Integrating Road Pricing into Urban Traffic Management Systems on Saddar Road Rawalpindi Pakistan

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Abstract

Congestion is one of the most problematic concerns that cities experience currently, and Rawalpindi – Pakistan is not an exception. The roads of Rawalpindi especially in the Saddar area have turned into one of the worst places for commuters as well as for city authorities and managers. The area concentrated with commercial centres, wholesale markets, government and private offices experiences a very high traffic density resulting in longer travel times, higher fuel consumption and more emissions. Therefore, this study considers road congestion pricing as an appropriate strategy for confronting this problem proactively since it is based on demand-side management using the software; VISUM. The study is aimed at helping policy makers early on develop equitable and workable road pricing. This can reduce traffic volume and discourage usage of private vehicles on roads by using private cars or even any other forms of transport in time slots, hence showing 8.3% reduction of volume when charges were implemented in the study period for car users and light transport vehicles. Equally promising is the financial impact: an estimated PKR 67 billion annually through road pricing, which is an enormous source for reinvestment into urban transport infrastructure, such as developing reliable public transport systems, improving road quality, and modern toll collection. This is where current developments in road pricing come in — to demonstrate how this transport management tool can have impacts on one of Rawalpindi's important urban routes before cautious endorsement is given to embracing this particular solution for improving sustainable accessibility without disadvantaging people.

Keywords: Road Pricing; VISUM; traffic Congestion; Fuel Consumption; Sustainable Transportation; traffic management.

1. Introduction

Congestion pricing (CP) a strategy aimed at reducing traffic congestion through toll charges on road usage has gained popularity worldwide for its ability to alleviate traffic flow issues and encourage the use of transportation while generating revenue for infrastructure enhancements [1,2]. However, in the context of Pakistan's political and economic challenges [3,5] thorough evaluation is essential to determine the practicality of implementing such a system, in the country. Various factors such, as disparities affecting movement patterns and the unreliability of public transportation systems contribute to transportation challenges in areas. Increased traffic is often seen in Pakistani cities, especially Karachi, Lahore and Rawalpindi where the road systems are not built to withstand such heavy volume of vehicles, along with ineffective vehicle control methods that have

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created near-permanent gridlock on many roads as well a lack of reliable method of public transport. These problems have been compounded by rising car ownership, accelerating urbanization, and under-investment in public transport — with colossal economic losses, more severe air pollution, and reduced quality of life as the result. [2,4].

Rising urbanization in less developed countries such as Pakistan is increasing the difficulties associated with the movement of people and goods as well as the development of urban infrastructure. Rawalpindi, one of the largest urban centers in Pakistan, which is a city bordering Islamabad, has considerable traffic-related problems that threaten the country's economy and environment [1-3]. The easterly direction on this road, starting from Saddar area to The Post Office, still is an intersection of its key congested arteries. Fumes, inadequate public transport, noncompliance with restrictions on parking, and the overwhelming addition of cars are the main reasons for congestion [2,5]. Although the corridor facilitates traffic flows of private commuters and commercial traffic, it is evident that persistent congestion increases the commuting time, fuel consumption, and worsens air quality [3]. A series of traffic management measures including road widening, flyover building and signal timing optimization have been used in Rawalpindi. However, these measures have only provided short term measures, as the increased degree of urbanization and increase in car ownership has quickly zeroed the advantages provided [4,5]. The target that these standard measures were aimed at namely the improvement of urban mobility in the longer run has not been achieved. Thus there is the clear necessity to come up with a systematic and innovative approach to traffic management [6] Despite being a recent phenomenon internationally, road pricing has revealed itself as a viable method for demand management, energy regulation, and congestion reduction [7]. Road pricing is a tolling regime that allows road users or transients to pay on an impeded basis for peak access to certain roads or urban areas in order to discourage excess trips and promote the use of other forms of transport, such as public transport, cycling and walking [8]. The implemented measure has already proven its effectiveness in Singapore, London, and Stockholm. The electronic road pricing in Singapore which was first instituted in the late nineties has been able to cut the traffic volumes in peak hours by almost 15% consistently [9]. In the central London congestion charge zone traffic was reduced by about 20% in the area while the charge also provided funds for investment in public transport improvements [10]. The introduction of a congestion tax in Stockholm has also been associated with significant reductions in traffic volumes and in emissions of greenhouse gases, further suggesting the good environmental effects of the policy [11].

2. Literature Review

The introduction of modern traffic modelling tools (VISUM software) and four-stage travel demand models have transformed the planning and assessment of road pricing schemes. Such tools enable policymakers to put several models into practice, including distance, time and flat rate measures, thereby enabling choices based on data [12]. For example, Melbourne used VISUM to evaluate efficiency of distance – based tolling, the results expressed a decrease of congestion and emissions as well as higher public acceptance in the future [13]. Likewise, case of Delhi helped in understanding the travelling demand models as an effective tool in explaining the commuter behaviour and need for city specific solutions to cater crowded population tract [14]. Though, road pricing was identified accurate in other parts of the world, its application in Pakistan is relatively new. Past research on traffic congestion in Rawalpindi has considered the problem in a structural perspective of Physical Infrastructure & Emission without explaining the behavioural changes that arise from the implementation of economic tools such as Road Pricing [15]. Currently, use of car is high due to socio-economic disparities, reliance on private car, and limited public transport are some issues, which may influence the implementation of Road Pricing in Rawalpindi [16]. All these contextual variables must be taken into consideration in order to guarantee feasibility and fairness of any offered solution [17]. The purpose of this research is to implement the concept of road pricing in Rawalpindi traffic management system with special reference to Saddar Road. Through the analysis with the help of VISUM software, the changes in pricing policies are discussed and their effects on congestion, emission and travelling behaviour of users are estimated [18]. Also, commuter attitude and stakeholder engagement studies offer information on willingness to pay, tolerance level, and perceived as hindrances to adoption of the concept [19]. Thus, this research formulated below aims at designing a sustainable and equitable model of traffic management to be implemented in Rawalpindi by employing a multiple-dimensional perspective. It is believed that the discovery of this research work will be imposing greatly to the existing theory in the management of traffic in urban areas in developing countries. In addition to relieving congestion, road pricing can bring about behaviour change, incentivise sustainable transport, and raise funds for investment in public transport [21]. However, they require efficient public transported networks, good policies, and public uptake for them to register success and serve everybody in the community equitably [22]. This research has sought to employ modern traffic modelling approaches and benchmarking of the best practices in the world to come up with some key policy and practical implications to progress the way to a more efficient and sustainable urban transport system in Rawalpindi. Here's a structured literature review in a table format for better clarity presented in Table-01.

Table.01nstructured literature review in a table format for better clarity:

Study	**Country of Study**	**Focus**	**Methodology**	**Key Findings**	**Relevance to Current Study**	**Software Used**	**Payment Method Applied**
Ahmed et al. [9]	Pakistan	Traffic congestion and air pollution in Lahore.	Analysis of traffic flow and air quality data.	Identified key congestion points in Lahore; highlighted environmental impacts of traffic congestion.	Provides insights into congestion challenges specific to Pakistan.	Not Applicable	Not Applicable
Khan et al. [2]	Pakistan	Traffic congestion in urban Pakistan.	Case study of Rawalpindi; interviews with commuters.	Highlighted poor road infrastructure and high vehicle dependency as primary causes of congestion.	Offers context-specific analysis of Rawalpindi's traffic issues.	Not Applicable	Not Applicable

Farooq et al. [15]	Pakistan	Evaluating urban traffic management in Pakistan.	Case study on urban transport policies in Karachi.	Recommended integration of public transport with road pricing to address congestion effectively.	Provides policy recommendations relevant to road pricing strategies.	Not Applicable	Not Applicable
Ali et al. [21]	Pakistan	Public transport alternatives in Rawalpindi.	Survey-based analysis of commuter preferences.	Highlighted gaps in public transport systems and willingness of commuters to shift to reliable options.	Reinforces the need for improved public transport alongside road pricing.	Not Applicable	Not Applicable
Raza & Ahmed [31]	Pakistan	Road pricing as a solution for urban congestion.	Simulation-based analysis of road pricing in Lahore.	Found significant reduction in vehicle usage with distance-based tolling; emphasized public acceptance.	Demonstrates the potential of road pricing in Pakistani cities.	Custom Model	Distance-based
Jamil et al. [32]	Pakistan	Behavioral impacts of tolls on commuters.	Behavioral surveys conducted in Islamabad.	Identified economic concerns and preferences for alternatives like carpooling and public transit.	Highlights behavioral factors critical to implementing tolls.	Not Applicable	Flat-rate
Hussain & Khan [33]	Pakistan	Environmental benefits of road pricing.	Case study on emissions reduction in Karachi.	Found significant reductions in CO2 and PM2.5 emissions with tolling; emphasized need for enforcement.	Reinforces the environmental case for road pricing in Pakistan.	Not Applicable	Time-based
Al-Momani & Al-Mashaqbeh [1]	Jordan	Evaluating toll road strategies in Amman, Jordan.	Micro-simulation using VISUMsoftware and survey data.	Road pricing reduced congestion and emissions; distance-based tolling preferred by 54% of users.	Highlights VISUM's application and effectiveness of distance-based pricing.	VISUM	Distance-based

Brown et al. [9]	Australia	Road pricing in Melbourne as a traffic management tool.	Pilot simulation study and behavioral survey in Melbourne CBD.	Achieved 11% reduction in vehicle count and 13% reduction in emissions with distance-and-time-based tolls.	Demonstrates the environmental and behavioral impacts of road pricing strategies.	VISUM	Distance-and-time-based
Gupta & Sharma [10]	India	Travel demand modeling in Delhi, India using four-stage model.	Household surveys and VISUM-based modeling.	Effective simulation of traffic demand for 2014 and 2021; provided insights for urban planning.	Validates the use of VISUMfor travel demand modeling in urban areas.	VISUM	Not Applicable
Ortúzar & Willumsen [4]	Global	Fundamentals of transport modeling.	Comprehensive review of travel demand modeling techniques.	Highlights four-stage modeling process: trip generation, distribution, modal split, and traffic assignment.	Provides theoretical foundation for the modeling approach.	Not Applicable	Not Applicable
Rahman et al. [5]	Bangladesh	Four-stage modeling in Dhaka city, Bangladesh.	Developed a simplified transport network model.	Identified trip distribution patterns and traffic assignment challenges in congested urban areas.	Shows applicability of four-stage modeling to South Asian cities.	Custom Model	Not Applicable
Wang et al. [6]	Global	Systematic review of road pricing impacts.	Reviewed empirical studies on pricing strategies worldwide.	Road pricing effectively manages congestion; acceptance depends on revenue allocation and transparency.	Reinforces the importance of public acceptance and equity in pricing strategies.	Not Applicable	Various
Zhang et al. [7]	China	Integrating road pricing and traffic demand management using VISUM.	VISUM-based simulations with varying pricing scenarios.	Found distance-and-time-based pricing most effective; recommended public transport improvements.	Demonstrates VISUM’s role in integrating pricing with demand management.	VISUM	Distance-and-time-based

Zhao & Li [8]	Global	Behavioral impacts of road pricing.	Analysis of empirical studies on user responses to pricing.	Behavioral shifts include reduced trips and increased public transport use; equity remains a challenge.	Highlights behavioral dynamics relevant to implementing road pricing.	Not Applicable	Not Applicable
Chen & Zhou [10]	China	Environmental benefits of road pricing in Beijing.	Case study using emission models.	Significant reductions in CO2 and NOx emissions; effectiveness linked to enforcement and compliance.	Supports the environmental argument for road pricing in urban areas.	Emission Models	Flat-rate

3. Research Methodology

3.1 Study Area

There are many cities in Pakistan with congestion traffic issues like big cities such as Karachi, Lahore, Peshawar, Quetta and Islamabad but Rawalpindi is chosen as the study area of this study due to current issue of bad air quality index (AQI) or in simple words, smog. Although many reasons are presented as the cause of this smog such as crops burning in rural Rawalpindi and Indian Punjab, however, the root cause of this life-threatening phenomenon is vehicular emission of hazardous gases, because the AQI of Rawalpindi was recorded normal in the days of Corona pandemic when the transport was limited to miniscule on the roads. Therefore, congestion pricing study is immediately required for Rawalpindi to mitigate the smog threat. Moreover, When the city was decided for this study, two factors were focused i.e. availability of traffic data for four-step travel demand modelling (TDM) and the presence of frequent traffic congestion in the city's hotspots of traffic flow.

The traffic data such as vehicular details, average household size and details of trips covered by the commuters in the city, modes of travel and types of vehicles assigned for different trips were acquired from different sources such as traffic reports, National Traffic Research Centre (NTRC), Pakistan Bureau of Statistics (PBS) and research papers. According to PBS report 2023, Rawalpindi covers a total area of 5285 sq.kms and has a population of 6,118,911 persons. Population density of the city is 1158 per Sq. Km [34]. Similarly, NTRC (2024) report provides the data on number and types of vehicles owned by people in Punjab, for example, the majority (1456098) vehicles are motorcycles or scooters and 115,576 are motor cars; along with other types of vehicles [35]. Other NTRC Research studies provided in-depth knowledge of Origin-Destination (O-D) matrix and freight transport (trucking) for Rawalpindi district. According to the Global Air Quality Index City Rankings, Rawalpindi's Air Quality Index (AQI) forecast presently ranks 226th globally [36].

Therefore, in order to mitigate the pollution caused by traffic flow in these localities, detailed congestion pricing research must be carried out. With 17.12 fatalities per 100,000 people, Pakistan is ranked 95th in the world for road safety (World Health Rankings, 2021). The automobile growth rate in Rawalpindi city, which is 2.10% annually (2017 to 2013), is a concerning scenario [37]. The number of cars has significantly expanded due to increased urbanization and urban population expansion, which has resulted in capacity challenges on roadways to handle the expanding number of vehicles.

Figure 1: Map of Study Area (Rawalpindi Saddar) with Zones 1, 2 and 3

Fig Z N addar Region)

3.2 Data Collection & Model Setup

This study purpose is to evaluate the feasibility of congestion pricing in Rawalpindi, focusing on Zones 1 (PC Chowk), 2 (Murree Chowk), and 3 (Saddar Region). In this study, advanced Four-Step Travel Demand Modeling (TDM) is used and supported by traffic simulation software like PTV VISUM, the methodology section evaluates traffic behavior, congestion levels, and the effects of introducing tolls in the study area. The study area includes a high-density traffic route, with significant vehicular flows observed at Zone 1 - PC Chowk, Zone 2 - Murree Chowk, and Zone 3 - Saddar Region. This study area links key commercial zones and residential areas, making it critical for day-to-day travelling. Existing data discloses regular bottlenecks and extended delays during peak hours, predominantly due to inadequate road infrastructure, diverse traffic flow, and inefficient traffic management.

Key characteristics of the study area include:

- Zone 1 (PC Chowk): A critical junction with high commercial and transit activity.
- Zone 2 (Murree Chowk): A primary link for traffic connecting Saddar to other parts of Rawalpindi and Islamabad.
- Zone 3 (Saddar Region): The central business district of Rawalpindi, with dense traffic volumes and mixed land use.

The spatial configuration of the area, visualized through OpenStreetMap and simulated in VISUM software, highlights the necessity for congestion management strategies such as congestion pricing.

3.2.1 Data Collection

Extensive data collection forms the foundation of this study, enabling accurate modeling and scenario analysis.

Traffic Data:

Traffic volume counts, speed measurements, and vehicle classifications data is collected during peak hours at each zone. Historical traffic data collected from the National Traffic Research Centre (NTRC) supplements this information.

Origin-Destination(O-D) Data:

Surveys and GPS tracking are used to develop an O-D matrix for the study area. The matrix records trip movements between zones, recognizing significant travel patterns and congestion points. The matrix is vital for simulating traffic redistribution post-toll implementation.

Demographic Data:

Socio-economic data, including income levels, vehicle ownership, and household characteristics, is obtained from the Pakistan Bureau of Statistics. This data is critical for mode choice analysis, ensuring that impartiality considerations are integrated into congestion pricing policies.

3.2.2 Four-Step Travel Demand Modelling (TDM)

The Four-Step TDM in VISUM is used to simulate the existing traffic network and scenario for congestion pricing.

Step 1: Trip Generation; Trip generation calculates the number of trips produced and attracted in each zone. The Saddar Region (Zone 3), with its dense commercial and retail activities, emerges as the highest trip generator. PC Chowk and Murree Chowk primarily attract transit and residential trips. Data from surveys and roadside counts feed into VISUMfor trip generation analysis, identifying the trip productions and attractions in each zone.

Step 2: Trip Distribution; Trip distribution models the movement of trips between the zones using a Gravity Model in VISUM. The O-D matrix visualizes these movements, showing the strongest trip connections between Zones 1 and 3 due to commercial activity. The introduction of tolls is expected to redistribute trips, with drivers avoiding tolled routes and shifting to alternate roads or travel modes.

Step 3: Mode Choice; Mode choice analysis evaluates the shift in traveller preferences between private vehicles, buses, and LTVs under congestion pricing. Before toll implementation, the majority of trips are made by private vehicles. Post-toll implementation, VISUM simulations show a significant shift to buses and shared mobility options.

Step 4: Route Assignment; Route assignment determines the redistribution of trips across the network post-pricing. Traffic assignment in VISUM reveals that tolled routes experience reduced traffic volumes, while alternative routes handle increased flows. This redistribution alleviates congestion in key zones while maintaining overall network efficiency.

3.2.3 Scenario Development and Analysis

The study evaluates the following congestion pricing scenario:

Flat Fee Model: Fixed tolls for cars (PKR 200) and LTVs (HiAce and coasters) (PKR 100) applied uniformly during the whole day across Zones 1, 2, and 3.

The impact of these scenarios is assessed across key metrics:

- Traffic flow improvements (volume reductions in peak-hour traffic).
- Modal shifts (increase in bus and shared mobility usage).

- Emissions reductions (lower PM2.5 and NOx levels).
- Revenue generation and reinvestment potential.

3.2.4 Data Visualization and Analysis

Geospatial analysis through GIS tools visualizes congestion hotspots, traffic redistribution patterns, and emissions zones. Pre- and post-toll OD matrices and traffic assignment maps generated in VI-SUMhighlight the spatial impacts of congestion pricing on the network.

4. Results and Discussion

The software used to perform the traffic modelling in this study is PTV VISUM 25 where open street map of the study area was imported into the software and nodes, links (roads) and zones (1,2 & 3) were defined as shown in figure 5. The vehicles considered for this study were public transport (PuT) i.e. Buses and private transport (PrT) i.e. Cars and Commercial Vehicles. The peak hours traffic count of the vehicles on the roads was obtained from literature and divided by K-factor for Urban Transport i.e. 0.093 to obtain the daily traffic count. Figure 6 shows the peak hour traffic count between the zones in VISUM. It is clearly visible from the figure that the traffic load is highest between PC chowk and Saddar during peak hours and commuters have to face congestion on the roads.

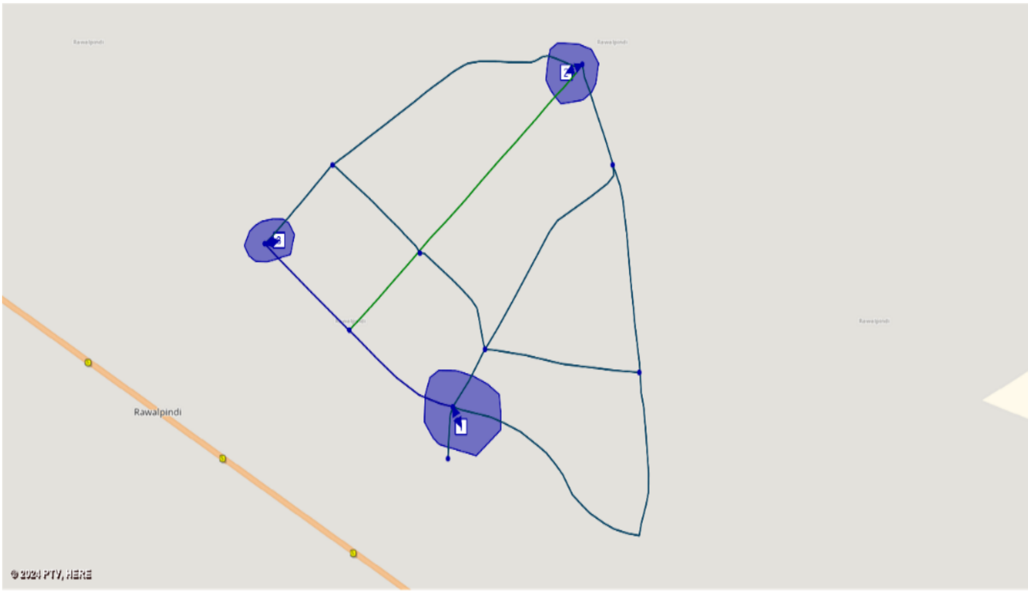


Figure 5: Open Street Map of Study Area with Zones in VISUMSoftware

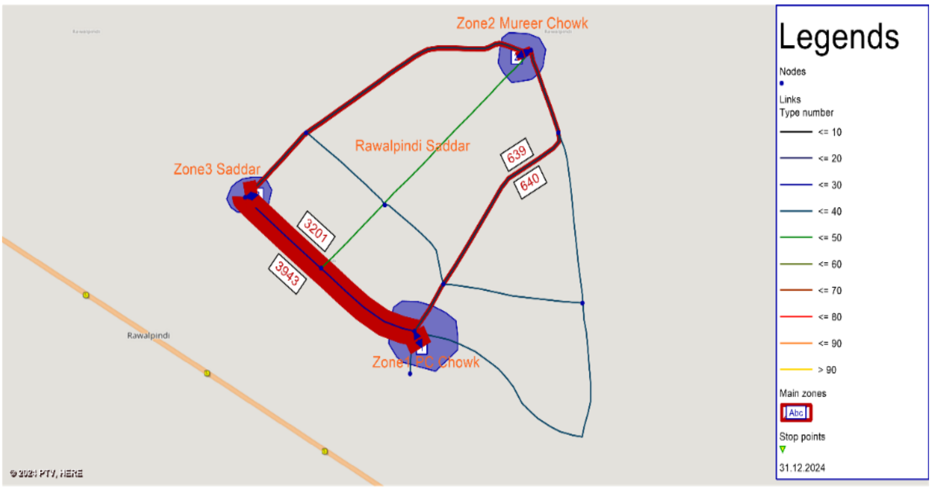
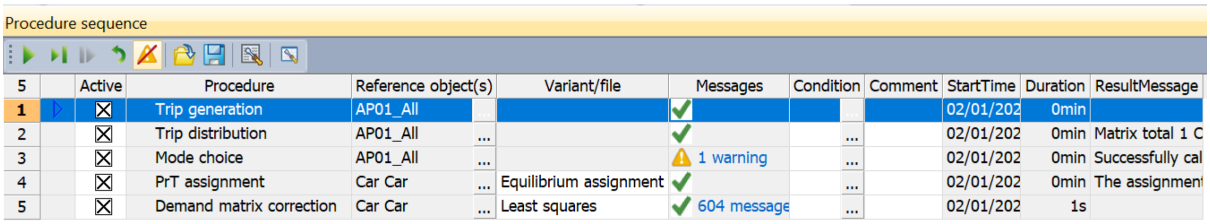


Figure 6: Study Area with Peak Hour Traffic Count

4.1 Four Step Travel Demand Modelling (TDM):

Travel demand modelling is important in transportation planning to provide new and efficient transportation systems and to improve the existing systems. One simplest model is four-step travel demand model that is used on a large scale by policymakers and practitioners. Before evaluating the feasibility of congestion pricing or road pricing to reduce the traffic congestion in the study area, it was important to develop standard 4-step travel demand modelling for the existing road network, including zones, in VISUM so that we could apply toll charges on the respective vehicles on the roads on daily basis and see the amount of reduction in the traffic count on the roads. Figure 7 shows the successful execution of this type of modelling in which trip generation, trip distribution, mode choice and traffic assignment were executed in an order, one after the other.


Procedure sequence

5	Active	Procedure	Reference object(s)	Variant/file	Messages	Condition	Comment	StartTime	Duration	ResultMessage
1	☒	Trip generation	AP01_All		✓			02/01/202	0min	
2	☒	Trip distribution	AP01_All ...		✓	...		02/01/202	0min	Matrix total 1 C
3	☒	Mode choice	AP01_All ...		⚠ 1 warning	...		02/01/202	0min	Successfully cal
4	☒	PrT assignment	Car Car ...	Equilibrium assignment	✓	...		02/01/202	0min	The assignment
5	☒	Demand matrix correction	Car Car ...	Least squares	✓ 604 message	...		02/01/202	1s	

Figure 7: Successful procedure sequence of 4-step TDM in VISUM

Figure 8: Study Area after 4-step TDM

The reddish lines among the zones in figure 8 show the amount of traffic assignment from one zone to the other zone after running the four step TDM in VISUM. The steps are explained below.

4.1.1 Trip Generation

It Is the process of determining the number of trips that will begin or end in each traffic analysis zone within a study area. This is used to develop a relationship between trip end production or attraction and land use. Trip generation is a general term used in the transportation planning process to cover the field of calculating the number of trip ends in a given area. Factors influencing the trip production and attraction include income level of families, car ownership, family size and composition, land use characteristics, distance of the zone from town center and accessibility to public transport system. First step of a standard 4-step modelling is trip generation which tells the number of trips being produced from and attracted towards a particular zone. Figure 9 shows the productions and attractions for each zone under study. These are calculated using VISUM software after putting population and household size of each zone into the software. The population of zone 1, zone 2 and zone 3 were taken as approximately 100000, 80000 and 120000 respectively while the household size of Rawalpindi is around 7 (Pakistan Bureau of Statistics, 2017).

Number: 3	Zone	Productions	Attractions
1	1	500042.00000000	420040.60000000
2	2	400042.00000000	336061.87255461
3	3	600042.00000000	504019.32744539

Figure 9: Productions and Attractions of trips in each zone

Maximum production of trips 600042 are originating from zone 3 and maximum attraction of trips 504019 are also towards zone 3 which shows that the zone 3 Saddar is highly active zone among all three zones in Rawalpindi Saddar while zone 2 is producing least number of trips 400042 and attracting lowest number of trips 336062. Zone 1 stands in between other two zones to produce and attract trips with 500042 productions and 420040 attractions. Overall, the amount of productions and attractions of trips among the zones is very high showing the immense degree of congestion on roads.

4.1.2 Trip Distribution

Trip distribution is a process by which the trip generated in one zone are allocated to other zones in the study area. These trips may be within the study area (internal – internal) or between the study area and area outside the study area (internal – external). The trips within study area are calculated in this study and internal-external trips are ignored.

After trip generation analysis in VISUM, next was finding that how these trips between zones were distributed and what is the specific number of trips between two specific zones. Figure 10 shows the Origin-Destination matrix for trip distribution among the three selected zones. The 0 diagonal values in the matrix shows the absence of trips within a single zone and this is the reason why sum of trips for a single zone is less than the productions at that zone. For example, total production at zone 1 is more than 5 lac however sum of trips in OD matrix is less than that i.e., 333361. The number of trips from PC Chowk to Mureer Chowk are 133356 and 133347 vice versa; PC Chowk to Saddar are 200005 trips and 200014 vice versa; and Mureer Chowk to Saddar are 160007 trips and 160025 trips vice versa.

3 x 3			1	2	3
	Name		PC Chowk	/lureer Chow	Saddar
		Sum	333361.33	293381.39	360012.61
1	PC Chowk	333361.33	0.00	133356.20	200005.14
2	Mureer Chowk	293354.80	133347.33	0.00	160007.47
3	Saddar	360039.20	200014.00	160025.20	0.00

Figure 10: OD Matrix Trip Distribution

Matrix editor (Matrix '1 OD')

3 x 3			1	2	3
	Name		PC Chowk	Mureer Chowk	Saddar
		Sum	679376.65	480546.52	714749.26
1	PC Chowk	668649.71	0.00	207094.80	461554.91
2	Mureer Chowk	460342.25	207147.90	0.00	253194.35
3	Saddar	745680.47	472228.75	273451.72	0.00

Figure 11: OD Matrix After 4 step TDM

Matrix editor (Matrix '1 OD')

3 x 3			1	2	3
	Name		PC Chowk	Mureer Chowk	Saddar
		Sum	575921.76	407513.37	605855.97
1	PC Chowk	566830.53	0.00	175655.97	391174.56
2	Mureer Chowk	390382.39	175700.97	0.00	214681.42
3	Saddar	632078.19	400220.79	231857.39	0.00

Figure 12: OD Matrix after toll applied

The OD matrix after four step travel demand modelling is shown in figure 11 where maximum number of trips originated and destined are from PC Chowk to Saddar (426364 and 436224) which shows the high level of congestion on this road but a significant reduction in the number of trips originated and destined between these two zones are calculated when a toll is applied on cars and LTVs (Hiace and Coasters), as visible in figure 12. Similarly, the trips originated and destined among other zones are also reduced as you can see by comparing figure 11 and figure 12.

4.1.3 Mode Choice

Modal Split is that aspect of the demand analysis process that determines the distribution of trips (number or percentages) in different transportation modes between zones. Its values depend on factors such as the traveller's income and the availability of transit service. The third step in the modelling is mode choice of the commuters when they travel between any two zones, and it is influenced by different factors. Factors affecting modal split are characteristics of trips (trip purpose, trip length), household characteristics (Income, car ownership, family size and composition), zonal characteristics (residential density, concentration of workers) and network characteristics (accessibility ratio, travel time ratio, travel cost ratio). Figure 13 shows the number of respective commuters that use public transport or Buses to travel between any two zones while figure 14 shows the same thing but after the toll charges have been applied. If we compare figures 13 and 14, we can see that the commuters are inclined towards the use of public transport or buses because mode choice of people using buses is increased after the toll is applied in VISUM.

Matrix editor (Matrix '2 Mode choice AP01_All x B')

3x3			1	2	3
	Name		PC Chowk	Mureer Chowk	Saddar
		Sum	247639.85	217940.46	267437.94
1	PC Chowk	247639.85	0.00	99064.60	148575.24
2	Mureer Chowk	217920.71	99058.02	0.00	118862.69
3	Saddar	267457.69	148581.83	118875.86	0.00

Figure 13: OD Matrix for Mode Choice Bus before toll

Matrix editor (Matrix '2 Mode choice AP01_All x B')

3x3			1	2	3
	Name		PC Chowk	Mureer Chowk	Saddar
		Sum	209541.41	184411.16	226293.64
1	PC Chowk	209541.41	0.00	83823.90	125717.51
2	Mureer Chowk	184394.45	83818.32	0.00	100576.12
3	Saddar	226310.35	125723.09	100587.27	0.00

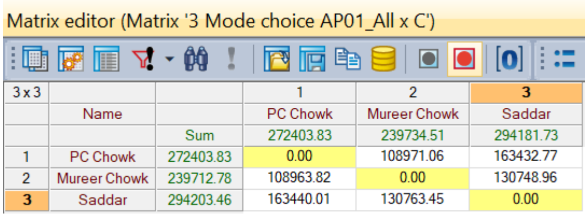
Figure 14: OD Matrix for Mode Choice Bus after toll

On the other hand, the mode choice Cars and LTVs by the travellers is reduced when the toll is applied. This is visible from figures 15, 16, 17 and 18 where it can be clearly seen that the number of trips among zones for mode choices cars and LTVs are decreased after toll.

Matrix editor (Matrix '3 Mode choice AP01_All x C')

3x3			1	2	3
	Name		PC Chowk	Mureer Chowk	Saddar
		Sum	321931.80	283322.60	347669.32
1	PC Chowk	321931.80	0.00	128783.98	193147.82
2	Mureer Chowk	283296.92	128775.42	0.00	154521.50
3	Saddar	347695.00	193156.38	154538.62	0.00

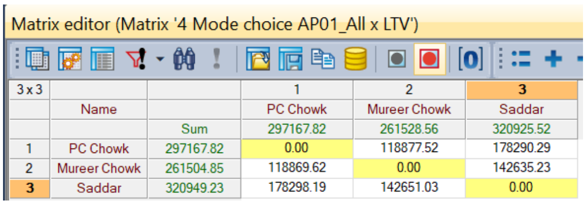
Figure 15: OD Matrix for Mode Choice Car before toll



Matrix editor (Matrix '3 Mode choice AP01_All x C')

3x3			1	2	3
	Name		PC Chowk	Mureer Chowk	Saddar
		Sum	272403.83	239734.51	294181.73
1	PC Chowk	272403.83	0.00	108971.06	163432.77
2	Mureer Chowk	239712.78	108963.82	0.00	130748.96
3	Saddar	294203.46	163440.01	130763.45	0.00

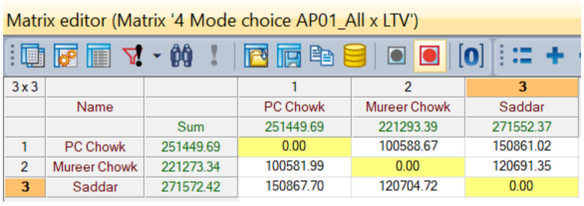
Figure 16: OD Matrix for Mode Choice Car after toll



Matrix editor (Matrix '4 Mode choice AP01_All x LTV')

3x3			1	2	3
	Name		PC Chowk	Mureer Chowk	Saddar
		Sum	297167.82	261528.56	320925.52
1	PC Chowk	297167.82	0.00	118877.52	178290.29
2	Mureer Chowk	261504.85	118869.62	0.00	142635.23
3	Saddar	320949.23	178298.19	142651.03	0.00

Figure 17: OD Matrix for Mode Choice LTV before toll



Matrix editor (Matrix '4 Mode choice AP01_All x LTV')

3x3			1	2	3
	Name		PC Chowk	Mureer Chowk	Saddar
		Sum	251449.69	221293.39	271552.37
1	PC Chowk	251449.69	0.00	100588.67	150861.02
2	Mureer Chowk	221273.34	100581.99	0.00	120691.35
3	Saddar	271572.42	150867.70	120704.72	0.00

Figure 18: OD Matrix for Mode Choice LTV

Figure 19 below shows the toll charges being applied on cars and light traffic vehicles in VISUM. The charges are supposed to be 200 Rupees for Cars and 100 Rupees for LTVs in this study. There are no charges applied on public transport and high occupancy vehicles (HOVs) to encourage people towards these modes of travel in order to reduce the congestion on roads. Moreover, bikes are also excluded from implementation of charges because it is a common practice in Pakistan to find escape routes by bikers.

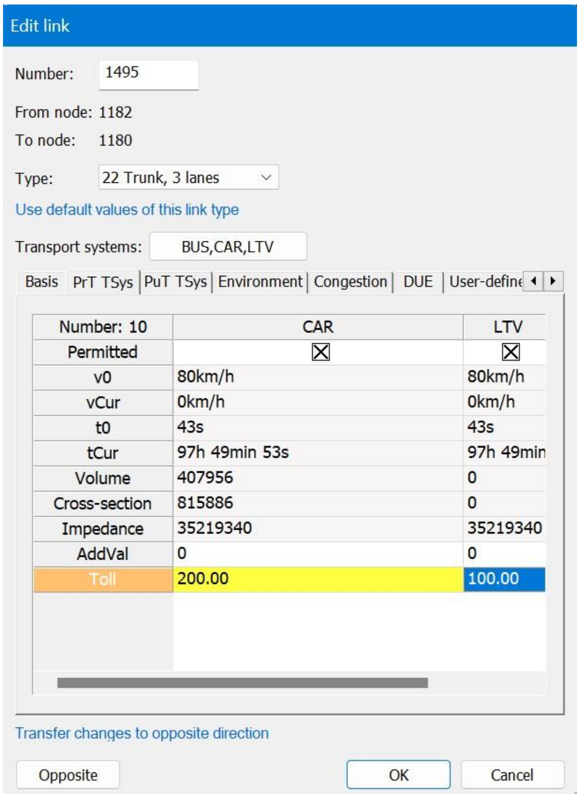


Figure 19: Application of Toll in VISUM (Car=200 Rs. And LTV=100 Rs.)

4.1.4 Traffic Assignment

The final step in the forecasting process is trip assignment. It is performed to determine the actual street and road routes that will be used and the number of vehicles that can be expected on each road segment. Traffic assignment is the stage in the transportation planning process where in the trip interchanges are allocated to different parts of the road network forming the transportation system. In this stage, the route to be travelled is determined and the inter-zonal flows are assigned to the selected routes. There are various types of traffic assignment techniques but the one that is used in this study is most frequent, called equilibrium assignment. The user equilibrium assignment is based on Wardrop's first principle, which states that “no driver can unilaterally reduce his/her travel costs by shifting to another route”. In this approach, all possible routes eventually reach a state of equilibrium.

The last step of the modelling is traffic assignment that means the decision taken by the commuters to travel on which link of road network suitable for them. Figure 20 shows the traffic assignment among zones after the modelling and before the toll charges applied in VISUM. The traffic count from zone 1 to zone 2 is 329569 and from zone 2 to zone 1 is 329538; zone 2 to zone 3 is 374546 and zone 3 to zone 2 is 374513; and zone 3 to zone 1 is 489517 and zone 1 to zone 3 is 489548.

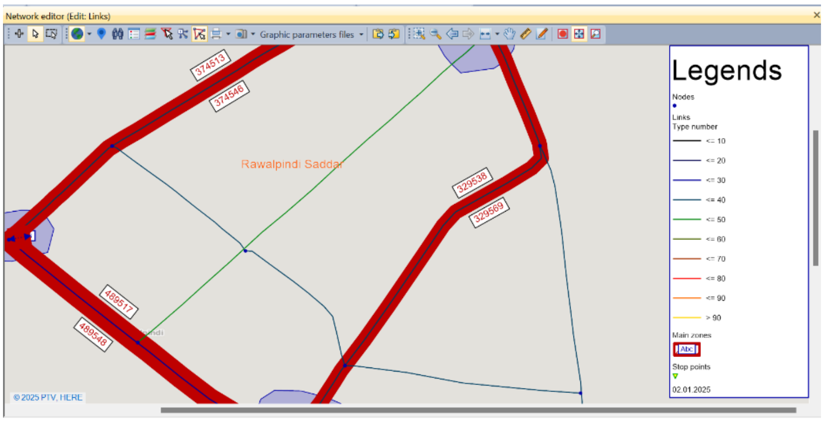


Figure 20: Traffic Assignment among zones before congestion pricing

Figure 21 shows the traffic assignment among three zones after the congestion pricing or toll charges are applied in VISUM. The traffic count on the roads is significantly reduced i.e., from zone 1 to zone 2 is now 302105 and zone 2 to zone 1 is 302076; zone 2 to zone 3 is 343334 and zone 3 to zone 2 is 343304; and from zone 3 to zone 1 is 448724 and zone 1 to zone 3 is 448752.

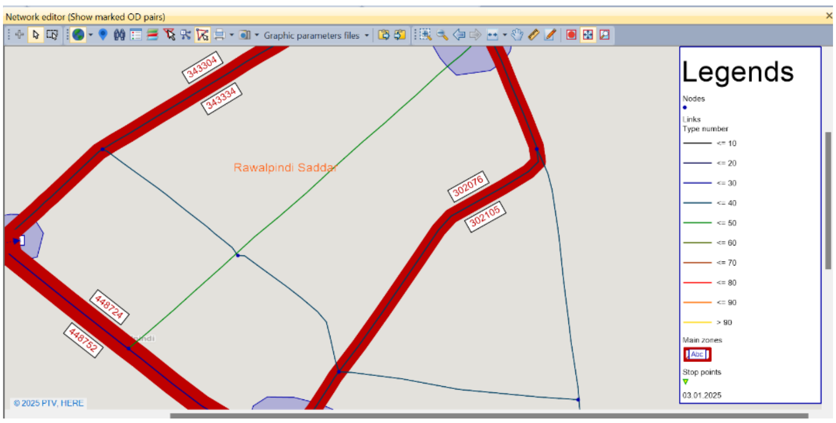


Figure 21: Traffic Assignment among zones after congestion pricing

4.2 Policy Scenario Analysis using TDM:

A policy scenario analysis is a tool that assesses how different policies or management options might affect the future and can contribute to policy design and implementation. The issue to be addressed in this study is to reduce the traffic congestion on the roads of Rawalpindi Saddar which will, in addition, reduce the pollution by decreasing the vehicular emission of hazardous gases. After looking at the successful execution of road pricing techniques in Singapore, London, Stockholm and Milan, we decided to run the standard four-step travel demand model on the study area in VISUM and applied the toll charges on the main roads between the selected zones of activities. This will generate revenue for the development of public transport system and for the improvement of the existing transport system such as road quality, increasing number of lanes, establishing pedestrian paths, installing streetlamps, development of parking areas and other road infrastructure.

So, a total of 300 rupees toll charge is suggested to be applied on the roads connecting the three zones under study. Of these 300 rupees, cars will be charged 200 rupees and light traffic vehicles will be charged 100 rupees while they travel through the designated roads on daily basis, because the modelling done and charges applied are on daily traffic count. When this toll is applied on the road network in VISUM, the number of traffic count on the roads is decreased and congestion is somehow minimized as evident from figure 22 in which the traffic count between two zones is sum of traffic on two lanes in opposite directions. For example, zone 1 to zone 3 is 979065 which is sum of zone 1 to 3 (489548) and zone 3 to 1 (489517).

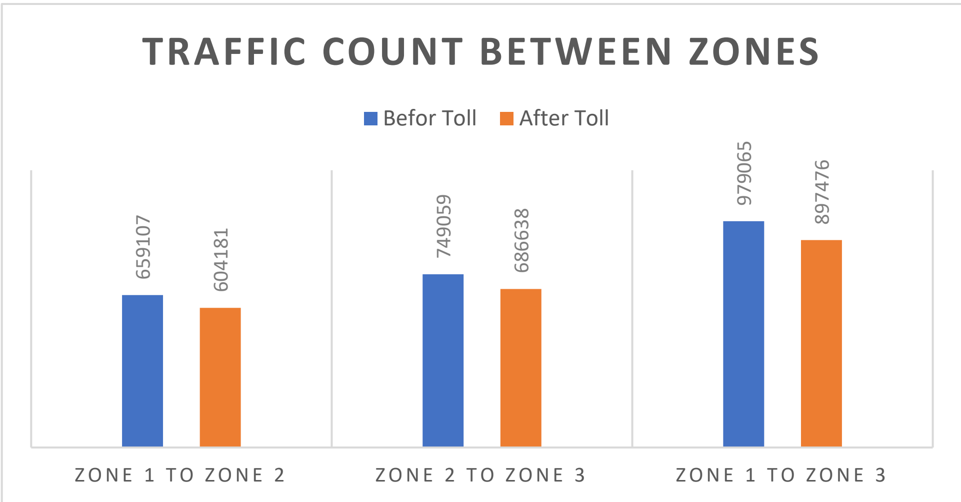


Figure 22: Traffic comparison of before and after road pricing

There is an 8.3% decrease in traffic volume after the application of toll charges. There is no toll charge applied on buses and public transport in order to encourage people to choose these modes of transportation and exercise carpooling. The possible challenge to this study's practicality was level of pricing which is addressed by putting toll charges affordable and only applicable on selective type of vehicles. The public would not accept such policy in Pakistan that affects their income level and not affordable because the overall financial condition of the country is poor. However, the public can be convinced by assuring them that the revenue generated by this type of road pricing will be invested to provide them better and reliable road infrastructure within the study area. Moreover, a pilot program can be run first before permanently applying the road pricing in which the toll will be collected for initial six months. The total possible daily revenue of implementation of this study is approximately 235 million rupees. The detail of revenue is given in table 2.

Table 2: Details of Revenue generated by road pricing in study area

Modes	Number of Units	Toll Charges (Rs.)	Revenue (Rs.)
Cars	806318	200	161263600
LTVs	744294	100	74429400
Total Daily Revenue			235693000
Monthly Revenue			5656632000
Annual Revenue			67879584000

Number of units in table 2 are obtained by adding up all the trips of cars and LTVs from figures 16 and figure 18. The monthly revenue is 5 billion rupees and the annual revenue reaches up to 67 billion rupees. While this idea seems to be producing so much tax for government, yet it needs a sophisticated mechanism and system to be deployed on the roads to collect this revenue. This study suggests the establishment of toll plazas at the entrance/exit of the zones i.e., PC Chowk, Mureer Chowk and Saddar. This is the custom method of toll collection in Pakistan and we do not suggest the advance systems like Singapore, London and Milan at this moment, however, as the program grows and revenue is collected enough to be utilized for adopting advance technologies then modern methods of toll collection such as ERP (Electronic Road Pricing) can be introduced in the Rawalpindi Saddar. So the toll will be collected through electronic toll booths and the compliance will be monitored using Automated Number Plate Recognition (ANPR) systems.

5. Discussion

Although this study provides an estimate of revenue generation, feasibility of road pricing and an idea of how much congestion can be reduced, efficiently, but it falls short of real time data for the whole day and based on only peak hours data; daily data of traffic count is bifurcated from this peak hour data. This study could not incorporate the data on car ownership, family composition and land use due to absence of accessibility. The open street map used in this research is over-simplified and ignores the detailed road network. Some policy recommendations from this study are stated below:

5.1 Policy Recommendations:

- There is a decrease in traffic volume on the roads as evident from VISUM analysis, therefore, the road pricing should be applied on the roads between PC Chowk, Mureer Chowk and Saddar region in the Rawalpindi Saddar.
- The toll charges should be such as discouraging private transport and encouraging public transport. So the cars should be charged 200 rupees and LTVs should be charged 100 rupees while travelling among the three zones during peak or rush hours.
- A daily revenue of 235 million rupees is expected from this road pricing which is a huge amount for a small region therefore the revenue should be invested on the well-being of the residents of the area and to improve the road infrastructure in the area.
- Initially, the traditional way of toll collection should be implemented on the roads by installing the toll plazas at the entrances/exits of the zones. However, as the program kicks up and collects enough money to be invested on technology then advance road pricing techniques should be adopted following the examples of Singapore, London, Stockholm and Milan.
- A six month pilot program is recommended for the study area so that the road pricing can be modified according to the feedback of the people of area.

- The same studies can be conducted for other cities facing traffic congestion. They can follow the same four step TDM to assess the impact of road pricing on their respective area of study.

6. Conclusion

The study draws attention to the urgent problem of traffic congestion in Rawalpindi Saddar, especially along the PC Chowk to Saddar corridor, which faces extreme bottlenecks during peak hours. This congestion leads to increased travel time, excessive fuel consumption, and increased emissions, contributing significantly to air pollution and smog in the city. The situation calls for innovative traffic management solutions beyond traditional infrastructure expansion, which has proven insufficient in addressing long-term congestion challenges. It draws inspiration from a successful city of road pricing that implemented the policies of Singapore, London, and Stockholm. Therefore, this study used VISUM software for traffic pattern modeling under congestion pricing strategy in Saddar. This can reduce traffic volume and discourage usage of private vehicles on roads by using private cars or even any other forms of transport in time slots, hence showing 8.3% reduction of volume when charges were implemented in the study period for car users and light transport vehicles. Equally promising is the financial impact: an estimated PKR 33 billion annually through road pricing, which is an enormous source for reinvestment into urban transport infrastructure, such as developing reliable public transport systems, improving road quality, pedestrian pathways, and modern toll collection technologies. All of these improvements will not only make congestion reduce even further but enhance overall urban mobility and accessibility as well.

The study also highlights the need for fair toll structures, which have charges that encourage public transport and shared mobility. Public transport vehicles and HOVs are exempted from paying tolls to promote their usage. This is in tandem with the best practices adhered to worldwide in addressing the region's socio-economic disparities. This is a worthwhile strategy for reducing traffic congestion in the metropolis. A six-month pilot program is thus recommended to gauge the public's view and refine the tolling strategy based on practical outcomes. A phased implementation permits policymakers to better address resistance potential and optimize the system before expansion into a permanent level. The review also recommends adopting traditional toll plaza setups initially while gradually transitioning toward advanced systems, such as electronic road pricing, as revenue builds and public acceptance increases.

In conclusion, the research is a confirmation of the fact that road pricing could be a workable and sustainable solution for countering traffic congestion and its corresponding environmental impacts in Rawalpindi Saddar. This reduces congestion, cuts down on emissions, and generates tremendous revenue; the strategy not only deals with short-term transportation challenges but also gives a way out to long-term urban development. Policymakers should encourage the concept and models for such congestion pricing, like these developed in the urban congested cities of other provinces in Pakistan.

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