ABSTRACT
With the escalating density of vehicles converging at road intersections, the surge in road accidents, traffic conflicts, and traffic congestion has emerged as a pressing concern. This research paper addresses these challenges by employing MC (manual control) techniques to mitigate encroachment issues at three selected intersections. These intersections were identified through a comprehensive analysis of the Ranking-based Instance Selection (RIS), enabling the design of suitable measures to facilitate smooth traffic flow and minimize the occurrence of crashes. In order to gather pertinent data, the study incorporates various parameters such as traffic volume, peak flow rate (PFR), traffic conflicts, accidents, and intersection inventory. Through the implementation of our proposed approaches, which involve both MC techniques and signalized operation, a supreme level of service (LOS) is attainable. Notably, our findings demonstrate a remarkable reduction in the volume-to-capacity ratio ($v/c$ ratio) of up to 0.62. This paper thus serves as a significant contribution to the field of traffic management, offering practical insights for optimizing intersection design and effectively addressing the challenges posed by increased traffic density.

INDEX TERMS
mixed traffic condition, un-signalised 4-leg intersections, level of service, empirical formulas, capacity of intersection

1. INTRODUCTION
The transport system is supposed to be a milestone for the country's development. It only has the potential to ramp the mobility up and down the consuming time usually required between two designations. More seldom, it is a principal reason for catastrophic consequences, leading users from bad to worse. Despite attaining adverse outcomes every day, halting it would not be a good step in spite of knowing its sped-up performance.

Above and beyond, urban economies suffer losses due to traffic congestion and accidents as a major part of productive time is wasted in commuting [1]. In Pakistan, these losses cost 4
to 6 percent of the GDP each year (WHO, 2005). In recent years, the main factor that aggravated congestion is urbanization. It has increased tremendously in many Asian countries as a result of significant economic growth. Among the South Asian countries, Pakistan is the sixth most populous country [2]. This increased urbanization has greatly affected the transport system in Pakistan.

According to the World Health Organization (WHO) Pakistan is facing a major road safety crisis, with a fatality rate of over 25,000 per year, making it one of the highest in the world. The impact of road accidents falls disproportionately on individuals from lower socioeconomic backgrounds, with pedestrians, motorcyclists, and passengers using public transportation being the primary casualties. Among these, young road users face heightened vulnerability owing to their impulsive behavior and flawed decision-making abilities. Road accident has significant economic costs, pushing families further into poverty and imposing a continuous burden on disabled victims and their families. Fatalistic attitudes toward road traffic accidents and a lack of awareness of road safety advancements are major challenges.


In Pakistan, pedestrians, although entitled to utilize the majority of public roads, face heightened vulnerability as the most exposed participants in road traffic. This vulnerability stems from inadequate provisions of pedestrian safety infrastructure, limited public awareness regarding available road crossing facilities, and a regulatory framework that fails to effectively enforce traffic laws to deter unsafe pedestrian practices. Furthermore, both two-wheeler riders and pedestrians exhibit noncompliance with traffic regulations, and adherence to safety helmet laws among two-wheeler riders remains remarkably deficient. Additionally, motorists display a lack of adherence to seat belt usage.

The road safety crisis in Pakistan needs to be addressed urgently through measures such as increased awareness campaigns, stricter enforcement of traffic laws, improvement of road infrastructure, and collaboration among safety stakeholders.

This study aims to reduce traffic crashes in Faisalabad City by using advanced sensing and communication technologies on traffic control devices. The focus is on improving the level of service (LOS) by addressing existing traffic patterns and reducing traffic problems caused by stalled vehicles, encroachment, and unpredictable incidents. Additionally, variable message signs and information dissemination technologies are utilized to provide travelers with relevant traffic information and travel recommendations.

The study showed that the physical and cognitive limitations of drivers made this type of intersection challenging and overwhelming, which was consistent with previous literature. The results suggested that proper delay times and regulations could significantly improve traffic flow characteristics for streaming traffic through study locations. Overall, the study highlights the importance of proper intersection inventory, including road signs, markings, and signal lights, in improving traffic flow and reducing the severity of conflicts. The findings can help transportation planners and engineers design safer and more efficient intersections, considering the limitations of drivers and the varying traffic conditions [8].

The studied scenario comprises three 4-legs non-signalized intersections that are not undergoing efficient progress; in contrast, they are considered part of the city’s prime locations. Owning the classification of areas as though a region occupied by educational institutes was considered an “educational area”. Not only that but shops, markets, workshops, and public property are the inclusion in the term of commercial; likewise, in the commercial area, most of the shops could be found there and that exclusive part of the city could be determined as hectic, congested, and as zero-movement of traffic on the intersection located in the commercial area. In addition, hybrid intersections are defined as those that have not only commercial and educational values but also contain recreation facilities nearby such as public parks, cinemas, restaurants, etc (Table 1).

In order to expose the most congested intersections, the area classification was prioritized following the “Ranking-based Instance Selection” (RIS) method (Fig. 1). Analyzing the 1,182 intersections situated in the commercial area, “intersection A” was addressed as dominant based on the RIS method. A traffic survey was conducted at unsignalized four-legged “Intersection A” in Faisalabad, Pakistan, as shown in Fig. 2. The intersection is situated on Sargodah Road, on the northeast side of the city, in close proximity to the General Bus Stand and a high school, in Fig. 2.

Table 1. A comprehensive overview of intersections analyzed in the study, where unique code names have been assigned snatching associated destination names. The utilization of these code names facilitates efficient problem-solving approaches for intersection-related challenges. The coordinates of each interaction are instrumental in visually mapping their physical appearance from a satellite perspective, aided by a detailed map. This integration of satellite imagery allows for a more comprehensive understanding of the intersections under investigation.

<table>
<thead>
<tr>
<th>Name of intersection</th>
<th>Type of intersection</th>
<th>Code name</th>
<th>Classification of area</th>
<th>Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jamia Chishtia Intersection</td>
<td>4-legged</td>
<td>A</td>
<td>Commercial</td>
<td>31.43412 N, 73.09254 E</td>
</tr>
<tr>
<td>GCUF Intersection</td>
<td>4-legged</td>
<td>B</td>
<td>Educational</td>
<td>31.41826 N, 73.06909 E</td>
</tr>
<tr>
<td>Iqbal Stadium Intersection</td>
<td>4-legged</td>
<td>C</td>
<td>Hybrid</td>
<td>31.43412 N, 73.09254 E</td>
</tr>
</tbody>
</table>
Fig. 1. Analysis of intersection types near the city center. It presents the distribution of intersections within a 3 km radius. Figure (a) highlights T-type intersections as the most prevalent, followed by Y-type and roundabouts. Meanwhile, Figure (b) showcases the distinct X-shaped 4-legs intersections alongside multi-legs intersections with more than four legs.
The intersection under study is unsignalized and has four legs, with each approach having two lanes without faded markings and an improper median turning lane on the major approach (eastbound and westbound). The major approach (northbound), on the other hand, is manually controlled in a state of chaos by a traffic warden. Westbound traffic flows from the east of the city towards the west, with two possible flow directions – through and left turn – sometimes obstructed by bus transport, affected particularly by Light Transport Vehicles (LTV). Eastbound traffic, on the other hand, flows from the west of the city towards the east, with two possible flow directions – through and right turn. A bus stop located on the outermost lane of the southbound approach towards the minor road has the potential to significantly impact the queues and conflicts on this lane, as well as the entire eastbound approach.

Moreover, the presence of available public property alongside the road limits the possibility of road expansion. Of particular concern are the left lanes on the minor road that demands careful maneuvering for vehicles executing this turn amidst traffic approaching from multiple directions. These directions encompass a multitude of simultaneous actions, including the uninterrupted flow of traffic from the east and west, vehicles making left turns from the west, and maneuvers involving the median turning lane on the eastern side. Furthermore, an inventory survey of each lane at “Intersection B” failed to document the presence of a zebra crossing, which serves to safeguard pedestrians by segregating the upstream and downstream sections of the road and prohibiting vehicular access while pedestrians are traversing zebra crossing. Intersection B was selected as the second study location due to its well-known and highly congested nature, mainly because of the presence of multiple schools and colleges on Imam Bargah Road running parallel to Hajvery Road, as indicated in Fig. 3. To perform a comprehensive analysis, a traffic and inventory survey was conducted at Intersection B, located close to Government College University, as shown in Fig. 3. The intersection is situated on Bakar Mandi Road on the northeast side of the city, as depicted in Fig. 3.

Above and beyond, the study highlights the challenges associated with unsignalized intersections having inadequate markings, faded zebra crossings, and improper median turning lanes. The presence of educational institutions near the intersection significantly aggravates traffic congestion, making it more difficult for drivers to navigate the intersection safely. The findings emphasize the need for proper road markings, traffic lights, and coordination of neighboring intersections to ensure a sustainable flow of traffic and promote safety. The study can aid transportation planners and engineers in designing safer and more efficient intersection B that takes into account the challenges posed by different types of traffic and the physical limitations of drivers.

Intersection C was ultimately chosen as the final study location following (RIS) method, owing to its highly congested nature in the evening, mainly due to recreational activities on Iqbal Stadium Road, as indicated in Fig. 4. To carry out a comprehensive analysis, a traffic and inventory survey was conducted at Intersection C, which is situated on New Civil Lines Road on the northwest side of the city. The intersection is located close to Iqbal Stadium and the Suzuki showroom. The left side of Fig. 4 provides a depiction of the intersections’ coordination along with $C_{x1}$, $C_{x2}$, $C_{x3}$, $C_{x4}$, $C_{x5}$, and $C_{x6}$, which can fix an abundance of troubles occurring every day, while its right illustrates a detailed drawing of the intersection, which includes the dimensions of the various road structural elements, the number of lanes on each roadway, and the area of the intersection. Additionally, Fig. 4 shows the sewerage line along four connected roads, as well as the covered area of surrounding buildings. The drawing also provides an illustration of the coordination of...
neighboring intersections. Such aforementioned coordination can facilitate the maintenance of a sustainable and efficient flow of traffic, while also addressing concerns relating to traffic safety.

The study highlights the challenges associated with unsignalized intersections that have inadequate markings, missing zebra crossings, and no median turning lanes. The presence of the stadium near the intersection significantly exacerbates traffic congestion, making it more challenging for drivers to navigate the intersection safely, resulting in immense traffic jams in the evening. The study conducted at Intersection C has provided valuable insights into the challenges posed by highly congested and unsignalized intersections, especially those with inadequate markings and...
no median turning lanes. By highlighting the need for proper road markings, traffic lights, and coordination of neighboring intersections, the study can help our researchers in designing a safer and more efficient Intersection C that prioritizes the safety of all road users. Furthermore, the study’s findings underscore the importance of taking into account the physical limitations of drivers, such as the presence of nearby buildings and sewerage lines, when designing intersections.

2. LITERATURE REVIEW

2.1. Exploring road crashes factors

In our study, we aimed to determine the factors that are becoming the cause of road crashes in different areas by utilizing random parameter models. We analyzed data from 392 urban arterial segments, which were part of 58 corridors in Vancouver, British Columbia. The results of our investigation indicated that numerous factors exerted a substantial influence on the occurrence rate of accidents. To obtain the most accurate outcomes, we developed a Poisson-lognormal (PLN) model [9] that incorporated random parameters such as roadway geometrics, traffic conditions, environmental factors, and driver behavior. This approach enabled us to account for the diversity in road geometrics, traffic characteristics, and other variables that could affect the occurrence of accidents.

According to past research, it has been found that accidents tend to occur in close proximity to or in front of stations [10]. This study has further found and provided valid arguments indicating that schools are hazardous places where crashes have more probability to take place. Moreover, it has been observed that commercial districts exhibit a comparatively elevated incidence of accidents. Furthermore, the specific architectural typologies and functional attributes of structures situated alongside roads exert a noteworthy influence on the vulnerability to accidents. The findings of the study provide clues into the patterns and underlying factors that contribute to accidents. The fact that accidents tend to happen around stations suggests that there may be issues with traffic flow and congestion in these areas. The presence of schools as hazard zones highlights the need for increased safety measures, such as traffic calming measures and improved signage.

Commercial areas, with their high volume of traffic and diverse range of vehicles, pose a significant risk to road users. In addition, in the study, types of buildings located along roads can impact the risk of accidents. For example, tall buildings can create wind tunnels that affect the stability of vehicles, while storefronts with large display windows can distract drivers. Overall, this study highlights the importance of understanding the factors that contribute to accidents and implementing appropriate safety measures to minimize their occurrence. By taking a comprehensive approach to road safety, we can work towards creating a safer and more secure environment for all road users.

2.2. Factors affecting crashes frequency

Our research employed random parameters count models to analyze vehicle crash frequencies. The study utilized data from a previous study conducted by [11]. The results of the study indicated that multiple factors have an impact on accident rates. Factors such as pavement condition rating, international roughness index (IR), pavement rutting, pavement friction, length of the segment being analyzed, shoulder width, horizontal curve, and type of median were all found to be significant factors affecting accident rates. Furthermore, the study identified that traffic-related factors, including the average annual daily traffic (AADT) in mixed traffic streams, played a crucial role in explaining the fluctuation in accident rates.

Burgut et al. [12] undertook a research investigation aimed at identifying the factors that increase the chances of road accidents in Qatar. The study utilized cross-sectional data collected from healthcare centers across Qatar. The findings of the study revealed that around 26 percent of drivers were involved in road traffic crashes, and out of these, 69 percent were males. Additionally, the study identified that approximately 23 percent of drivers involved in crashes were not wearing seat belts while driving, and almost 38 percent of drivers were either eating or drinking while driving. Shockingly, around 42 percent of drivers involved in road crashes were found to be using mobile phones while driving, further compounding the risk of accidents.

The width of a road is a crucial factor in determining traffic flow, and ultimately the safety of road users. Previous studies have established that the risk of accidents decreases with a decrease in road width. Conversely, a high-speed limit on main roads has been found to increase the rate of accidents.

Lin et al. [13] quoted that in rural areas and on main roads where traffic flow tends to be higher, the likelihood of accidents is also greater. This underscores the need for appropriate safety measures, such as traffic calming devices, and improved road infrastructure, to reduce the risk of accidents. In contrast, in urban areas, where traffic flow tends to be higher, the rate of accidents is often lower. This could be attributed to a variety of factors, such as reduced speed limits, improved road infrastructure, and better enforcement of traffic regulations. It is clear, however, road safety is a complex issue that requires a multifaceted approach. By considering factors such as road width, speed limits, and traffic flow, we can begin to identify areas where safety measures can be implemented to reduce the risk of accidents. Ultimately, the goal is to create a safe and secure environment for all road users, regardless of where they are traveling.

2.3. Severity of injuries sustained by pedestrians

The aim of this research was to explore the severity of injuries sustained by pedestrians through the use of alternative disaggregate models [14]. Using Danish road accident data, the study analyzed detailed characteristics of road users with various model specifications. The results suggested that road
user activities and characteristics play a significant role in injury severity analysis. However, the model used for injury prediction may have underestimated essential behavioral attributes related to accidents.

2.4. Conflict analysis and traffic safety

The use of traffic conflict techniques [15] provides valuable insight into the risk of accidents and can inform the design of appropriate safety measures. By understanding the factors that contribute to conflicts, such as road design and operational factors, the researchers can work towards reducing the risk of accidents at signalized junctions. However, the lack of research on unsignalized intersections in developing countries highlights the need for further investigation into this area.

In a nutshell, the study highlights the importance of utilizing innovative techniques to examine the relationship between conflicts and accidents. Furthermore, it emphasizes the imperative of conducting further comprehensive investigations concerning unsignalized intersections within urban regions of developing nations, aiming to enhance our comprehension of the elements that contribute to conflicts in these areas and facilitate the development of suitable safety measures.

The study [16] defines “Traffic conflict” referring to an observable scenario in which two or more road users converge spatially and temporally to such a degree that a collision becomes imminent if their trajectories remain unaltered. This definition underscores the importance of understanding the factors that contribute to conflicts on the road, and the need for appropriate safety measures to mitigate the risk of accidents. By using this definition, researchers and policymakers can work towards developing a better understanding of the underlying causes of traffic conflicts, and take steps to improve road infrastructure and implement effective traffic management strategies to promote road safety.

3. PREREQUISITE OF TRAFFIC FLOW

In order to determine LOS at intersections, it is necessary to study traffic flow and analyze intersection capacity. This section provides a theoretical overview of previous research in these areas, which is divided into two parts. The first part discusses the literature on exclusive approaches, while the second part explains empirical formulas used to determine true values. Understanding these concepts is crucial in accurately analyzing traffic and ensuring safe and efficient intersection design.

3.1. Classification of commercial vehicles in Pakistan

As per the definition, a commercial vehicle is a motorized vehicle that possesses the ability to transport both goods and passengers. Therefore, there are two major categories of commercial vehicles, namely those that are designed to carry passengers, including buses, coaches, and vans, and those that are intended to carry goods, such as trucks, trailers, semi-trailer trucks, and tankers. “V” indicates the inclusion of all types of vehicles included while measuring traffic volume at exclusive intersections.

\[ V = V_{R1} + V_{M2} + V_{R3} + V_{C4} + V_{L5} + V_{W6} + V_{Z7} \] (1)

Where

\[ V = \text{Total volume of traffic} \]
\[ V_{R1} = \text{Auto-Rickshaw/Qingqi} \]
\[ V_{M2} = \text{Motor cycle} \]
\[ V_{R3} = \text{Bicycle} \]
\[ V_{C4} = \text{Car, 4W jeep, and Land Cruiser} \]
\[ V_{L5} = \text{Large bus} \]
\[ V_{W6} = \text{Wagon, Hiace, and Minibus (up to 16 seats)} \]
\[ V_{Z7} = \text{Mazda, Coaster (up to 24 seats)} \]

3.2. Peak hour factor

The peak hour factor (PHF) is employed to transform the hourly traffic volume into a flow rate that corresponds to the most intense 15-min period during the rush hour.

\[ \text{PHF} = \frac{V}{4 \times \text{v}_{15}} \] (2)

Where

\[ V = \text{Total volume of traffic in an hour} \]
\[ \text{v}_{15} = \text{Peak volume of traffic at fifteen-minute intervals} \]

3.3. Peak flow rate

The determination of the peak hour factor (PHF) involves dividing the volume of traffic during the peak hour by four times the volume observed during the busiest 15-min interval. The actual or design flow rate can be computed by dividing the peak hour volume by the PHF. The peak flow rate, represented by “\( v \)”, is calculated by converting the traffic volume into passenger car units (PCU).

\[ \text{PFR} = \text{v}_{15} = \frac{V}{\text{PHF}} \] (3)

3.4. Passenger car unit (PCU)

Passenger car unit (PCU) is a quantitative measure employed in the field of transportation engineering to evaluate the flow rate of traffic on a highway. PCE represents the relative influence that a specific mode of transportation exerts on traffic parameters when compared to a single-passenger car. It serves as a standardized unit for expressing the capacity of a roadway. While a single car is considered as one unit, a bicycle or motorcycle is considered as half a car unit, as depicted in the provided Table 2.

3.5. Stopping sight distance (SSD)

The forward visibility on a roadway pertains to the length of the road that remains observable to the driver or the continuous distance along the road where an object of
exclusive height remains visible to the driver. It consists of two components: a. The distance covered during the time it takes for the driver to perceive and react, and b. The distance necessary to apply the vehicle’s brakes and bring it to a complete stop.

\[
SSD = PRD + BD
\]

Where,

\[
PRD = 1.47 \times V_{i} \times tr
\]

\[
dr = Distance \ travelled \ during \ PRT \ (feet)
\]

\[
Vi = velocity \ (mph)
\]

\[
tr = PRT = 2.5s \ (generally)
\]

3.6. Intersection level of service and v/c ratio

The intersection level of service is determined by analyzing intersection delays and saturation flows. Based on the resulting values, the level of service is expressed using a letter from A to F. This criterion is based on the average delay experienced by each vehicle during a specific time period. Unfortunately, the intersections being studied have a low level of service, except for intersection A, which did have a level of service B. The other two intersections’ levels of service vary during the morning and evening peak hours (Table 3).

3.7. Time headway (Ht)

The time headway denotes the temporal interval between two vehicles as they pass a particular reference point, and its utilization serves in the computation of the overall capacity of the intersection.

<table>
<thead>
<tr>
<th>Level of services</th>
<th>LOS</th>
<th>General operating condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>Smooth flow</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>Reasonably smooth flow</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>Steady flow</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>Approaching unstable flow</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>Unstable flow</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>Breakdown flow</td>
</tr>
</tbody>
</table>

4. METHODOLOGY

This section proposes a research methodology to analyze geometric features and determine the LOS of three selected intersections. A methodology flowchart is provided in Fig. 5, and detailed explanations of each step are presented in the following sections.

4.1. Selection of study area

The research team selected three intersections shown in Fig. 6 for analysis after considering several factors, including appearance, traffic congestion, classification area, intersection type, and surrounding encroachments. These three intersections were chosen from a total of 6,200 intersections located within a 3-km radius of Faisalabad, encompassing all types of intersections in the city. The radius was drawn from the Faisalabad clock tower.

4.2. Data collection

In order to gather data on traffic volume, video graphic surveys were undertaken during the busiest periods of the day (7:00 AM, 1:00 PM, and 6:00 PM) within the timeframe spanning from April 6th to June 12th, 2022. Each survey consisted of 1 h of video footage. The surveys were conducted four days a week, specifically on Monday, Wednesday, Friday, and Sunday. The collected data shown in Table 4 was used to analyze directional movement across the intersections.
**Fig. 6.** Unveils the careful selection process of three marked intersections, guided by key factors such as appearance, traffic congestion influenced by area classification, intersection type, and nearby encroachment. A topographical map of Faisalabad city serves as the backdrop, with code names A, B, and C assigned to the chosen intersections. Zooming in on the affected intersections, highlighted by vibrant red marks, gaining a deeper understanding of their significance within the urban landscape.

**Table 4.** Showcases the collection of traffic flow data from three meticulously studied intersections across a span of four days. The traffic density, represented by the symbol “k” denoting the volume of traffic per hour, provides invaluable insights into the dynamic nature of these intersections. As the data unfolds, an intriguing pattern emerges. The recreation day, Sunday, stands out as particularly crowded at the intersections under study.

<table>
<thead>
<tr>
<th>Description</th>
<th>Morning</th>
<th>Afternoon</th>
<th>Evening</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PFR</td>
<td>k</td>
<td>Ht</td>
</tr>
<tr>
<td><strong>Intersection A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monday</td>
<td>6,932</td>
<td>6,437</td>
<td>0.55</td>
</tr>
<tr>
<td>Wednesday</td>
<td>6,856</td>
<td>5,483</td>
<td>0.657</td>
</tr>
<tr>
<td>Friday</td>
<td>7,544</td>
<td>7,058</td>
<td>0.51</td>
</tr>
<tr>
<td>Sunday</td>
<td>7,428</td>
<td>6,912</td>
<td>0.521</td>
</tr>
<tr>
<td><strong>Intersection B</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monday</td>
<td>5,040</td>
<td>4,494</td>
<td>0.801</td>
</tr>
<tr>
<td>Wednesday</td>
<td>5,800</td>
<td>5,161</td>
<td>0.698</td>
</tr>
<tr>
<td>Friday</td>
<td>6,760</td>
<td>6,162</td>
<td>0.584</td>
</tr>
<tr>
<td>Sunday</td>
<td>6,520</td>
<td>5,723</td>
<td>0.629</td>
</tr>
<tr>
<td><strong>Intersection C</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monday</td>
<td>7,188</td>
<td>6,738</td>
<td>0.534</td>
</tr>
<tr>
<td>Wednesday</td>
<td>8,432</td>
<td>6,619</td>
<td>0.543</td>
</tr>
<tr>
<td>Friday</td>
<td>8,108</td>
<td>6,894</td>
<td>0.522</td>
</tr>
<tr>
<td>Sunday</td>
<td>8,212</td>
<td>7,088</td>
<td>0.507</td>
</tr>
</tbody>
</table>
4.3. Inventory

An intersection inventory is a detailed record of all intersections within a particular geographic area, comprising information about their specific location, type (e.g., signalized, unsignalized, roundabout), number of lanes, turning lanes, medians, and other geometric attributes. In addition, it may encompass data on traffic volume, pedestrian infrastructure, crash history, and other pertinent information that can aid in evaluating the performance of intersections and devising strategies to improve them [18]. Intersection inventory is an indispensable tool for transportation planning and management, facilitating the identification of possible trouble spots and the prioritization of projects for enhancement.

For example, if the inventory indicates that an intersection has a certain number of lanes, but in reality, there are fewer lanes due to construction, it can cause congestion and conflicts for traffic [18]. Therefore, it is essential to maintain an accurate and up-to-date intersection inventory to prevent potential conflicts.

Geometric measurements of the intersections were obtained through direct surveys conducted over a period of three days, namely Monday, April 11, 2022, Tuesday, April 12, 2022, and Wednesday, April 13, 2022. The findings derived from the surveys revealed that the existence of encroachments exerted an adverse influence on the operational effectiveness of the intersections. These encroachments were assessed in conjunction with the data obtained from traffic volume surveys (Tables 5 and 6).

Table 5. Illustrates a comprehensive inventory of intersections, offering a visual representation of key geometric features and data variables. Using a binary system where 1 represents YES and 0 represents NO, it captures the presence or absence of each feature, meticulously measured with the aid of a measuring tape.

<table>
<thead>
<tr>
<th>Description</th>
<th>Intersections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lanes</td>
<td>A  B  C</td>
</tr>
<tr>
<td>Grass median (1 if present, otherwise 0)</td>
<td>2  3  2</td>
</tr>
<tr>
<td>Number of intersection in 500 m</td>
<td>0  0  1</td>
</tr>
<tr>
<td>Channelization (1 if present, otherwise 0)</td>
<td>1  0  0</td>
</tr>
<tr>
<td>Zebra crossing (1 if present, otherwise 0)</td>
<td>0  1  0</td>
</tr>
<tr>
<td>CCTV cameras (1 if present, otherwise 0)</td>
<td>0  0  0</td>
</tr>
<tr>
<td>Stop lane marking (1 if present, otherwise 0)</td>
<td>0  0  0</td>
</tr>
<tr>
<td>Manual Contro (1 if present, otherwise 0)</td>
<td>1  1  0</td>
</tr>
<tr>
<td>Parking slots on Intersections (1 if present,</td>
<td>0  0  0</td>
</tr>
<tr>
<td>otherwise 0)</td>
<td></td>
</tr>
</tbody>
</table>

| Units                                            |     |
| Lane width                                       | m   |
| Left shoulder width                              | m   |
| Right shoulder width                             | m   |
| Central Median Width                             | m   |
| Main Carriageway Width                           | m   |

5. ENROACHMENT AND CONFLICT ANALYSIS

The term “encroachment” in the context of selected intersections refers to a situation where vehicles and pedestrians occupy space illegally, causing obstruction in the flow of traffic and potentially leading to accidents. Encroachment can also occur due to parked cars, street vendors, beggars, different types of stalls, and pedestrians crossing the street in areas that are not designated for crossing.

Encroachment is a significant problem that can greatly impact the safety and efficiency of intersections, especially in areas with high traffic volume. This issue is prevalent in many cities in Pakistan and is often attributed to the lack of enforcement of traffic laws and regulations. The level of encroachment at intersections A, B, and C shown in Fig. 7 was assessed using a scale ranging from 1 to 10, with higher values indicating more significant encroachment.

The process of gathering data for traffic counts and conflicts took place during the busiest hours of the day, spanning four days within the summer months of 2022, particularly in the months of April, May, and June. Each intersection involved the participation of two observers. One observer focused on tallying traffic conflicts, while the other observer documented traffic volumes from a single approach, with intervals of 20 min. Subsequently, they exchanged approaches and proceeded to record the traffic conflicts and volumes accordingly. The two observers were stationed at two different locations (Fig. 8 (b) (c)), which were located between 300 and 900 m away from the “intersection A”. Furthermore, alongside the aforementioned tasks, the observers carried out a comprehensive roadway inventory throughout the duration of the survey days. This inventory encompassed a wide array of data, including details pertaining to street alignment and width, the number of lanes, curb radii, the condition, and markings of the pavement, channelization features, parking arrangements, obstructions affecting sight distance, as well as the presence and condition of various signage.

The process involved consolidating various types of conflicts into a unified category and calculating their collective count, followed by determining the percentage of each conflict type relative to the total number of conflicts. Subsequently, the conflict types were ranked in descending order based on their respective percentages. The resulting rankings were presented in Fig. 8, alongside the relative cumulative frequency distribution of conflicts. The findings indicate that the left-turn, same-direction conflict type attained the top rank. This outcome can be attributed to several factors, including the absence of a dedicated left-turn storage lane, inadequate channelization at “Intersection A,” deficient road markings, insufficient sight distance for left-turning vehicles in relation to oncoming through traffic, a specific range of encroachments, and a high volume of left-turning and opposing through vehicles observed across the majority of the analyzed intersections.

Conversely, the conflict type involving a right turn from the left obtained the lowest rank, likely attributed to its rare
Table 6. Serves as the foundation for evaluating intersection performance, with a particular focus on “Intersection C.” The findings astoundingly reveal that this intersection experiences a higher number of accidents and exhibits a unique Lane change type of conflict, unmatched by the other intersections under study. Prepare to witness the intricate tapestry of intersection dynamics, as conflict counts unveil a wealth of insights.

<table>
<thead>
<tr>
<th>Intersection name</th>
<th>No. of accidents</th>
<th>Time</th>
<th>LT same direction</th>
<th>RT same direction</th>
<th>Slow vehicle</th>
<th>Lane change</th>
<th>Opposing LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>PH</td>
<td>42</td>
<td>18</td>
<td>76</td>
<td>0</td>
<td>64</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>PH</td>
<td>23</td>
<td>13</td>
<td>134</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>PH</td>
<td>138</td>
<td>59</td>
<td>112</td>
<td>5</td>
<td>43</td>
</tr>
</tbody>
</table>

Fig. 7. Unveiling the extent of unauthorized land use and occupation, this figure delves into the captivating realm of encroachments. Range and type of encroachment are examined, shedding light on the affected land and its repercussions. The scale of encroachment, employing a 1 to 10 rating, unveils the occupied areas alongside roads, with a striking dominance of (8) car parking encroachments. Within this intricate tapestry, Intersections A, B, and C emerge as focal points, each harboring diverse levels of encroachments. Their presence significantly impacts the efficiency of the studied intersections, portraying a profound influence on their overall performance.
incidence. This conflict arises when the leading vehicle on the left side executes a right turn by crossing the central portion of the main street roadway into an opposing lane, prompting the driver of the following vehicle to take evasive measures. The presence of this issue can be linked to inadequate road markings and the absence of central medians.

In order to ascertain potential risks and operational challenges, the boundaries of safety problems were established, and specific issues were identified and chosen for the implementation of countermeasures. The severity of each problem was assessed by computing the average and atypical daily conflict counts within the study area, employing the methodologies outlined by Parker et al. [19]. The outcomes are visually depicted in the provided figure. Noteworthy, the results diverged significantly from the prior findings reported by Crowe et al. [20]. In Fig. 9 (a) Notably, “Intersection A” experienced the highest number of conflicts, predominantly stemming from left turns (LT) initiated from the left side. In contrast, conflicts associated with right turns (RT) originating from the right side witnessed a significant decrease. This decline can be attributed to the presence of a smaller island strategically positioned on the right side, effectively reducing the occurrence of such conflicts. In Fig. 9 (b) the survey conducted during the designated period revealed that “Intersection B” exhibited a distinct pattern. The conflicts predominantly observed were associated with right turns executed from the left side (RT-LT conflicts). Overall, the findings suggest that the daily counts of conflicts were markedly greater in the vicinity of Iqbal Stadium when compared to the area surrounding GCUF. Nevertheless, as Fig. 9 (c) displays, “Intersection C” demonstrated a consistent occurrence of conflicts across different types, with no significant changes observed. However, the overall number of conflicts steadily increased over time. This rise can be attributed to factors such as improper road marking and vehicles encroaching upon designated areas.

5.1. Priority ranking of intersections

A process of prioritization was undertaken to ascertain the intersections presenting the highest level of hazard among all the unsignalized four-leg intersections that were examined. This prioritization process involved assessing the risk
level of each intersection and developing a priority ranking on the basis of the risk index. Some conflict types were found to be better indicators of risk than others. The concept of risk was defined as the likelihood of accidents resulting in injuries, with three levels of risk developed by Mullard et al. [21]. Based on this categorization, conflict types that result in right-angle or head-on collisions were identified as displaying a significantly elevated propensity for injury accidents. Conversely, conflict types leading to rear-end collisions, whether involving a turning vehicle or not, exhibited a moderate potential for injury accidents. In contrast, other conflict types were determined to be comparatively less hazardous and primarily posed additional challenges to drivers due to the heightened demand for their attention.

The diverse conflict types were evaluated and assigned rankings according to three distinct risk levels. The conflict types encompassing opposing left turns from the left lane, and right turns from the left lane were identified as carrying the highest level of risk. Conversely, conflict types involving left turns in the same direction, right turns in the same direction, lane changes, right turns from the left lane, and left turns from the right lane were determined to possess the lowest risk. To calculate the risk index, the formula suggested by Taylor et al. [22] was utilized:

\[
(RI)_{ij} = K_i(IV)_{ij}
\]

\[
(RI)_j = \sum_{i=1}^{n} RI_{ij}
\]

Where

\(RI_{ij}\) = The risk index corresponding to conflict type “i” at intersection “j”,

\(K_i\) = the relative weight assigned to conflict type, 
\(= \frac{W_i}{\sum_{i=1}^{n} W_i}\)

\((IV)_{ij}\) = The indicator value associated with conflict type “i” at intersection “j”,

\(n\) = the number of conflict types,

\(W_i\) = The weighting factor attributed to conflict type “i”,

\(RI_j\) = total risk index for intersection ij

In order to ascertain the weighting factor, the conflict type achieving the highest rank was assigned a value of 1, followed by assigning a value of 2 to the conflict type with the subsequent highest rank, and finally assigning a value of 3 to the conflict type with the lowest rank. Subsequently, the relative weight for each conflict type was calculated. Furthermore, the primary conflict rate per 1,000 vehicles was employed as an indicator value for each conflict type at the respective intersection.

Utilizing the provided data, the risk index was approximated for every conflict type and subsequently computed for each individual intersection. A priority ranking was then developed for the studied intersections based on the risk index, with Table 7 Presenting the risk index and the corresponding rank order for each intersection. The findings indicated that among all the intersections examined, “Intersections C” emerged as the intersection posing the greatest safety risks. Consequently, it was determined to be of utmost importance and assigned the highest priority for implementing countermeasures.

<table>
<thead>
<tr>
<th>Intersection name</th>
<th>Risk index</th>
<th>Priority ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>35.6</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>37.7</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>22.52</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 7. A comprehensive analysis of risk index, providing a meticulous evaluation of each conflict type across intersections. The calculated risk index for individual intersections comes together to shape a compelling narrative of safety priorities.
6. RELATION BETWEEN LOS AND V/C RATIO

In scholarly investigations, the v/c ratio (volume-to-capacity ratio) is commonly employed by researchers as a metric to assess the operational efficiency of unsignalized intersections. Likewise, practitioners rely on this ratio as a principal indicator of intersection performance. In this study, the researchers sought to gain deeper insights into this relationship by examining the correlation between the level of service (LOS) and v/c ratio for the intersections under scrutiny. Based on their findings, they put forth distinct v/c thresholds for each LOS category. Their approach involved initially reviewing the v/c thresholds suggested by the Canadian Capacity Guide, followed by an exploration of the connection between the LOS categories proposed in their study and the corresponding v/c ratio.

6.1. Relation between LOS and v/c ratio based on CCG 2008

Within the realm of signalized intersections, the Canadian Capacity Guide presents thresholds delineating the various levels of service (LOS) based on the volume-to-capacity (v/c) ratio. Seeking to establish a lucid and unambiguous correlation between LOS and the v/c ratio, as stipulated by the guide, the researchers embarked on this study. Adhering to the guide’s recommendation of a cycle time of 100 s, they scrutinized the impact of factors beyond the v/c ratio, including green time and cycle time, on delay. To delve into this intricate relationship, the researchers meticulously computed delay values across a range of v/c ratios and green ratio (g C/C0) ratios spanning 0.3 to 0.7. Moreover, they ventured further by calculating delay values for v/c ratios extending from 0.05 to 1.3. Notably, the guide posits a saturation flow value of 1800 PCU (passenger car units) per hour per lane, applicable to urban areas boasting commendable pavement conditions and favorable weather conditions. The researchers employed the mathematical model presented in the guide to compute the delay. This model, expressed by an equation (7), encompasses the relevant variables and parameters necessary for accurate estimation.

\[ d = d_1 PF + d_2 + d_3 \]  

(7)

\[ d - 1 = 0.50 C \frac{\left[1 - \frac{x}{x} \right]^2}{\left[1 - \frac{x}{x} \right]} \]  

(8)

\[ d_2 = 15T(x - 1) + \sqrt{(x - 1)^2 + \frac{240x}{cT}} \]  

(9)

where, \( d \) is the average control delay in sec/veh, \( d_1 \) is the average uniform delay per vehicle, \( d_2 \) is the average incremental delay per vehicle, PF is the progression adjustment factor, \( T \) is the analysis period in minutes and all other variables are previously defined.

6.2. Determination of v/c ratio

The v/c ratio, which is the measure of flow rate relative to the capacity of an intersection, is commonly referred to as the “degree of saturation”. It is a critical output of unsignalized intersection analysis as it indicates the amount of intersection capacity being utilized by current traffic. Essentially, it is a measure of the existing or proposed capacity of the intersection. In order for an intersection to operate effectively, its v/c ratio must be less than or equal to 1. If the v/c ratio is greater than 1, it indicates that the intersection is unable to handle the current traffic demand.

Additionally, if the v/c ratio exceeds 1 in future projections, it indicates that the intersection will not function properly. Analysis of the current conditions of intersections has revealed high v/c ratios, which means that the flow rate is significantly greater than the capacity of the intersections.
At Intersection C during peak hours, the maximum v/c ratio exceeded 1, which indicates that the demand was more than 200 percent of the capacity provided. The highest value of v/c was recorded during the morning peak hours. Since capacity is difficult to measure in the field, equation (10) is used to estimate it.

\[
C = (0.38 + 0.34n)(s)(d)(f)
\]  

where,

- \(C\) = capacity (in vehicles per hour)
- \(n\) = number of lanes
- \(s\) = saturation flow rate (in vehicles per hour per lane)
- \(d\) = distance between vehicles (in feet)
- \(f\) = adjustment factor (usually between 0.8 and 1.0)

### 6.2.1. Determination of v/c ratio and LOS prior to MC stimulation in the peak hour.

The graphs depicted in Fig. 10 (a) and (b) provide insights into the intricate relationship between the level of service (LOS) and volume-to-capacity (v/c) ratio at intersections. The analysis reveals a...
direct proportion between the headway ratio ($H_t$) and v/c ratio, indicating that as $H_t$ increases, so does the v/c ratio. On the other hand, the LOS values (ranging from 1 to 6, denoted as A to F) exhibit an inverse relationship with $H_t$. Remarkably, both Intersections A and B exhibit a maximum LOS of 3, symbolizing “LOS C,” which occurs at v/c ratios of 0.95 and 0.85, respectively. This suggests that these intersections operate at an optimal level, with reasonably low congestion and satisfactory traffic flow.

A shorter time headway between cars leads to higher volume-to-capacity ratios, indicating increased traffic volume within the intersection. However, Fig. 9 unveils a contrasting scenario at Intersection C. Here, a higher number of conflicts are detected, leading to a higher LOS denoted as E. Specifically, Fig. 10, a peak v/c ratio of 1.10 is observed, resulting in LOS E. This indicates a decline in performance, with increased congestion and decreased traffic efficiency compared to Intersections A and B. Overall, these graphs offer valuable insights into the relationship between LOS, v/c ratio, and $H_t$ at intersections. They highlight the importance of maintaining an appropriate v/c ratio and minimizing conflicts to achieve optimal intersection performance and ensure smooth traffic flow.

6.2.2. Analysis of traffic flow through MC method. The analysis revealed remarkable results for intersections when a traffic officer manually controlled the delay time. In this particular scenario, one-hour data collection included tracking traffic conflicts and volume. The findings demonstrated a substantial reduction in congestion and accidents, highlighting the effectiveness of this approach. However, it also brought to light a notable drawback: the queue length on each road connected to the intersection experienced a significant increase. Despite the overall positive outcomes, the observed trade-off between reduced congestion and longer queues emphasizes the need for a comprehensive evaluation of the impact on traffic flow and user experience.

Figure 11 (1)(2)(3), (4)(5)(6), and (7)(8)(9) provide an insight into the traffic flow at intersection A in the absence of manual control. The lack of regulation and adjustments in this scenario leads to congestion and inefficiency. Inputs from specific sources intersections, such as $A_{x1}$, $A_{x2}$, $A_{x3}$, and $A_{x4}$, result in poor traffic release at Intersection A. However, when manual control (MC) operation is implemented not only in Intersection A but in Intersections B and C as well, improvements in efficiency are observed. Despite these enhancements, the study falls short of achieving the desired and expected level of service (LOS).

To address the challenges at Intersections A, B, and C and minimize conflicts and accidents, parts (3)(6)(9) introduce a novel approach. By transforming the unsignalized Intersection A, B, and C into the function of signalized ones, employing the principles discovered by a team member, a stopwatch and proper delay time are utilized during one peak hour. The results highlight substantial differences experiencing parts (3)(6)(9) as though showcasing a significant reduction in congestion, revealing acceptable queue lengths, decreased traffic conflicts, zero accidents recorded, and a balanced input-output relationship.

Figure 11 presents an analysis of traffic flow at Intersection B and Intersection C without manual control. In both cases, congestion hampers the smooth release of traffic from input sources, such as $B_{x1}$, $B_{x2}$, $C_{x3}$, and $B_{x4}$ for intersection B, and $C_{x1}$, $C_{x2}$, $C_{x3}$, and $C_{x4}$ for intersection C. However, the implementation of manual control (MC) operations improves efficiency to some extent, although the desired and expected level of service (LOS) is not achieved.

To optimize traffic management and minimize conflicts and accidents at both intersections, a novel approach, showcased in Fig. 11 part (6) for intersection B and part (9) for intersection C, involves transforming unsignalized intersections into the functionality of signalized ones. This is achieved by employing a stopwatch, adhering to proper delay times, and implementing a 70-s green-red cycle length,
specifically during one peak hour. The analysis of this method provides additional insights into the impact of the cycle length on traffic management. The results demonstrate significant differences between Parts (4)(5) and (6) for Intersection B, and between Parts (7)(8), and (9) for Intersection C. These differences include reduced congestion, acceptable queue lengths, decreased traffic conflicts, zero incidents, and a balanced input-output relationship.

In order to resolve traffic conflicts and ensure smooth traffic flow without congestion, we employ a method called the MC technique. This technique involves a consistent cycle of stopping and running traffic, similar to a signalized intersection. Figure 12 displays the coefficient of variation, which demonstrates the extent to which the v/c ratio varies when using or not using the MC technique at three different locations studied. The remarkable consideration of negative axis values into their positive counterparts was undertaken to unveil the profound disparities witnessed before and after the meticulous application of the MC method on the revered Intersections A, B, and C.

### 7. CONCLUSION AND FUTURE WORK

This research paper addresses the growing concerns related to road accidents, traffic conflicts, and traffic congestion resulting from encroachment and level of service (LOS) 5, which represents an unacceptable E grade, at the studied intersections. Through the implementation of Manual Control (MC) techniques, this study effectively mitigates encroachment issues at three carefully selected intersections. The analysis reveals that a shorter time headway between cars correlates with higher volume-to-capacity ratios, indicating increased traffic volume within the intersection. Our study successfully reduces the volume-to-capacity ratio (v/c ratio) from an initial value above 1.00 to 0.67 and 0.61 through the implementation of our proposed approaches. Additionally, the study significantly reduces traffic conflicts and alleviates traffic congestion to a considerable extent.

The combined employment of MC techniques with signalized operation enables the attainment of a supreme level of service (LOS). Notably, the findings of this study showcase a significant reduction in the volume-to-capacity ratio (v/c ratio) of up to 0.635. These outcomes make a significant contribution to the field of traffic management, providing practical insights for optimizing intersection design and effectively addressing the challenges posed by the increasing density of vehicles.

In future research, the collected data can be utilized to investigate other factors influencing road intersections in Faisalabad, including a comparative analysis of the efficiency of unsignalized, manual control, and signalized intersections. Furthermore, it is essential to expand the coverage of intersection inventory, incorporating fully coated lane markings, zebra crossings, medians, and other geometric features. It is worth noting that the level of congestion at intersections directly correlates with the frequency of traffic conflicts, highlighting the importance of diligent monitoring and management.

### REFERENCES


