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Optimizing Commuter Travel Times on Traffic Signals Using Phasing Techniques – A Pathway for Cost-Effective Intelligent Transportation System

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Abstract

In recent times, population growth has contributed to increased motorization and urbanization in Pakistan which hinders traffic mobility. As a consequence, the country is faced with urban sprawl that leads to almost daily recurrent gridlocks on roads. Due to the changing landscape of the Central business district and suburban development, accessibility to workplaces is decreasing and people see cars and other automobiles as a necessary addition to their life. Burgeoning twin cities like Rawalpindi and Islamabad incur economic costs due to traffic congestion observed during peak hours, as people move to their workplaces, schools, colleges, business centers, recreational places, etc. through the main thoroughfare i.e. Peshawar Road, Rawalpindi highway. The traffic congestion has inflated the twin cities and is exacerbated due to a lack of proper transportation planning and design needs resulting in an imbalance between the demand and capacity of road networks. These traffic delays lead to road damages and environmental degradation and end up costing road users fuel costs in terms of lost time. Furthermore, the public well-being is impacted by air and noise pollution having health implications. The paper attempts to address and mitigate traffic delays and congestion issues on Peshawar Road, Rawalpindi by using pre-timed split and protected phasing with signal coordination, offset, and bandwidth techniques in the software Synchro Studio. The preliminary data for this research was collected through an extensive literature review, traffic counts, and the geometrical features of the Peshawar road highway. The current traffic condition analyzed, is based on pre-timed split phasing without signal coordination. Subsequently, improved design alternatives are considered for an efficient movement of vehicles whichare based on pre-timed split and protected phasing with signal coordination. These simulations are modeled in Synchroto optimize road user travel time. The benefits of each phasing scheme are compared to conclude that protected phasingwith signal coordination reduces the travel time and total delays of the vehicles traversing the corridor by up to 52.8 % and 56% respectively when compared with the prevailing situation.

Keywords

Travel time, Delays, Signal Coordination, Pre-timed Split, Protected Phasing, Delay costs, Traffic Signals

Introduction

The transportation network plays a vital role in the development of any country. All sectors of a country's economy are affected through economic linkages made possible through the transportation network. A transportation network ensures safe travel within time, promotes business activities, and cuts down traveling costs while providing access to markets for services and goods. A reliable transport network provides rapid access to the workforce, thus, generating employment opportunities. The economy with better road networks is positioned more advantageously as compared to an economy with poor networks. Currently, the Pakistani government is confronted with the identification and solution of transportation problems. Traffic congestion in urban transportation, poor planning of road network, lack of governance, and corruption have worsened the present transportation problems in major cities of the country. In Pakistan, transportation problems are traditionally managed by constructing bigger roads which is not the solution.

The area of study is situated along the GT Road N5 connecting Peshawar to Lahore and Islamabad. The road runs roughly parallel to the M1- motorway between Rawalpindi and Peshawar. N5 highway provides access to the

Afghan border via the Khyber Pass too, with headlong connections to Central Asia and Kabul via Salang Pass. Peshawar Road Rawalpindi (PRR Highway) serves the areas like West ridge, Askari, Commercial hub, Saddar, Chaklala, Airport, etc. Due to the location of General Headquarters (GHQ), Peshawar Road carries special movements of the Pakistan Army that includes heavily armed trucks. Intersections are the bottlenecks of urban transportation networks (Ghanbarikarekani, 2018), and delay time at intersections is about 20%− 50% of total travel time. There has been a considerable amount of research that endorses intersection signal optimization as the key to reducing and managing traffic congestion (Shen, 2018). The risks posed by congestion give the impetus to explore new techniques of signal coordination on PPR Highway to minimize congestion, and delays thereby reducing the journey time.

There are a variety of high and low-cost interventions that could be incorporated to mitigate the predicaments of traffic congestion. Cost-effective approaches involve improving signal timing and phasing while other alternatives that involve spending some capital are adding lanes along roadways or even grade separation (Hadidi, 2022). The focus of the research is to devise economical alternatives by different phasing techniques in tandem with signal coordination of the green time is essential for efficient movement of vehicles through signalized intersections without stopping. In an uninterrupted flow, the timing is synchronized for traffic movements and the progression speed is managed. The result of signal coordination is the reduction in traffic delays, travel time, energy, and fuel consumption.

This is achieved by the following key objectives of this research

- To analyze current traffic demand on PRR Highway by manual calculations and mobile recordings.
- To mitigate traffic congestion on PRR Highway by pre-timed split phasing and protected phasing design approaches.

It is envisioned that the analysis of the present scenario and design of current traffic demand during peak conditions may help design the alternatives following the optimization of road user travel time with energy conservation and environment protection. Suitable recommendations for further research will be recommended to assess signal coordination using modern tools and techniques that will be adaptable to road users.

2. Methodology

The methodology of the research project is summarized in the figure below.

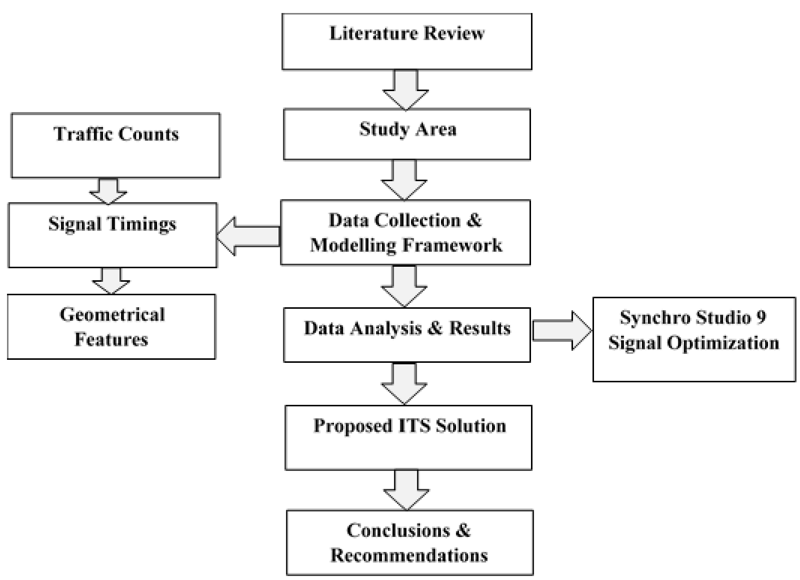

Fig 1. Research Methodology

3. Study Area

The area considered for our research is the urban arterial (Peshawar Road, N5) of Rawalpindi consisting of the following intersections are selected:

3.1 Signal 1: General Post Office GPO

This is a 4-legged signalized urban intersection located on PPR Highway. There are two major roads with Westbound WB going towards Saddar and Eastbound EB running towards the GHQ. The minor roads are Southbound SB going towards RA Bazar/Kashmir Road and Northbound NB runs towards Saddar/Kashmir Road.

3.2 Signal 2: General Head Quarters GHQ

This is a 3-legged signalized urban intersection located on PPR Highway. There are two major roads with WB going in the direction of GPO and EB towards Pearl Continental Hotel. The only minor road is NB and goes in the direction of Murree Road.

3.3 Signal 3: Pearl Continental Hotel PC

This is a 4-legged signalized urban intersection located on PPR Highway. There are two major roads with WB going towards GHQ and EB running towards Kacheri. The minor roads are SB and NB going towards Sarwar Road.

3.4 Signal 4: Kacheri Chowk

This 4-legged signalized intersection is located on Mall road Rawalpindi. It has two major roads with WB going in the direction of PC and EB going towards Airport Road. While the two minor roads, NB is going towards Rashid Minhas Road and SB running towards Ayub Park Road.

Fig 2. The Entire Corridors of PRR Highway

4. Data Collection and Modelling Framework

The basic aim of our study was to enhance traffic signal timing and coordination for each intersection on PPR Highway for the prevailing and expected conditions of the traffic at the intersections that are to be analyzed. The procedure involves collecting traffic counts for the different movements of traffic. i.e. through and turning movements at the intersections by count method and videos recorded. The traffic volumes were further validated by using the JAMAR counter. Furthermore, geometrical features of the intersection were recorded including the number of lanes, their widths, and median width. To represent a true depiction of real traffic, vehicular classification is done by converting these traffic counts into Passenger Car Equivalents and using them as an input for volumes in Synchro (Ali, 2015). The values used for Passenger Car Equivalents (PCE) are shown in Table 1.

Table 11. Vehicle Class & its PCE factor (Ali, 2015)

Vehicle Type	PCE Factor
Bike	0.4
Motor Car	1
Van/Pickup	1.5
Bus	2
Heavy	2.3

Subsequently, peak hour volumes and peak hour factor was determined for every individual intersection from the recorded traffic counts. The days and timings considered in Synchro 9, imitate an actual situation where the periods selected during the specified weekday and weekend as shown in Table 2. The selected timeframes represent critical intervals involving peak hours.

Table 2. Traffic counts considered for the following time and days of the week

Day	Morning Peak Hour	Evening Peak Hours
Thursday (Working Day)	7:30 – 10:30	16:00 – 19:00
Sunday (Weekend)	-	16:00 – 19:00

Before conducting research, an initial survey of field travel, travel distance, and cycle lengths between signals were measured. Generally, signals are automated. However, during peak timings and special movements of armed forces, these are controlled manually by traffic wardens and the Pakistan Army personnel. To have an optimum level of signal coordination in major streets and highways, the recommended distance by the Manual on Uniform Traffic Control Devices (MUTCD, 2000) between signals should fall within 800 meters for major streets and highways. The distance between the intersections of the corridor was calculated which is less than the specified standards of signal coordination. Furthermore, cardinal directions i.e. North-South (NS) to minor roads and East-West (EW) to major roads were assigned. Mirroring of directions (NB into SB and left into right and vice versa) according to American traffic signal standards for synchro analysis and design is done to represent Pakistan's road network typology.

Table 3. Travel distance between the nodes

Travel Nodes	Travel Distance (m)
GPO to GHQ	455
GHQ to PC	505
PC to Kacheri	870

4.1 Optimization Process

The SYNCHRO optimization procedure materializes after testing all the possible cycle lengths for observed intersections. SYNCHRO then determines the shortest cycle length that is suitable for critical percentile traffic for each phase. It is necessary to clear critical percentile traffic, if the splits for each phase are not able to do that, it will try a higher cycle time until the critical percentile is cleared (Siddiqui, 2015). After setting up the cycle time for each phase, SYNCHRO selects the cycle time with Measures of Effectiveness (MoEs). Finally, SYNCHRO optimized offsets and the phase sequence. Delay is the key measure of effectiveness. Stopped delay is used to quantify the coordinated actuated traffic signal system. MOEs, field measured travel times, and stopping delays collected before (non-coordinated) and after (coordinated) are compared. Changes in the MOEs measured in the field and calculated by SYNCHRO are compared and the adaptive best alternative split features are implemented. Synchro is signal-timing and optimization software package that uses the Intersection Capacity Utilization (ICU) 2003 method and supports the Highway Capacity Manual (HCM,2010) and (HCM, 2000) methodology.

5. Data Analysis and Results

Traffic signal optimization is achieved by considering different phasing techniques i.e. split phasing and protected phasing. The current traffic was analyzed using pre-timed split phasing without signal coordination followed by pre-timed split and protected phasing by signal coordination incorporating bandwidth and offset techniques. Among the different traffic signals, there are pre-timed or actuated modes or sometimes a combination of the two. Despite advancements in the field of traffic planning and operations, many major cities still rely on pre-timed signal settings. (Parr, 2011). This is because real-time traffic controllers require sensors and processors to function which induces a high cost of installation and maintenance (Patel, 2015). The Pre-timed control signal has a fixed cycle time and green time. The signal program processes periodically and can be controlled on-site and easily updated if needed. The split phasing considers an assignment of right-of-way to all movements at a particular approach which is followed by all of the movements of the opposing approach. In contrast, to split phasing, the protected phasing has a signal phase, where only through traffic has green or right-turning traffic has green (Udomslip, 2017).

The data recorded and processed to give peak hour volumes, peak hour factor is further used along with existing cycle length and green time to determine existing overall delay, the capacity of each movement, and for the whole signal along with Level of Service (LOS) and Intersection capacity utilization (ICU) with the help of software SYNCHRO. A comparative analysis of the results produced by Synchro studio 9 gives a holistic view of the traffic conditions of split phasing before improvement and the design split and protected situations for the morning, evening, and weekend after improvement. The results presented in Table 4 signify the importance of using the design alternatives with signal coordination through the corridor which yields reduced cycle lengths in comparison to split phasing without signal coordination.

Table 4. Analysis and design conditions

Stages	Phasing	Cycle Length (sec)	Coordination
Before Improvement	Split (four-phase)	107- 172	No
Design 1 (Pre-timed Split)	Split (four-phase))	125	Yes
Design 2 (Protected Phasing)	Split (four-phase))	125	Yes

The three alternatives of signal phasing are represented in Figure 3, the first stage is one without any signal coordination where we can see the travel delay by each vehicle, the total delay, and lastly, the total travel time throughout the corridor of PRR Highway is considerably higher and is the impetus to the design alternatives modeled. It has been observed that the most time-efficient phase design is protected phasing with signal coordination during all periods and days of the study.

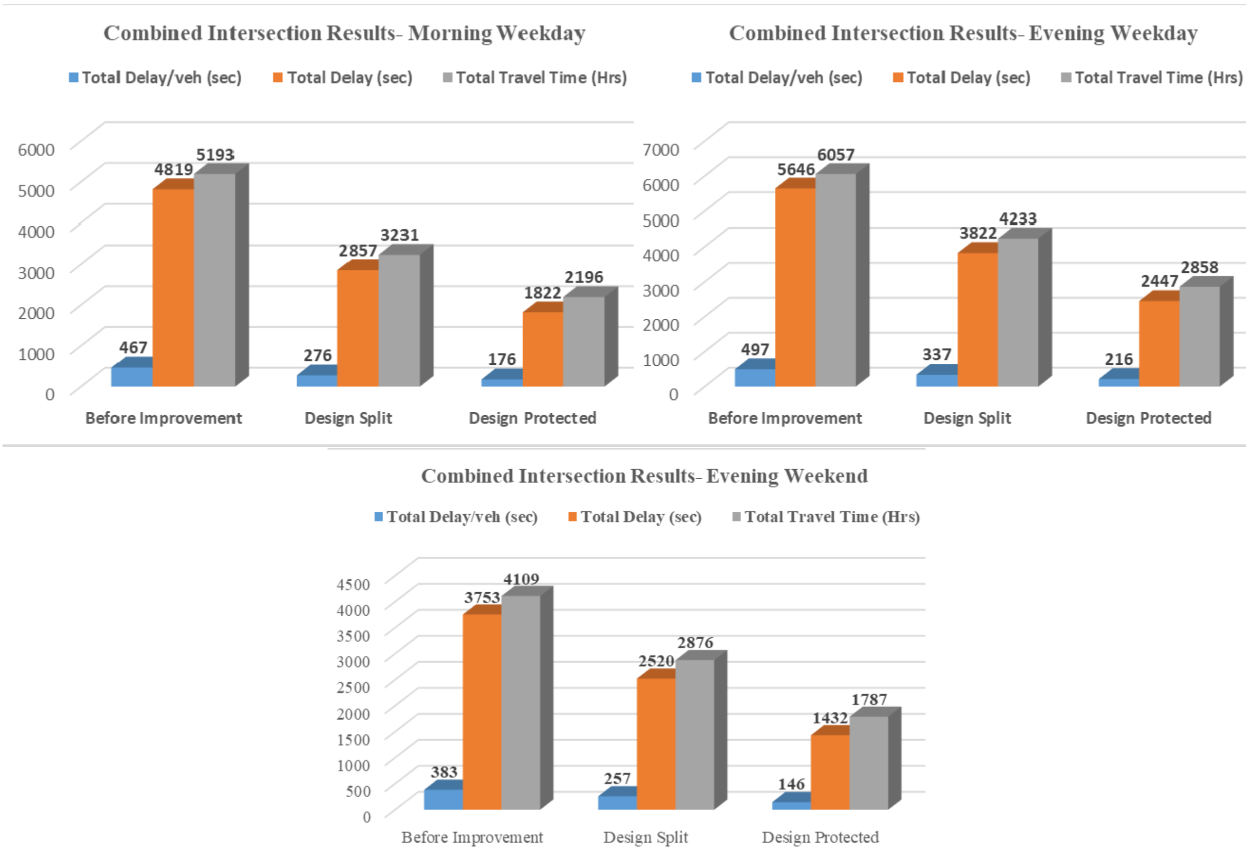

Fig 3. Intersection combined results of total delay/veh (sec), total delay (sec), total travel time (hrs), (a) morning peak hours of weekday, (b) evening peak hours of weekday, and (c) evening peak hours of weekend.

5.1 Cost Benefit Analysis

The cost-benefit analysis of the proposed interventions and their implications on the tangible metrics of a sustainable transportation system such as time and cost as a result of the phasing techniques are depicted in Table 6. Assuming a free-flow speed for different segments considered for the analysis, the unit travel time costs are derived for the year 2019 by using the CPI index for the years 2014 & 2015. The unit travel time cost for cars is taken as 295 PKR rupees. For travel time savings the following equation from (HCM, 2010) is used.

Saving Delay Cost = (Occupancy of Vehicle) x (AADT x Travel Time Saved) x (Unit Travel Time Cost) (1)

Where,
AADT = 1700 veh/hr

By leveraging the benefits of these phasing techniques. From the analysis, it is concluded that the reduction in travel time as a result of design interventions leads to saving time per vehicle which in turn contributes to saving of costs incurred by delays. Using the unit travel time cost already derived above, the total monetary benefit was calculated which is PKR 223.3 and PKR 167.535 Million per year for the different directions of traffic. Conclusively Table 6, clearly depicts that the design-protected alternative for signals is more feasible as the travel time cost is reduced. Since travel time cost is directly related to savings, this alternative will help in the reduction of the cost of road users which has a direct influence on the economy of the country.

Table 6. Travel time savings

Direction	Travel Time (sec/veh)			Saving Time (hr/veh)		Saving Delay Cost/year (Rs. Millions)	
-	Before Improvement	Design split	Design Protected	Design split	Design Protected	Design split	Design Protected
East	510	405	330	0.0291	0.05	153.3	223.38
West	465	390	330	0.0208	0.0375	109.5	167.535

6. Proposed ITS Solution

An Intelligent Transport System (ITS) module is proposed that is capable of adjusting to real-time traffic conditions with pre-timed protected phasing and loop detectors which circumvents to actuate cycle length for this traffic corridor. The working principle of the ITS module is explained below for different conditions and illustrated in Figure 4.

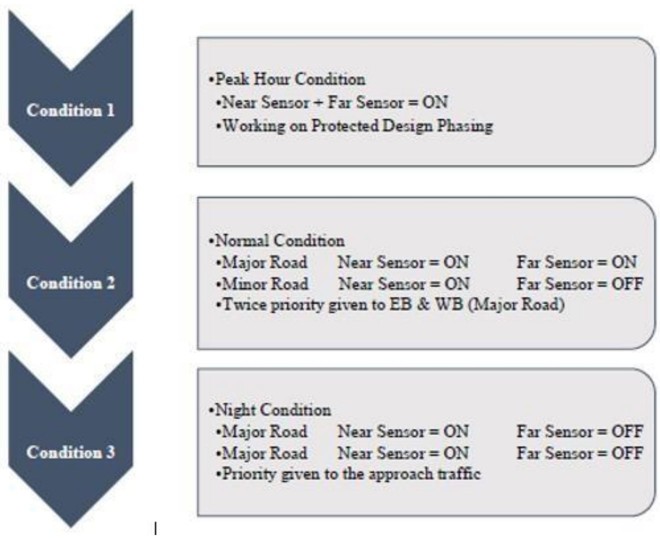

Fig 4. ITS Module Conditions

The first condition is the peak hour condition which means more traffic at intersections and due to heavy traffic, long queues will be formed, at both Near & Far sensors. They will detect traffic that will activate Protected phasing at the intersection. Condition 2 is the normal condition where when on a major road a large number of traffic is observed, which will be detected by near & far sensors. On the other hand, minor roads would have less traffic so the only near sensor will detect the traffic. Due to the above condition, ITS will give twice priority to main road traffic i.e.

- through traffic on the main road will get green.
- right protected traffic on the main road will get green.
- again, through traffic on the main road will get green.
- again, the right protected traffic on the main road will get green.
- through traffic on the minor road will get green.
- right protect traffic on the minor road will get green.

The third condition assumes night conditions where traffic is less so only near sensors will detect traffic and upon the detection of traffic on any approaching intersection, it will get green (because of the absence of traffic on other approaching), in addition to that protected phase will work normally.

7. Conclusion

Due to increased motorization, poor implementation and enforcement of traffic laws, growing population, and urban sprawl, the worst kind of traffic flow were observed at PRR Highway situated along the GT Road N5 connecting Peshawar to Lahore and Islamabad. A review of this congestion suggested the need for new techniques of signal coordination on Peshawar Road to mitigate congestion, reduce traffic delay, and enhance safety and mobility. Existing traffic demand was evaluated using manual traffic counts and recordings. From these counts, it was observed that the road users were facing continuous delays due to the presence of signals on Peshawar road. This study provided indications of good practices that could be followed in the evaluation of alternatives transportation systems from a decision-making perspective. The current scenario indicated that severe congestion occurs due to pre-timed split signals which resulted in more consumption of fuel, and vehicles produced more and more emissions which are deteriorating the environment. Moreover, the level of service is adversely impacted as a result of these traffic delays. The noise disturbances from vehicles and unnecessary honking aggravate people's misery leading to frustration and psychological disorders. It can be seen from the results that the optimization of signal timings using protected signal phasing helped in the reduction of road user travel time by 52.8%, which is directly linked to the reduction of total delays by 56% when compared with the current scenario. This helped in the mitigation of congestion caused by signals on Peshawar Road. The environment would also be protected by the reduction of pollutants caused by slow-moving vehicles with a 1.93 times reduction in vehicular traffic as compared to the current scenario. Design protected signals were also more economically efficient as compared to improving congestion by any geometrical interventions like underpasses or grade separation. Considering all the possible solutions and analyzing the results, it was concluded that the intervention of using protected phasing with signal coordination was the best possible option for this corridor as it provided the minimum delays, reduced fuel consumption, and ensures efficient flow with minimum travel time.

8. Recommendations

The potential of an Integrated ITS with a fully actuated traffic signal with different cycle lengths on both major & minor roads needs to be explored for a transportation system equipped to cater to real-time changes in traffic streams. Furthermore, the geometrical changes with a combination of channelization and diversion of traffic by providing alternative routes are suggested to optimize traffic mobility.

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