A Framework for Sustainable Transport using Microsimulation - Evaluation of traffic progression at an Intersection in Rawalpindi, Pakistan

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Abstract. Traffic congestion remains a formidable challenge in urban environments, significantly contributing to environmental degradation through increased emissions and inefficient energy use. Addressing this concern, our study explores the potential of traffic microsimulation for evaluating and enhancing urban transport sustainability. Microsimulation offers a detailed traffic flow analysis, enabling the assessment of current traffic conditions and determining the Level of Service (LOS) for specific road segments. In this context, the current study presents a case study applying PTV VISSIM, a leading microsimulation software, to an intersection in Rawalpindi, Pakistan. This intersection, characterized by heavy traffic and frequent congestion, is an ideal subject for analyzing the efficacy of microsimulation in managing complex traffic scenarios. Insights derived from the simulation model are then used to design and evaluate sustainable transport interventions, such as intelligent traffic management systems, optimized signal timings, and eco-friendly routing strategies. The findings affect urban planners, policymakers, and engineers striving to create resilient, environmentally conscious transportation systems. Integrating microsimulation techniques and PTV VISSIM is a valuable tool for assessing and implementing sustainable transport strategies: "I believe it is important to contribute to the ongoing discussion on how we can mitigate the environmental impact of urbanization."
Keywords: Microsimulation, Signalized Intersection, Sustainable transport

1. Introduction

The growing global emphasis on sustainability has brought attention to the sustainability of transportation systems. While sustainability is an often-discussed idea, tools for practical implementation are restricted [1]. Different methodologies have been proposed & conducted to ease progressively serious urban transportation issues. This paper presents a simulation-based systematic framework for economical transportation systems assessment & improvement [2]. Direct field studies were used to collect data on traffic levels. The data collected indicated that inadequate intersection planning, traffic signal shortages, and poor traffic management primarily cause traffic congestion.

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Different remedial measures based on intersection enhancement, alternative service plans, intersection signalization, and sustainable measures are proposed as a solution [3].

The model is designed to permit computational experimentation and inference regarding transport modal split & emission of pollution in the national transport system. Model inputs include, transport networks (different modes), stock of vehicles, passenger distribution into a network. Model outputs comprise of socio-economic indicators. Characteristics describing Various descriptors of infrastructure, vehicles & exhaust gases are given [4]. To limit the impact of congestion in this problem setting, a Microsimulation is performed in PTV VISSIM. This model integrates the road & its users and is their driving behavior and impact on congestion. Throughout the experiments conducted, the emissions of CO2 are calculated; this allowed us to define a set of congestion minimization strategies that also reduce emissions [5]. In addition, various other costs of construction and maintenance issues also have to be considered in the whole decision-making process. This paper will focus on those problems as well as other emerging issues and quantify these impacts by using computer simulations that, in turn, can help transportation agencies to make better decisions aimed to delivering more sustainable infrastructures.[5].

2. Literature Review

The leading issue in the transportation system is congestion, causing many environmental and economic losses.

2.1 Congestion

Usually occurs when the demand for transportation increases more than the available capacity. Congestion is a global issue faced by almost every country, with significant economic losses and a lack of a sustainable environment. One of the most congested cities in the world was London in 2022, and it's compared to top cities worldwide. The average number of hours each driver spends in traffic marks the congestion in Figure 1 [6] [7].

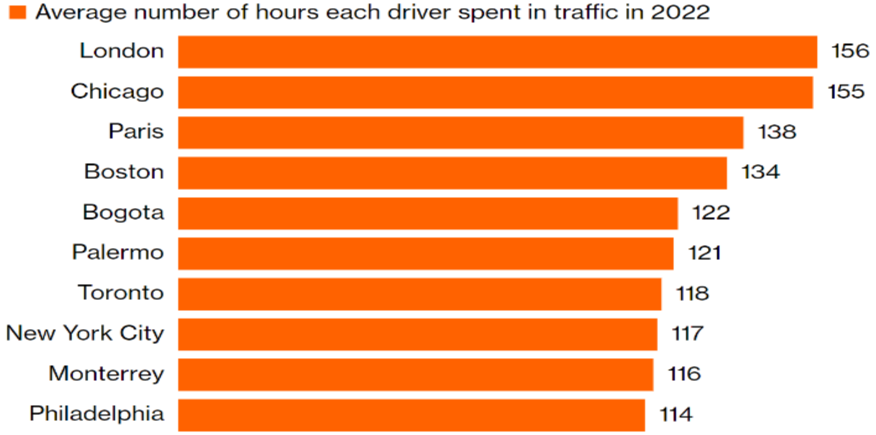

Fig.1. Cities Where People Spent the Most Time in Traffic Source: INRIX Research

2.2 Annual Congestion Cost

The yearly congestion costs are essential in forming transportation sustainability by impacting economic, social, and policy-related aspects. A joint research effort by LUMS and Lahore Safe City reveals that congestion is causing a substantial financial burden, estimated at Rs. 100 billion annually. This amount closely mirrors the entire budget allocated to the Punjab police. The economic toll is evenly distributed between the opportunity cost of time lost in congestion and the heightened fuel consumption [8]. A study by the NED University of Engineering and Technology revealed that the yearly expense of traffic jams in Karachi is approximately Rs200 billion. This figure corresponds to 1.5% of Pakistan's GDP [9]. The users responsible for annual congestion costs are business traders 53%, motorists 22%, transport experts* 18% & pedestrians 7% [10].

**Inadequate and restricted strategies used by transportation and traffic planners are identified as key elements leading to traffic jams.*

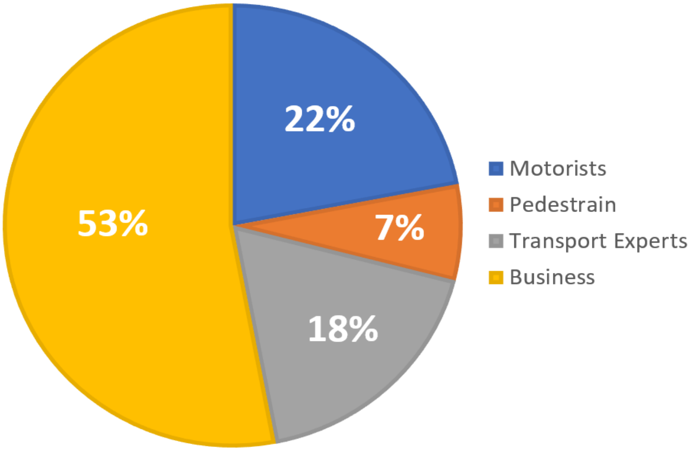

Fig.2. Users Responsible for Traffic Congestion (Lahore)

2.3 Environmental Aspects

Mainly consider greenhouse gas emissions, noise pollution, and air quality. Traffic congestion degrades the natural, sustainable environment due to increased emission rates and reduced speed or congestion. Figure 3 illustrates the increase of different gas emissions with reduced vehicular speed. Generally, CO2 emissions are always greater than VOCs (Volatile organic compounds) [11].

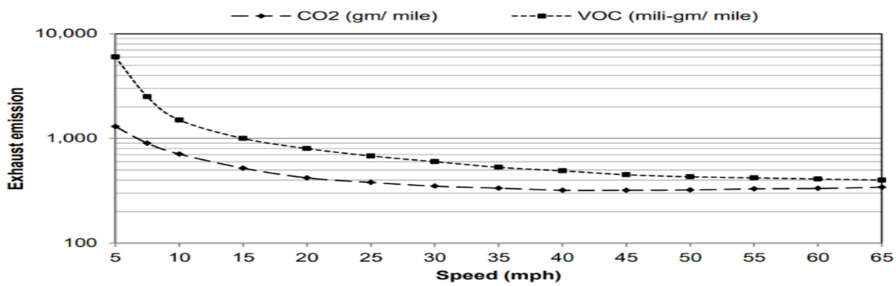

Fig.3. Source: An Impact Evaluation of Traffic Congestion on Ecology (Planning Studies and Practice, Vol. 3, No. 1)

Microsimulation has been employed in several countries to evaluate traffic progressions; one of the studies in Ethiopia assessed the capacity and LOS of signalized intersections in Addis Ababa. The relevant data was collected from specific intersections using appropriate survey equipment to evaluate LOS at various sites. The study conducted capacity analysis utilizing analytical methodologies and geometric elements in the PTV VISSIM software program package. This analysis aimed to determine the level of service for the junctions under examination. The capacity analysis throughout the study was performed based on analytical methods with some geometric elements using the PTV VISSIM software program package to identify the level of service for the studied intersections [12].

Another study analyzed applied microsimulation techniques in urban areas. The software tool used was PTV VISSIM to model and analyze the selected intersections in an urban setting. The authors calibrated the data using real-world traffic data, and the evaluation was conducted based on LOS and average delay values.[13].

A case study of an Indian intersection tested on PTV VISSIM. The same software tool, i.e., PTV VISSIM, is used to create and calibrate the current field condition (base model) based on traffic volume counts and spot speeds [14]. A dramatic growth in the city's automobile population has far-reaching social and economic consequences, including longer commute times, more severe traffic congestion, and higher fuel costs [15], making evaluating and improving the conditions a significant challenge.

Another study evaluated one of the most problematic intersections in Uzbekistan to prepare simulations and improve its traffic flow [16]. Several studies have shown the capability of microsimulation tools like PTV VISSIM to evaluate and enhance traffic progression, which can help improve the sustainability of transport systems [17], [18], [19], [20], [21], [22].

3. Methodology

The general outline of our methodology consists of the data collection phase, simulation model, level of services proposed, and their solutions for a sustainable environment or transport system.

3.1 Site Specifications

The site we're working on is an intersection located in Rawalpindi, Pakistan; *PC* intersection* (33°35'20.1"N 73°03'27.9"E). This is a four-legged signalized

intersection with four lanes on Saddar & Kacheri roads and two lanes on ABS & Sarwar road (Figure 4). The main traffic is observed on the roads towards West & East, i.e., towards Saddar & Kacheri. The signal time for the main roads is 70 seconds for both red & green lights and 20 seconds for the roads in the North & South directions. Many delays & congestion are observed at peak hours of the day, which disturbs the sustainable environment. The LOS for this intersection was calculated with the simulation model in PTV VISSIM.
**Pearl Continental Hotel, Aziz Bhatti Shaheed (ABS)*

Fig.4. PC Intersection (Google Earth Pro)

3.2 Data Collection Phase

Data was collected manually using a logbook, and the following elements were recorded on-site by six observers.

- Vehicle counts
- Vehicle classification
- Signal times
- Lanes widths
- Left & right turning vehicles
- Speed limits

Different vehicles were enlisted in each road direction at peak hours. The peak hours were 7:00-8:30 AM (Morning), 12:00-1:00 PM (Noon), and 5:00-6:00 PM (Evening). Vehicle classification included motorbikes, passenger cars, LTVs, and buses. Traffic count data is shown in Figure 10 below ***(Peak Hour Data Vol)***.

3.3 Site Pictures at Peak Hours

Fig.5. Observing Data At site: (Morning) 7:00-8:00 AM

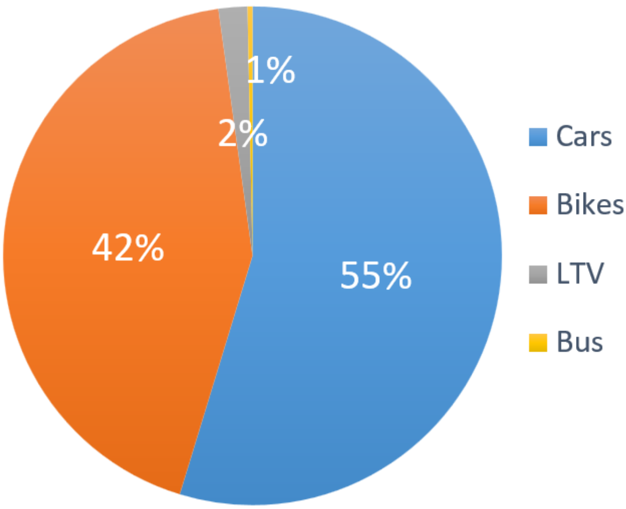

Fig.6. Vehicle Classification (Avg of six days)

Fig.7. Observing Data At site: (Morning) 7:00-8:00 AM

Figures 5 & 6 show the site pictures where we collected data at peak hours: morning 7:00-8:00 AM. The morning was the time when buses were included in the flow because of the school & college timings.

Fig.8. Observing Data At the site: Evening 5:00-6:00 PM

Fig.9. Observing Data At the site: Evening 5:00-6:00 PM

Figures 7 & 9 are pictures of peak hours in the evening (5:00-6:00 PM), referring to office hours when the congestion was quite high.

This data represents the percentages of vehicle classification (average of six days) and data collected at the site.

Passenger cars were the highest in number (55%), bikes were the second, making 42% of the vehicle classification, LTVs & buses made the lowest percentages of 2% & 1%.

**LTV: Light Transport Vehicle. Our data for LTVs include Hiace & Coasters.*

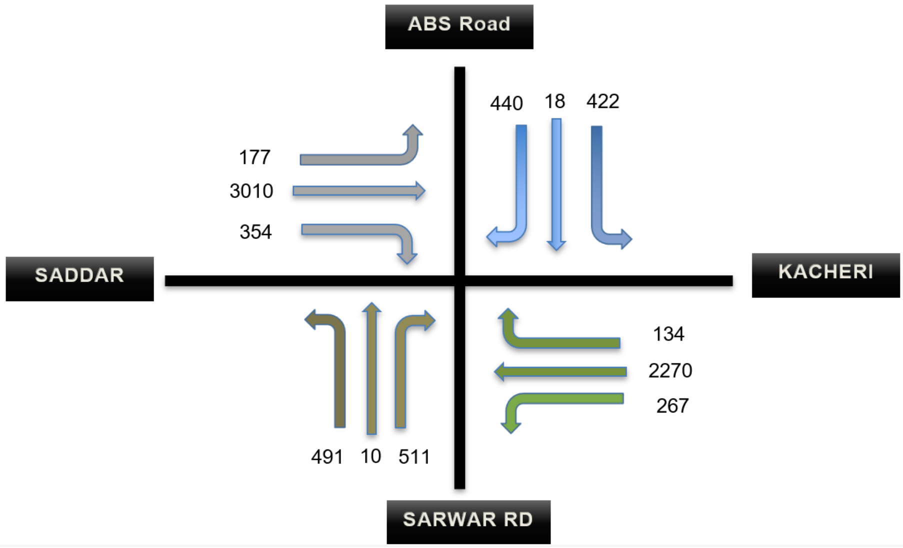

Fig.10. Peak Hour Data (Avg of six days)

3.4 Microsimulation Model (PTV VISSIM)

Collecting the data at the site (traffic volumes, lane widths, signal times & speed limits, etc.) was used to model the intersection in PTV VISSIM. Inputting all the data gave us a model with the help of which we were able to find out the current results of the intersection. Figures 5,7 & 6 represent the 2D & 3D simulation model. From this model we could find out the LOS of the intersection (of each roadway) shown in Table 1. Vehicle delays were discovered, and the software gave different emission gases and fuel consumption values according to the input data.

Table 1 below shows data extracted from PTV VISSIM after inputting actual data collected from the site. The table shows the movement of vehicles on each route or the direction of flow of cars through the corresponding intersection. LOS at each flow direction was found by adding nodes in the software and running the evaluation results for the specific nodes. The second column gives us results based on the vehicle delays (in seconds). It can be seen that most of the LOSs are F, which leads to a poor sustainable transportation system. Some LOS are D because of the low traffic flowing through that point.

Table 1 Level of service and Vehicular delays at each approach

No.	Movement Direction	Level of Service (LOS)	Vehicle Delays (sec)
1	Kacheri Rd – Towards Saddar	F	155.04
2	Kacheri Rd – Sarwar Rd (Ent)	F	148.22
3	Kacheri Rd – ABS Rd (Ent)	F	166.46
4	Saddar Rd – Sarwar Rd (Ent)	D	43.01
5	Saddar Rd – ABS Rd (Ent)	D	46.93
6	Sarwar Rd (Exit) – ABS Rd (Ent)	F	236.31
7	Sarwar Rd (Exit) – Towards Saddar	F	364.88
8	Sarwar Rd (Exit) – Towards Kacheri	F	123.90
9	Saddar Rd – Towards Kacheri	D	41.94
10	ABS Rd (Exit) – Towards Kacheri	F	361.48
11	ABS Rd (Exit) – Sarwar Rd (Ent)	F	633.91

3.5 Benefits of Microsimulation for Sustainable Transport

Microsimulation, particularly in the context of traffic and transportation planning, offers several benefits for enabling sustainable transport planning. Here are some key advantages:

Detailed Analysis of Traffic Flow: Microsimulation allows for a granular analysis of individual vehicles and their interactions within a transportation network. This level of detail is crucial for understanding the intricate dynamics of traffic flow, which is essential for sustainable transport planning.

Evaluation of Infrastructure Changes: Planners can use microsimulation to assess the impact of proposed changes to transportation infrastructure, such as new road layouts, intersection designs, or the introduction of dedicated lanes for sustainable modes of transport (e.g., public transit, cycling lanes).

Optimization of Traffic Signal Timing*:* Microsimulation facilitates fine-tuning traffic signal timings, optimizing the efficiency of signal-controlled intersections. This can help reduce travel times, minimize delays, and improve the overall traffic flow, contributing to sustainable and efficient transportation systems.

Emission and Environmental Impact Analysis: Microsimulation tools often include features to estimate and analyze emissions from vehicles. This capability allows planners to assess the environmental impact of transportation plans and identify strategies to reduce emissions, contributing to sustainability goals.

Scenario Testing and Sensitivity Analysis: Planners can use microsimulation to conduct scenario testing and sensitivity analysis, exploring different what-if scenarios and understanding the potential outcomes of various interventions. This helps in making informed decisions that align with sustainability objectives.

3.6 PTV VISSIM Model

Figure 11 shows the plan view of the simulation model of the current intersection. All the signals are red & no vehicles can be seen because the simulation has not been executed yet.

Fig.11. Plan View of Simulation (No Traffic)

Figure 12 represents the 3D view of Traffic flowing where the vehicles can be seen clearly. The 3D view is good for visualizing the model & interpreting the data required.

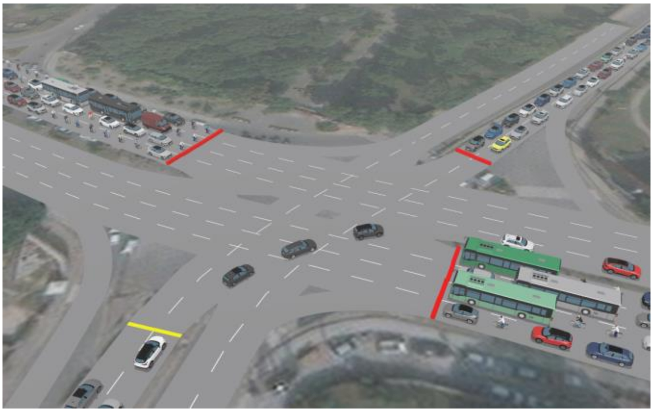

Fig.12.3D View (Traffic Flowing)

Figure 13 also shows the plan view, but the simulation is running, and traffic is flowing. The colored cylindrical shapes are the vehicles.

Fig.13. Plan View (Traffic Flowing)

Table 2 Shows different Gases Emissions in Grams

No.	Movement Direction	EmissionsCO (g)	EmmisionsNOx (g)	EmissionsVOC (g)
1	Kacheri Rd – Towards Saddar	10.9	2.1	2.5
2	Kacheri Rd – Sarwar Rd (Ent)	680.7	132.4	157.7
3	Kacheri Rd – ABS Rd (Ent)	8.9	1.7	2.0
4	Saddar Rd – Sarwar Rd (Ent)	521.2	101.4	120.8
5	Saddar Rd – ABS Rd (Ent)	242.0	66.5	79.2
6	Sarwar Rd (Exit) – ABS Rd (Ent)	326.0	63.4	75.5
7	Sarwar Rd (Exit) – Towards Saddar	181.8	35.3	42.1
8	Sarwar Rd (Exit) – Towards Kacheri	2575.0	501.0	596.7
9	Saddar Rd – Towards Kacheri	447.3	87.0	103.6
10	ABS Rd (Exit) – Towards Kacheri	209.9	40.8	48.6
11	ABS Rd (Exit) – Sarwar Rd (Ent)	3642.5	708.7	844.1

Table 3 Fuel Consumptions at roads in US liquid Gallons

No.	Movement Direction	Fuel Consumption (US liquid Gallons)
1	Kacheri Rd – Towards Saddar	52.1
2	Kacheri Rd – Sarwar Rd (Ent)	3.0
3	Kacheri Rd – ABS Rd (Ent)	6.4
4	Saddar Rd – Sarwar Rd (Ent)	2.6
5	Saddar Rd – ABS Rd (Ent)	4.6
6	Sarwar Rd (Exit) – ABS Rd (Ent)	0.2
7	Sarwar Rd (Exit) – Towards Saddar	7.4
8	Sarwar Rd (Exit) – Towards Kacheri	4.8
9	Saddar Rd – Towards Kacheri	36.8
10	ABS Rd (Exit) – Towards Kacheri	9.7
11	ABS Rd (Exit) – Sarwar Rd (Ent)	0.2

3.7 PTV VISSIM Node Evaluation (Results)

Figure 14 shows the evaluation results of Nodes in PTV VISSIM. It offers all the movement directions of vehicles & the current state of the intersection. It carries information about the level of service, vehicle delays, movement directions, Emissions, and fuel consumption.

Number: 13	Movement	QLen	QLenMax	Vehs(All)	Pers(All)	LOS(All)	LOSVal(All)	VehDelay(All)
1	1 - 1: ABS Road (Exit)@44.5 - 4: Sarwar Road (Ent)@62.8	79.90	89.18	1	1	LOS_F	6	633.91
2	1 - 1: ABS Road (Exit)@44.5 - 9: Twrds Kacheri@84.8	79.90	89.18	93	93	LOS_F	6	361.48
3	1 - 5: Sarwar Road (Exit)@24.1 - 2: ABS Road (Entrance)@4...	85.51	94.02	2	2	LOS_F	6	236.31
4	1 - 5: Sarwar Road (Exit)@24.1 - 8: Twrds Saddar@63.7	85.51	94.02	84	84	LOS_F	6	364.88
5	1 - 5: Sarwar Road (Exit)@24.1 - 9: Twrds Kacheri@84.8	59.80	101.68	122	122	LOS_F	6	123.90
6	1 - 7: Saddar Road@65.9 - 2: ABS Road (Entrance)@41.4	71.15	155.85	247	247	LOS_D	4	46.93
7	1 - 7: Saddar Road@65.9 - 4: Sarwar Road (Ent)@62.8	71.15	155.85	137	137	LOS_D	4	43.01
8	1 - 7: Saddar Road@65.9 - 9: Twrds Kacheri@84.8	71.15	155.85	1922	1922	LOS_D	4	41.94
9	1 - 10: Kacheri Road@94.5 - 2: ABS Road (Entrance)@41.4	138.53	192.23	126	126	LOS_F	6	166.46
10	1 - 10: Kacheri Road@94.5 - 4: Sarwar Road (Ent)@62.8	138.53	192.23	67	67	LOS_F	6	148.22
11	1 - 10: Kacheri Road@94.5 - 8: Twrds Saddar@63.7	138.53	192.23	1076	1076	LOS_F	6	155.04

Fig.14. Node Evaluation Results (PTV VISSIM)

Figure 15 shows the same evaluation results for the nodes. Still, it has values for fuel consumption and different gas emissions of vehicles flowing through the intersection, making it very useful for calculating a sustainable transport system. Where it's easy for us to think of an economical solution for the future design.

Number: 13	SimRun	TimeInt	Movement	FuelConsumption	LOS(All)	VehDelay(All)	EmissionsCO	EmissionsNOx	EmissionsVOC
1	1	0-3600	1 - 1: ABS Road (Exit)@44.5 - 4: Sarwar Road (Ent)@62.8	0.157	LOS_F	633.91	10.989	2.138	2.547
2	1	0-3600	1 - 1: ABS Road (Exit)@44.5 - 9: Twrds Kacheri@84.8	9.738	LOS_F	361.48	680.718	132.443	157.763
3	1	0-3600	1 - 5: Sarwar Road (Exit)@24.1 - 2: ABS Road (Entrance)@4...	0.128	LOS_F	236.31	8.922	1.736	2.068
4	1	0-3600	1 - 5: Sarwar Road (Exit)@24.1 - 8: Twrds Saddar@63.7	7.457	LOS_F	364.88	521.232	101.413	120.801
5	1	0-3600	1 - 5: Sarwar Road (Exit)@24.1 - 9: Twrds Kacheri@84.8	4.893	LOS_F	123.90	342.021	66.545	79.267
6	1	0-3600	1 - 7: Saddar Road@65.9 - 2: ABS Road (Entrance)@41.4	4.664	LOS_D	46.93	326.044	63.436	75.564
7	1	0-3600	1 - 7: Saddar Road@65.9 - 4: Sarwar Road (Ent)@62.8	2.601	LOS_D	43.01	181.812	35.374	42.137
8	1	0-3600	1 - 7: Saddar Road@65.9 - 9: Twrds Kacheri@84.8	36.839	LOS_D	41.94	2575.023	501.006	596.787
9	1	0-3600	1 - 10: Kacheri Road@94.5 - 2: ABS Road (Entrance)@41.4	6.400	LOS_F	166.46	447.351	87.038	103.678
10	1	0-3600	1 - 10: Kacheri Road@94.5 - 4: Sarwar Road (Ent)@62.8	3.003	LOS_F	148.22	209.900	40.839	48.646
11	1	0-3600	1 - 10: Kacheri Road@94.5 - 8: Twrds Saddar@63.7	52.111	LOS_F	155.04	3642.538	708.706	844.193

Fig.15. Node Evaluation Results with Emissions & Fuel Consumption (PTV VISSIM)

3.8 Future Solutions (Research)

Since the LOS is equal to F for the intersection, we have some better solutions:

In alternative intersection designs, the first possibility could be an underpass. Where the traffic will be flowing freely without any signals, but a roundabout must be constructed above because it's a four-legged intersection. This will improve the Level of Service (LOS) much better than the existing LOS because delays would be vastly minimized. This is a better solution for the environment as our evaluation results show much fuel consumption during the congestion phases and the emission of different gases that affect the atmosphere. Constructing an underpass will greatly reduce these factors by making the flow of traffic uniform without any delays.

Table 4 Respective Travel times at the four-legged Intersection.

No.	Vehicles (All)	Travel Time (s)	Distance Traveled (m)
Towards Saddar	346	77.63	242.44
Towards ABS Road	5	69.71	149.05
Towards Kacheri	521	55.76	239.60
Towards Sarwar Road	7	70.91	149.05

The second solution could be an overpass, which could be costlier but provide a better sustainable transportation system than the current stage. An overpass or a flyover has the same good impact on the current situation, where the flow can be made constant by removing the signals completely. Emissions of dangerous gases like CO, Nox & VOC in grams are given in the evaluation/results table. These values will be reduced by designing a suitable overpass for the required area and intersection.

Implementing adaptive signal control, which can adjust the signal timing and coordination based on real-time traffic conditions and demand. This can improve traffic flow, reduce delays and stops, and enhance safety and mobility.

Traffic Management Technologies implement intelligent transportation systems (ITS) technologies, such as traffic surveillance cameras and vehicle-to-infrastructure communication, to enhance traffic management and control.
Smart Traffic Control: implement smart traffic control systems that use real-time data and predictive analytics to optimize signal timings and traffic flow.
Implementing an advanced signal system at the intersection works to some extent. However, it will not provide a complete sustainable transport system because few vehicles would still be stopping, making some of the delay time. Making an adaptive system does help in making the LOS better because the LOS of all roads at our intersection is F, which is extremely bad.

4. Conclusion

This paper presented a framework for sustainable transport using a microsimulation evaluation of an intersection in Rawalpindi, Pakistan. The study aimed to evaluate the LOS of the intersection using microsimulation techniques, which was rated as F, indicating severe congestion and delays. The study involved data collection, microsimulation modeling, and evaluation of two alternative solutions: an underpass or an overpass and adaptive signal control. Future work will evaluate these alternatives at the same intersection and select the most cost-effective one.

The study demonstrated the potential of micro-simulation for evaluating sustainable transport solutions in developing countries. The study also provided insights into drivers' traffic characteristics and behavior in Rawalpindi, which can inform future planning and design decisions. However, the study had some limitations, such as manual data collection, which may introduce errors and biases, and the lack of field validation; factors that could impact the outcomes' accuracy and applicability must be considered.

For future research, using more accurate and automated data collection methods, such as video cameras or sensors, and conducting field experiments to validate and calibrate the microsimulation model is recommended. It is also suggested to explore other sustainable transport solutions, such as public transit, bicycle lanes, or pedestrian facilities, and to assess their impacts on the intersection performance and the environment.

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