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Analysis of Frequent Car Accidents in the City of Tabuk, Saudi Arabia: A Survey-Based Study

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Abstract

Ensuring road safety is significantly influenced by driver behavior and the driving environment, which are significant factors in the prevention of traffic accidents. While plenty of research has been performed about driving behavior in developed nations, a significant gap exists in comprehending the role of road design and infrastructure in developing countries like Saudi Arabia. This study aims to address this gap by analyzing a high-frequency accident hotspot on the Tabuk University Bridge along King Fahd Road. A survey was conducted focusing on the role of human, operational, and infrastructural factors contributing to recurring accidents to identify potential root causes of frequent accidents. Using a combination of police reports, historical accident data, and traffic simulation collected from survey data, this study examined the bridge's design, vehicular speed criteria, and traffic flow patterns. The analysis of survey results reveals that design flaws, particularly the narrowing of lanes and inadequate merging areas, exacerbate accident risks, especially during peak hours. Based on the output, three solutions were proposed, with the expansion of the bridge and reallocation of lane widths showing the most promising performance in reducing accident occurrences. The paper aims to assess modern approaches and practices in bridge design at crucial urban areas within the city. The findings of this research contribute to the development of targeted interventions for enhancing road safety in Saudi Arabia's rapidly evolving urban environments.

Keywords
Car accident, Survey analysis, Traffic movement, Driving simulator, Accident history.

1. Introduction
Road safety has been a persistent social and economic issue in Saudi Arabia over the last several decades. The Kingdom of Saudi Arabia has witnessed an alarming rise in both the number and severity of road traffic accidents, leading to high rates of injuries and fatalities. According to Mansuri et al. (2015), the consequences of such accidents not only impact public health but also strain the nation's economy. Despite concerted efforts by lawmakers and transportation authorities to reduce accident rates through policy changes and awareness campaigns, Saudi Arabia remains one of the countries with the highest rates of road traffic accidents, ranking among the top 10 globally, as reported by analyzed by (Kamh et al., 2024).

Various factors contribute to this high accident rate. Human behavior is a significant driver of road accidents, with aggressive driving, speeding, distracted driving (particularly the use of mobile phones), and driving under the influence of alcohol or drugs being some of the key causes (Alhazmi et al., 2022; Ramisetty-Mikler & Almakadma, 2016). However, human factors alone do not fully explain the accident statistics. Infrastructure deficiencies—such as poor road design, inadequate signage, and insufficient safety standards—also play a crucial role in increasing the likelihood of accidents (Miaou, 1994; Rolison et al., 2014). Several analyses of the accidents have been conducted by public and transportation enthusiasts, and solutions to the problem have been suggested (Al-Hajj et al., 2022; Vardi, 2014). Of course, these were mostly not based on scientific facts or research. However, the vast majority of car accidents are caused by one of the four major factors shown in Table 1.

Table 1. The main factors contributing to a car accident

	Operational Factors	Human Factors	Infrastructure Factors	Nature Factors
Clarification	Traffic management in the city	Driver behavior	Damage to or design errors in roads	Environmental situations
Example	Traffic light timing errors	Speeding	A sharp horizontal curve on a highway	Snowy weather

The issue of road infrastructure is particularly critical in Saudi Arabia, where rapid urbanization and growing vehicle ownership have significantly outpaced the development and upgrading of road safety measures (Rohrer et al., 2021). The country's population has been growing steadily over the past few decades, with increasing urbanization driving expansion in cities like Riyadh, Jeddah, and Tabuk (Alghnam et al., 2019; Islam & Gazder, 2023). With this expansion has come a dramatic rise in motor vehicle ownership, placing enormous strain on the country's road networks, many of which were not designed to accommodate such high traffic volumes (Yagoub et al., 2021). As a result, road networks in rapidly developing urban areas are often overwhelmed, leading to what are known as "black spots"—areas with a disproportionately high number of road traffic accidents (Amoudi et al., 2021). These black spots, particularly in cities like Riyadh and Tabuk, are characterized by a frequent recurrence of multi-vehicle accidents, often during peak traffic hours. Research shows that infrastructure inadequacies such as narrow lanes, poor signage, and improper merging zones contribute significantly to the recurrence of accidents in these areas (Bindajam & Mallick, 2020). On another study, Rahman et al. (2022) highlight that Saudi Arabia's road safety issues stem not only from insufficient safety measures but also from the absence of long-term planning that anticipates the consequences of rapid urban expansion. This has led to a reactive approach to infrastructure development, where roads are expanded only after traffic congestion and accidents become serious issues.

Recent advancements in Intelligent Transportation Systems (ITS) and the application of big data analytics offer promising avenues for reducing road traffic accidents (Alkaabi, 2023). ITS technologies are generally divided into two broad categories: systems that enhance traffic mobility and systems that minimize human error. The former includes innovations like the Advanced Traveler Information System, Advanced Traffic Management System, and Advanced Public Transport Management System, all of which improve traffic flow and reduce travel time (Anwar et al., 2023; Singh & Gupta, 2015). The second category is the minimization of human factors, which are responsible for nearly three out of four accidents on the roads (Suzuki et al., 2022).

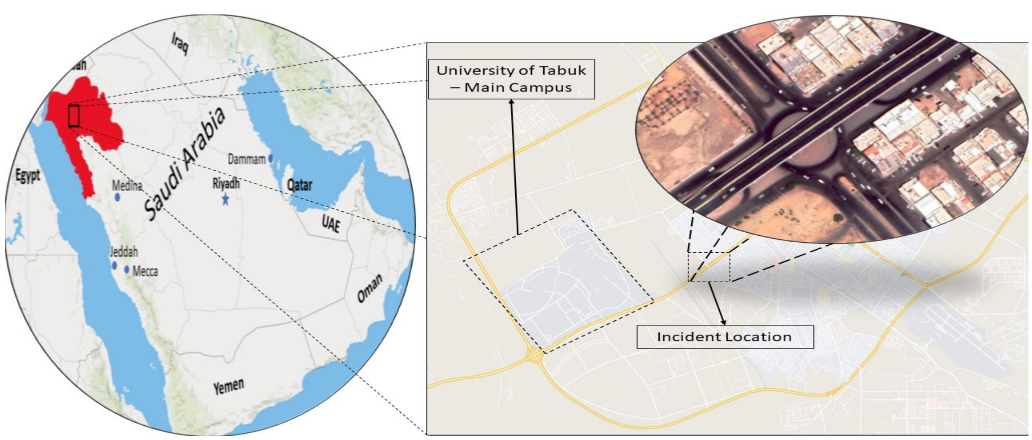

Figure 1. Location of the incident studied in this work.

Although human factors are to blame for most traffic safety incidents, the safety and design of the infrastructure are also essential for safer roadways. However, there has been only limited research conducted on real-world cases to investigate the latter factors and their role in the worsening accident rate. Based on the literature studies, a significant amount of study has already been conducted focusing on the impact of driver psychology on traffic accidents in Saudi Arabia (Akin et al., 2022; Alhomoud et al., 2022; Mohamed & Bromfield, 2017). Consequently, very few survey-based studies have focused on the impact of infrastructure design on accidents, particularly in Tabuk City. Therefore, this research aims to analyze and address unanswered questions regarding the causes behind a major accident-prone (aka hot spot) in the city of Tabuk, located in the northwest region of the Kingdom of Saudi Arabia, as shown in Figure 1. This location has experienced multiple accidents (involving more than 15 vehicles) in each of the last five years.

1.1 Motivation of the study

The motive behind this study is to identify the causes of recurring accidents on the Tabuk University Bridge on King Fahd Road in Tabuk City, coming from the east and heading to Tabuk University. And then develop solutions to prevent their recurrence. According to the accident rates that occurred on the aforementioned site, it is classified among the black spots on the city's road network map, which requires studying it in detail and in a scientific manner; This is to put in place appropriate preventive measures.

1.2 Objectives

This paper aims to study the causes of the repeated accidents on the Tabuk University Bridge House located on King Fahd Road in Tabuk City, to develop appropriate solutions that prevent the recurrence of such accidents in the future, and submit specific recommendations in the form of urgent recommendations that include: quick measures that can be implemented immediately, and long-term measures that can be included in the plan to develop the future road and transportation network in the city.

3. Research Methodology

This research will use several steps to reach the results. The analysis phase will be divided into two critical steps, which are having a general idea of the crash location and collecting the data. The latter step requires several procedures and methodologies to ensure that reliable and effective solutions can be provided. The remaining steps of the research will be the analysis of the collected data, the determination of the possible causes of the accidents, and the verification of the proposed solutions using a simulation approach.

3.1 Understanding the scene of the accident

The first crucial step is to understand the facts surrounding the incidents and gather crucial information about the scene. This preliminary step is necessary to design the research plan process and evaluation methodology. Examples of information to gather include

- The exact location of the accidents
- The entrance and exit properties of the bridge and the number of traffic lanes
- A review of an aerial photo of the roads surrounding the bridge and the demands of nearby traffic
- Pavement conditions of the bridge
- Initial visual analysis of the bridge's overall safety and structural characteristics

3.2 Data collection

This step is especially critical for successfully achieving the goals of this research. The magnitude of the research makes the step multifaceted. Thus, the process of data collection has different approaches and will rely on different sources. However, this research will follow four routes to acquire the needed data:

3.2.1 Police analysis

Police are the first officials to respond and arrive at the scene. For the police analysis, data collection will involve gathering detailed information on the accidents, including the date, time, and specifics of each incident, such as the number of vehicles involved and the severity of damage sustained by each. Visual evidence, including images and videos of the accidents, will be analyzed to provide further interpretation of the events. Input from those involved, including their interpretation of the accidents and any suggestions they propose, will be considered. Additional environmental factors like weather and road conditions at the time of the accidents will also be documented. To ensure comprehensive analysis, contact information for victims will be collected to facilitate follow-up inquiries and clarification of any details.

3.2.2 Historical data of the accidents

To have a better understanding of what happened, it is important to reach out to the victims involved in previous accidents, especially the first collision of each accident. Besides the obvious question of "what happened?" other important questions need to be asked. Information needs to be gathered on all factors that could contribute to accidents, including behavioral causes.

For the historical record of the accident, the data collection will include information on the point of origin and the intended destination of the trips involved to identify any patterns or potential detour options for future recommendations. Events leading up to and during the accidents will be documented to assess the behavior of the drivers and others involved, allowing for an analysis of whether human factors played a significant role. Additionally, the estimated speed of the vehicles before the accidents will be examined to understand the extent to which speed may have contributed. Information on the model, type, and maintenance level of each vehicle will be gathered, as variations in vehicle performance, especially in braking, and mechanical issues may have exacerbated the incidents. The health status and awareness of the drivers prior to the accidents will be evaluated to determine if any medical conditions or distractions influenced the outcomes. Lastly, the demographic information of the drivers will be recorded to identify any common characteristics that might offer insight into accident causation trends.

3.2.3 Area observation (what triggered the first collision?)

After the initial data collection, the researcher will have a preliminary idea of the major factor(s) that contributed to the accident. In this step, questions regarding other plausible factors besides human factors that might have contributed to the accidents (especially the first crash of each case) will be answered, such as questions about the bridge design. Therefore, further data will need to be collected, such as:

- The distance needed to stop a car at the crash site: in highway design, much attention is given to the distance and sightline needed to stop a car. As shown in Figure 2, a curve in the road can obstruct the sightline of the driver. This is true whether the curve is on the level or on a hill. Thus, there are several standards in highway design to make sure the sight distance of a vehicle is always longer than the braking distance. It is known as the stopping sight distance (SSD) and is determined as shown in Equation 1. In this step, a thorough investigation will be implemented to check the possibility of whether the bridge design had any involvement in the accident.

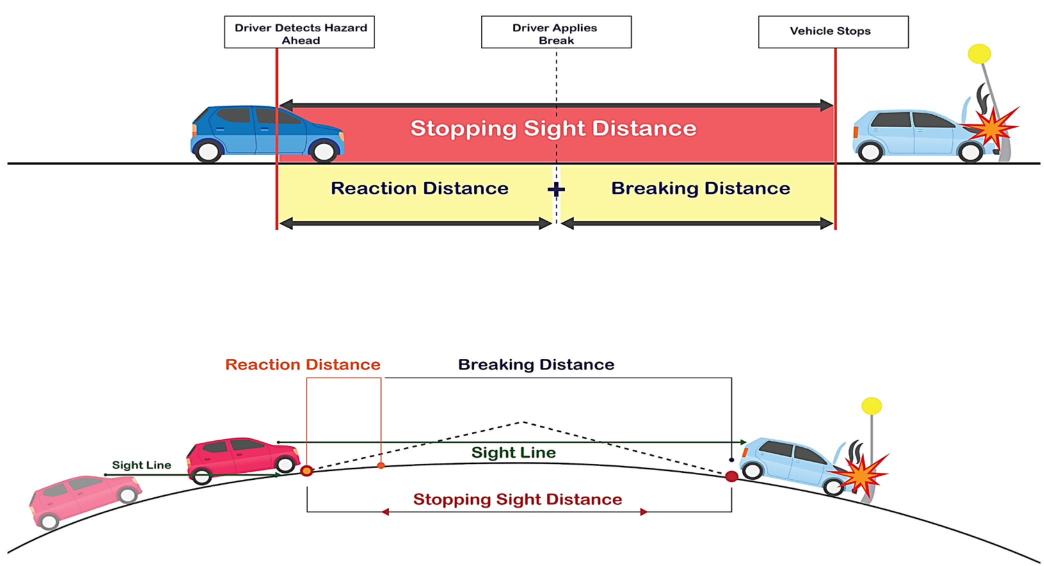

Figure 2. The main components of stopping sight distance

- The speed limit at the crash site: in this step, different speeds will be checked to see if the speed limit at the crash site is appropriate and whether it could have contributed to the accident.

- The speed at which the accident occurred: changes in speed at the crash site will be compared to see if the speed of the vehicle in the accident varied before reaching the bridge, while going over the bridge, and after going over the bridge. Several factors impact the braking distance, such as slope and weather. Additionally, variations in speed and surface conditions, assuming a normal vehicle and healthy driver, greatly impact the SSD, making this speeding factor a major part to closely investigate (Al-Turaiki et al., 2016).
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- The measurements of the bridge and its design characteristics: this step will provide information such as the surface grade level and overall dimensions of the bridge. This step is a critical part of this research due to the cost and/or effort that would involve fixing any design issue. However, as shown in Figure 3, the solution of the design issue, if it exists, does not always mean overhauling or construction but rather minor surface alignment work.
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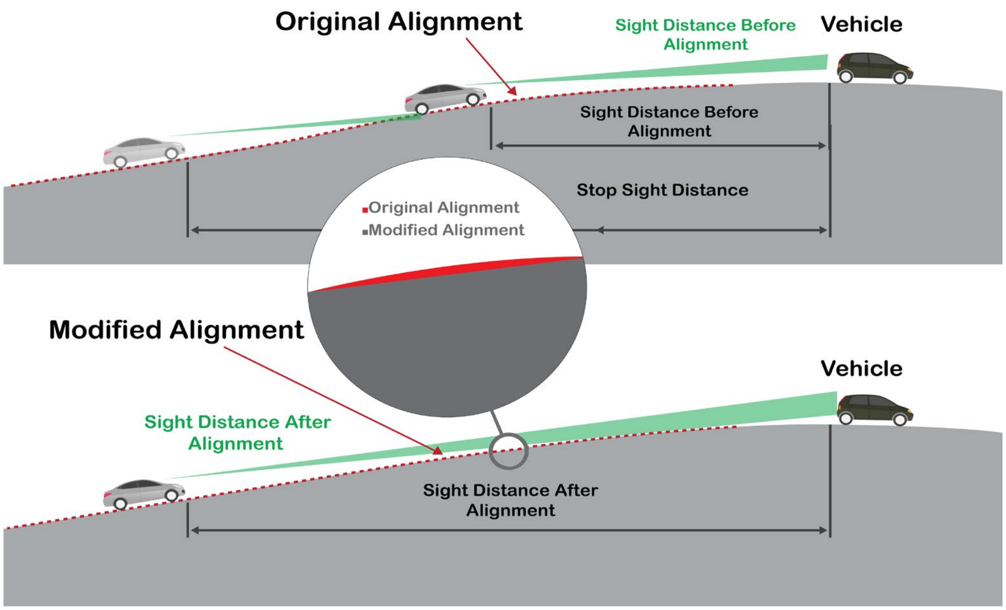

Figure 3. Stopping sight distance on a vertical road curve

- The status of the pavement at the accident site: in this step, the skid resistance of the pavement will be measured to ensure that it meets highway safety standards and could not be a cause of the accident.

$$SSD = vt + \frac{v^2}{2g\left(f \pm \frac{n}{100}\right)} \tag{1}$$

Where:
v = Speed of the vehicle
t = Reaction time
f = Friction coefficient
n = Slope of road surface

3.2.4 Secondary observation

This step ensures that no factors that might have caused the accidents will be left unchecked. Several factors could have contributed to the accidents, including:

- Animals crossing the road or other obstructions: animals or road obstructions might have caused the first crash, which led to a pile-up of cars.
- Speed camera location: if drivers suddenly become aware that a camera is recording their speed, they may suddenly hit the brakes and skid, causing other cars to skid as well and an accident.
- The University of Tabuk gating system: the main gate located near the accident site could be a cause of accidents. In this step, several observations need to be conducted at each gate of the main campus and the class schedule of

the campus needs to be reviewed to determine when students are leaving classes, getting into their cars, and leaving the area. Scheduling issues could create congestion on campus roads and in areas surrounding the campus.

3.3 Data analysis and proposed solutions
In this step, the data is collected, and answers are reviewed. The main questions of why the accidents took place and why many vehicles were involved rather than only two vehicles will be answered. Having the data analyzed will highlight facts that can be proven scientifically. Finding the causes of the accident will provide the opportunity to find a solution(s) that could prevent similar events of a similar magnitude from happening again. The process of analysis will use a series of steps, including statistical analysis of the collected data, to detect anomalies or any unusual patterns in the data that the human brain cannot detect. Additionally, simulation of the data using state-of-the-art software will ensure the accuracy of the findings and the value of the candidate solutions.

3.4 Implementation of solutions using a driving simulator
This is the final step in providing safe and reliable solutions for the issue. While this step is the final one among different prior steps, it is the most important and demanding one. During this step, a traffic simulator will be used to mimic the real-world scenario and driving environment of the accident site to test each solution separately and capture its effect precisely. A simulation model will be developed for the study area based on aerial imagery data from a drone, with the aim of developing different scenarios for the proposed solutions and evaluating them through the simulation model to choose the best one. The model was developed using VISSIM software, which is one of the most famous, best, and most widely used models in simulating and analyzing traffic movement worldwide.

4. Results and Discussion
4.1 Analysis of Previous Traffic Accidents
Traffic safety studies require data related to driver behavior, traffic control procedures, and traffic safety procedures available on the road network, in addition to previous accident data, which is the backbone of the data through which we can see many causes of traffic safety problems. Often, accident data is scarce, which requires data for long periods of time, usually less than three years. This is so that any statistical analysis can be carried out, which is often not available in traffic studies related to road safety. It is well known that the results and accuracy of data analysis depend on the size and accuracy of the available data. Still, the nature of traffic accident data varies, as they occur randomly and unexpectedly, which makes collecting accurate data about each accident a difficult task that requires certain technical expertise, as the accident is investigated after it occurs, and often the accident lacks reliable eyewitnesses. In the case of this study, we will rely on accidents that have recently occurred at the site of the study, on the paper of those accidents, and on the statements of witnesses to them in order to reach an idea of how the accident occurred and its circumstances. Figure 4 shows real pictures of previous accidents in the study area.

Figure 4. Photos from previous incidents.

Based on the survey data, it can be seen that all accidents that occurred on the bridge house were of the recurring rear-end collision type, where more than two cars were involved in one accident. Additionally, accidents mostly happen on Sunday (and Monday) at the start of the school day.

4.2 Road Characteristics Analysis

The university bridge consists of three parts. For traffic lanes, each lane width is 3.0 m (The width of the path is considered traffic relatively small according to the specified speed and type of road), as the standard width of the track is 3.6 m. Figure 5 shows a picture of the inadequacy of the track width for the movement of trucks and buses in general. When heading down the bridge towards the university, the width decreases to reach 2.9 m for the right lane and 2.75 m for the left lane; this leads to the fact that when descending, the brake works as if two lanes actually, where drivers avoid driving right next to the car next to them. The decrease in the width of the left lane appears from a distance as if there is a break in the sidewalk of the central island into the road on the left side.

Figure 5. Decrease in the width of the right and left lanes on the bridge descent

4.3 Evaluating the merge area after getting off the bridge

There is a speed bump at the exit just before the merge, which forces drivers to slow down to a very low speed and then start accelerating again, with cars next to them on the bridge at high speeds, making it difficult (Al-Wathinani et al., 2021). The engineering design of the service roads is also flawed, as there is a direct connection from the left lane to the service road, which forces drivers to merge, and their speed is still at low numbers because of the artificial speed bump as seen in Figure 6, as in the merging sectors of a two-lane road, it is done gradually from the right lane side, from the American Highway Capacity Manual HCM, which is the most widespread and widely used reference worldwide. By adding the merger sector problem with the problem of the reduced road width on the bridge house located immediately before the merge point, we have two potential collision points: the first: the right lane side due to the aforementioned high merge, and the second: the left lane side due to the breakage of the median and the sudden narrowing of the lane, referred to in the previous item. The two points work together to cause the sudden reduction in speed and the sudden change in the lane that drivers make at that point when traffic volumes increase and there are three cars driving side by side in the three lanes, which forces the driver of the vehicle in the left lane to reduce speed so that the two adjacent cars can pass.

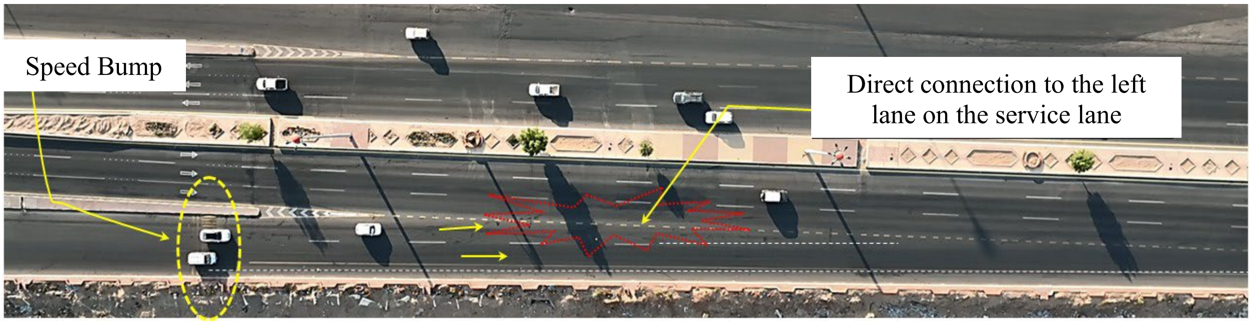

Figure 6. Direct left lane connection forces drivers to merge early at low speeds.

4.4 Analyzing the Volume of Traffic Movement

Figure 7 shows the percentages of traffic volume distribution on the three lanes on the bridge descent during peak and off-peak periods, which clearly shows a decrease in the percentages of use of the right and left lanes on the bridge descent, indicating that drivers avoid using them, which confirms the observations referred to in the previous item, regarding the presence of a decrease in the width of the right and left lanes on the bridge descent.

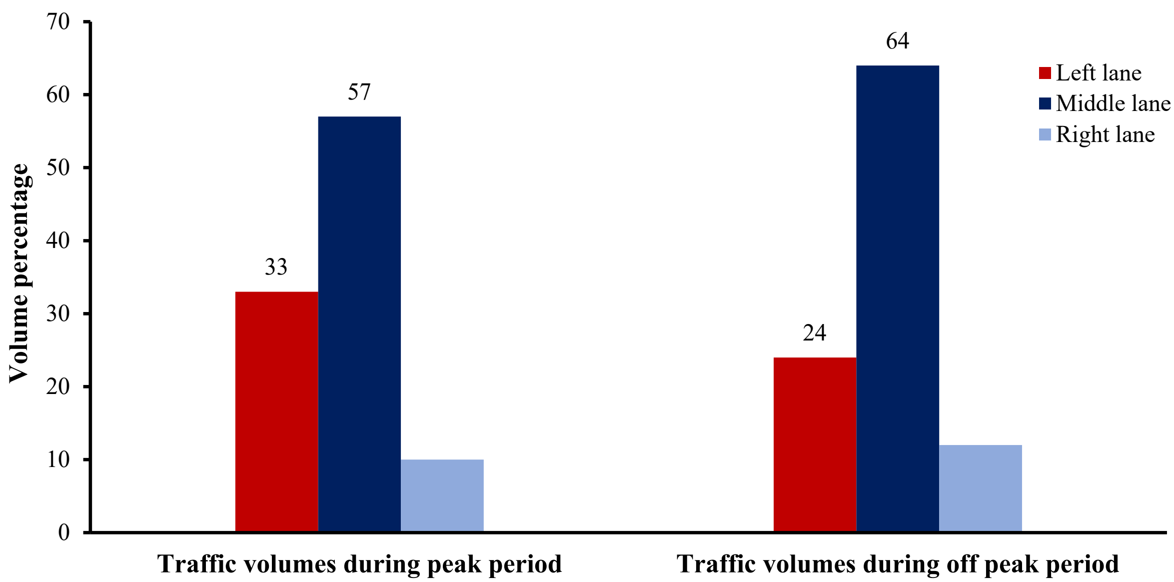

Figure 7. Traffic volume distribution ratios on the three lanes on the bridge house.

4.5 Analysis Speed of Vehicles

Speeds were measured at the bridge house and at the bridge ramp, using aerial photography, during off-peak periods to determine the change in speed distribution at the house, compared to the ramp, and whether the engineering design has an effect on speeds in the case of free movement, and that it is not due to traffic congestion. The distribution of speeds is also an input into the steps of developing the traffic simulation model in order to ensure that the traffic movement in the program represents reality (Figure 8).

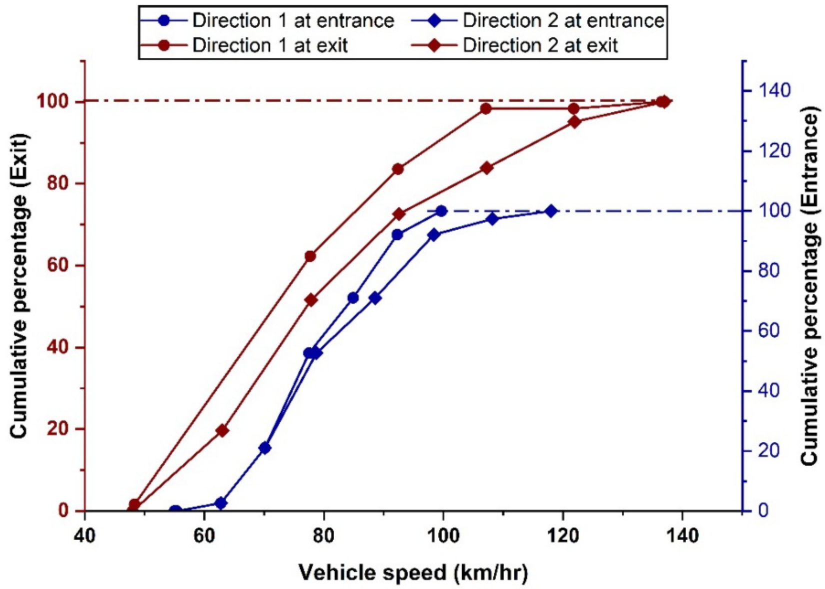

Figure 8. Vehicular speed analysis

Figure 8 shows the cumulative distribution of speeds at the bridge entrance and the bridge exit for both directions of movement, where direction (1) represents the direction of movement for those coming from the university and direction (2) represents the direction of movement towards the university, which is the direction under study. It is clear from the two figures that the speeds in the direction towards the university are higher than the opposite direction for those coming from the university and that there is a difference between the cumulative distribution of speeds in both directions. In a similar study of Shi et al. (2023) analyzed bridge structures in China using similar methods. They found that lane width and road gradient significantly affected speed distributions, leading to higher accident rates on downhill sections of bridges.

4.6 Proposed Solutions

Based on the analysis and survey data, three proposed solutions were put forward as follows:

The first one involved bridge house expansion. This proposal includes expanding the bridge house to become four traffic lanes, with the width of the lane being modified so that there is no decrease, as is the case in the current situation, and that the expansion is from the service road side, as is the case in the bridge house for the opposite direction, as shown in Figure 9.

Figure 9. Bridge House Extension Proposal (Example of Bridge House Model for Reverse Direction).

The second proposal involves converting the bridge to two traffic lanes, aiming to reduce lane conflicts and improve safety by providing a more organized traffic flow, as seen in Figure 10. The design would include wider lanes marked by solid yellow lines to separate opposing directions and dashed white lines for lane changes within each direction. This configuration simplifies traffic patterns, potentially minimizing accidents caused by sudden lane changes. However, while this proposal enhances safety, it may lead to longer travel times during peak hours due to reduced capacity compared to the four-lane option.

The third proposal suggests closing the bridge entirely and diverting all traffic to the adjacent service road. This approach will eliminate the congestion and safety issues on the bridge by redirecting vehicles through alternative routes. While this would alleviate problems on the bridge itself, the service road may struggle to handle the increased traffic volume, leading to significant delays and congestion.

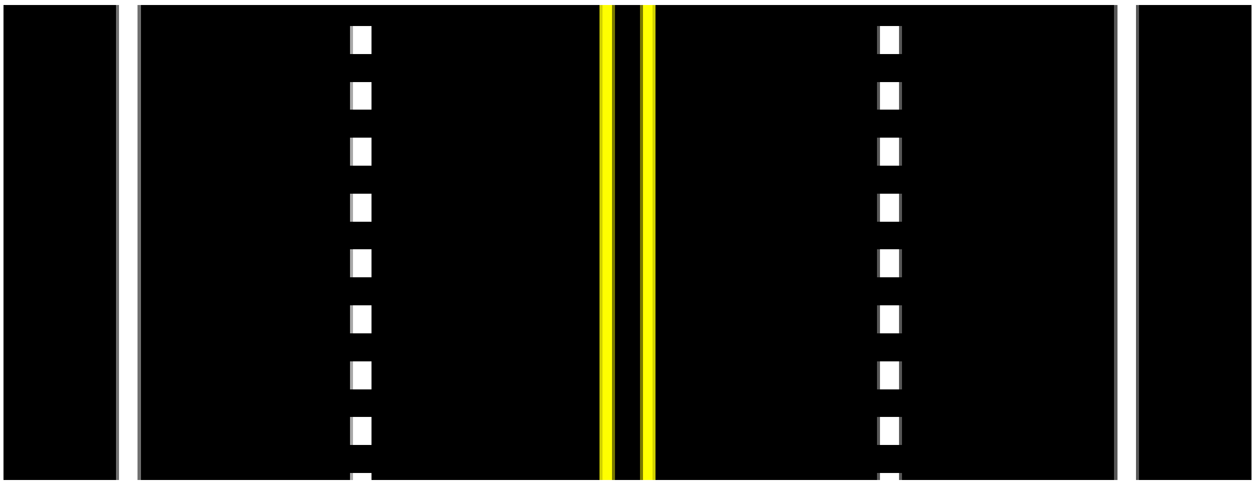

Figure 10. Converting the bridge to two lanes only with a shoulder at the end.

4.7 Comparison Between Proposed Solutions

The average journey time of vehicles in the study area is used as a key metric in comparing different traffic solution alternatives which is shown in Table 2 below. The comparison demonstrates that Solution 1, which involves widening the bridge to four lanes and reallocating lane widths, yields the most favorable results in terms of travel time reduction. Specifically, Solution 1 results in a consistent decrease in average journey times compared to the base scenario, with minimal delays across all time intervals. The second proposed solution, converting the bridge to two lanes with a shoulder, also shows improvement in travel time over the base scenario, though it is not as effective as Solution 1. For instance, at the 900–1500-minute interval, Solution 1 achieves an average travel time of 108.079 minutes, while Solution 2 slightly outperforms it at 102.584 minutes.

Table 2. Average journey time using different proposed solutions.

TIME INT (min)	Average Travel Time (min)			
	Base	Solution 1	Solution 2	Solution 3
900-1500	108,566	108,079	102,584	183,210
1500-2100	117,307	116,472	109,079	430,687
2100-2700	124,017	123,879	115,137	522,548
2700-3300	126,887	126,480	117,822	574,300
3300-3900	121,635	122,664	113,287	589,505
3900-4500	124,464	124,729	115,826	598,287

Considering the overall simulation output, it is clear that widening the lanes to 4 at the bridge house and widening the left lane is the most appropriate. It is clear here that converting the bridge to 2 lanes may be a possible solution, and although the simulation was based on the available data, the changes made to the bridge and the roads leading to it require an expansion of the study to include them, as the changes made were not included in the data collected in this study.

5. Conclusions and Recommendations

The study outcomes can be summarized in the following points:

- All accidents occurred in the same location and of the same type and coincided with the beginning of the peak period, indicating a link between the volume of traffic and the engineering design of the site due to the accident.
- The accident occurs as a result of cars suddenly slowing down, with a speeding car behind them, not leaving enough distance, which causes the collision, and with the lack of sufficient sight distances for oncoming cars due to the vertical curve of the bridge, successive collisions occur.
- The traffic volume study showed that drivers prefer to drive in the middle lane, and avoid the right and left lanes; the reason is due to what was mentioned in the previous point.
- The study of speeds showed that there is a difference in the distribution of speeds in the two directions of movement, as they tend to be higher in the direction under study (the direction to the university) compared to the opposite direction during off-peak periods.
- The operating speed on the bridge house for the direction under study is estimated to be about 95 km/h, which is higher than the permissible values, indicating the need to take action to adjust the speeds in the direction under study.

Finally, three scenarios for solutions were evaluated. The first one is to expand the bridge house, increase the width of the left lane, and remove the overhang so that the house becomes four lanes, like the bridge house in the opposite direction. The second proposal is to re-plan the bridge so that it becomes two lanes. The third solution is to close the bridge and divert traffic to the service road. The simulation and analysis program for the three scenarios showed that the first scenario was the best, followed by the second scenario and that the third scenario was not preferred at all and would cause serious traffic problems. In spite of this, it is imperative to recognize certain limitations of the study. The research insufficiently takes into account human behavior and its potential significant impact on the accidents that occurred. Therefore, distractions must be examined to achieve a comprehensive grasp of the underlying reasons.

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Biography

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