUS) under supervision of Moshe Ben Akiva, before that he accomplished his PhD Degree in Transportation Modelling from Institute for Transport Studies (ITS), University of Leeds, UK. He has expertise in mode choice modelling. His research interest includes activity based modelling and transport network analysis.

Syed Fazal Abbas Baqueri earned his Bachelor degree in civil Engineering from NED University of Engineering and Technology, Pakistan in 2011. He also did Masters in Transportation Sciences from Hasselt University, Belgium. He is currently enrolled in PhD program at Transportation Research Institute, Hasselt University, Belgium. He has also worked as a Research Assistant at NED University of Engineering and Technology. His research interests include activity based travel demand modelling and Land use and Transportation interaction models.