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Enhancing Traffic Operations and Safety Performance at Roundabout Intersections: A Simulation-Based Case Study of Dhalkebar Roundabout on the East-West Highway

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Abstract

The main aim of this study is to explore alternatives to enhance the traffic operational and safety performance of the Dhalkebar three-legged roundabout in terms of capacity, delay, operational speed, LoS, and traffic conflicts using VISSIM microsimulation model and Surrogate Safety Assessment Model (SSAM) software under three improvement alternatives viz; with geometric improvement, metering concept, and turbo roundabout. The evaluation of the alternatives has been conducted for both base-year traffic and forecasted (in next 10 year) traffic scenarios. For the base-year traffic scenario, it was found that alternative III performed the best, with reductions in delay, traffic conflicts, and improvements in capacity by 34.55 seconds, 1044 conflicts, and 604 PCU/hr, respectively. Additionally, the LoS improved to level B, and the average operational speed was higher compared to the other two alternatives. Similarly, for the forecasted traffic scenario, alternative III again showed the best performance, with reductions in delay and conflict, along with an increase in capacity by 44.58 seconds, 5776 conflicts, and 1074 PCU/hr, respectively. The LoS improved to level C, and the average operational speed was higher than the other alternatives. Therefore, in terms of both safety and traffic operational performance, alternative III was identified as the best improvement option for both the base and forecasted traffic scenarios.

Keywords: *Turbo Roundabout; Metering; Simulation Capacity; Delay; Conflict*

1. Introduction

Traffic congestion is a serious problem affecting both developed and developing countries. Commuters face significant challenges, such as delays and long queues, especially at major intersections during peak hours. Intersections are particularly problematic because vehicles from different directions try to use the same space at the same time (Aderamo & Atomode, 2011). To reduce conflicts and keep smooth traffic flow, various control measures are used at intersections, those are classified as uncontrolled, stop-controlled, roundabouts, signalized, and grade-separated intersections (Indo-HCM, 2017). According to the World Health Organization (WHO), road traffic injuries are the leading cause of death for children and young adults aged 5 to 29 years. They are also the eighth leading cause of death for all age groups, surpassing serious diseases like HIV/AIDS and tuberculosis. The fatality rate from road crashes approximately 1.19 million per year (WHO, 2023). This highlights the need to prioritize the safety of road users when designing roads and intersections. Roundabouts are known for their effectiveness in reducing delays, improving traffic flow, and enhancing safety at uncontrolled intersections (Muley & Al-Mandhari, 2014). Roundabouts have gained global recognition as an effective traffic management solution by improving safety, reducing congestion, and enhancing traffic flow efficiency. Countries like the United Kingdom, France, and Australia have successfully integrated roundabouts into their road networks, demonstrating significant reductions in traffic delays and accident rates (Rodegerdts et al., 2010). In the United States, modern roundabouts have shown benefits in reducing vehicle emissions and fuel consumption by minimizing stop-and-go traffic (Bared et al., 1997). However, in the Nepalese context, modern roundabouts are a relatively new concept, with their effectiveness influenced by rapid urbanization, increasing vehicle ownership, and mixed traffic conditions (Shrestha & Bajracharya, 2018). Cities like Kathmandu face severe congestion, at key roundabout intersections (Poudel & Shakya, 2019). Proper design, public education, and integration with other traffic management strategies are essential for their successful implementation in Nepal, aligning with global best practices to enhance urban mobility and road safety.

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Dhalkebar intersection is part of East-West highway. It connects three approach roads from the Lahan side, Bardibas side, and Janakpur side. Number of traffic volume increased yearly at the Dhalkebar roundabout due to rapid urbanization and upgradation of different road sections connected to it. In the Janakpur approach leg it was recorded that number of traffic increased from year 2011/2012 to 2020/2021 was 3417 PCU to 6275 PCU. Similarly, in Lahan approach leg number of traffic increased from year 2011/2012 to 2020/2021 was 5722 PCU to 11332 PCU and in Bardibas approach leg number of traffic increased from year 2011/2012 to 2020/2021 was 3985 PCU to 11597 PCU (DoR SSRN, 2021).

2. Relevant Literatures

2.1. Roundabout and Performance Parameters

At a roundabout, traffic flows in a clockwise direction, characterized by merging, weaving, and diverging movements, which generate multiple conflict points. The geometric design of a roundabout, including its shape and size, significantly influences vehicular speeds around the central island. These speeds directly affect the gap-acceptance process, which in turn impacts the roundabout's capacity and level of service (LOS). A well-designed roundabout can minimize conflict points and enhance capacity (Polus & Shmueli, 1997). Conversely, a poorly designed roundabout may result in operational and safety challenges, such as increased crash rates, heightened conflict points, extended travel times, queue formation, and delays (Flannery, 2001). As per the Indo-Highway Capacity Manual (Indo-HCM) 2017, a guideline tailored to Indian traffic conditions and driver behavior, capacity is defined as the maximum number of vehicles that can pass through a specific point under prevailing conditions. Capacity serves as a critical performance metric for roundabouts (Indo-HCM, 2017). Delay, another key performance indicator, refers to the additional time required for vehicles to traverse the roundabout (Indo-HCM, 2017). According to the Highway Capacity Manual (HCM) 2010, published by the Transportation Research Board (TRB), speed and travel time are interrelated measures of operational performance (HCM, 2010). Operational speed is typically quantified as the average traffic flow speed or the 85th percentile speed of passenger cars (Indo-HCM, 2017). The level of service (LOS) is a qualitative metric that encompasses factors such as speed, travel time, freedom to maneuver, frequency of traffic interruptions, comfort, convenience, and safety (Indo-HCM, 2017). Additionally, traffic conflicts are a critical indicator of safety performance at roundabouts (Parker & C.V., 1989). Collectively, these metrics—capacity, delay, operational speed, LOS, and traffic conflicts—are essential for evaluating the operational efficiency and safety performance of roundabouts.

2.2. Microsimulation Using Vissim

PTV VISSIM, developed by PTV Planung Transport Verkehr AG in Germany in 1992, is a widely recognized traffic simulation software used for modeling and analyzing traffic systems. It is particularly effective for evaluating intersection geometries and assessing transportation priority schemes, such as public transit or emergency vehicle prioritization. VISSIM is a versatile tool employed in traffic planning, design, and management, enabling engineers to simulate diverse traffic scenarios and identify optimal solutions prior to project implementation (Lin et al., 2013). The software's strength lies in its behavior-based microsimulation approach, which allows for the detailed modeling of complex transportation systems and the evaluation of alternative design strategies. This capability has been endorsed by the Washington State Department of Transportation, highlighting its utility in addressing complex traffic challenges and supporting evidence-based decision-making in transportation projects (WSDOT, 2021). Worldwide, numerous studies have utilized PTV VISSIM to assess and evaluate the operational performance of roundabouts and intersections. For instance, Kłos and Sobota (2019) employed the VISSIM microsimulation model to conduct a case study in Gdańsk, Poland, analyzing existing and future scenarios by altering the geometric configurations of roundabout inlets. The study focused on metrics such as average time losses and level of service (LOS). The findings revealed that modifying and improving the inlet geometry of the roundabout led to an enhanced LOS and a reduction in average travel time losses. Similarly, Zainuddin et al. (2018) applied the VISSIM microsimulation model to evaluate the operational performance of a T-leg intersection on Pengkalan Weld Road, Malaysia. The study compared the existing T-leg intersection with a proposed roundabout upgrade, demonstrating significant improvements in vehicle delay times and overall LOS after the conversion to a roundabout. In another study, Elhassy et al. (2021) conducted a comparative analysis between conventional three-legged roundabout and improved turbo roundabouts in Florida, using VISSIM microsimulation software. The results indicated that turbo roundabouts exhibited superior operational performance, with notable improvements in delay, capacity, and safety compared to conventional roundabouts. Additionally, Martin-Gasulla et al. (2016) investigated roundabout intersections in Spain using the VISSIM microsimulation model, incorporating a metering concept to regulate traffic flow. The study focused on a roundabout with three major approach legs and concluded that the implementation of metering significantly enhanced both operational performance and safety at the intersection. Collectively, these studies underscore the effectiveness of VISSIM as a robust tool for evaluating and optimizing the design and performance of roundabouts intersections.

2.3. Surrogate Safety Assessment Model (SSAM)

The Surrogate Safety Assessment Model (SSAM), developed by the Federal Highway Administration (FHWA), is a robust analytical tool designed to assess, identify, and estimate traffic conflicts among diverse road users. SSAM operates by analyzing trajectory data generated from microsimulation software, such as VISSIM, enabling the identification of potential conflict points without the need for actual crash data. This approach provides a cost-effective and proactive alternative to traditional field-based crash and conflict data collection methods. By simulating various traffic scenarios, SSAM facilitates the evaluation of potential safety improvements at specific locations based on the identification and analysis of traffic conflicts. A case study conducted by Ghanim and Shaaban (2019) in Doha, Qatar, demonstrated the efficacy of SSAM in identifying traffic conflicts at intersections. The study compared field-observed conflicts with those generated by SSAM using VISSIM trajectory data. The results revealed a strong correlation between observed and simulated conflicts, leading to the conclusion that SSAM is a reliable tool for identifying traffic conflicts at intersections. This finding underscores the potential of SSAM as a valuable tool for assessing conflict scenarios, including those at roundabouts, where traffic interactions are complex and safety evaluations are critical. In another case study conducted in the United States, SSAM was applied to evaluate a 1,880-meter road stretch using VISSIM trajectory data. The simulation model was first calibrated to replicate real-world conditions, ensuring the accuracy and reliability of the SSAM outputs. The calibration process confirmed that SSAM-generated conflict and crash scenarios closely mirrored those observed in the field. Following calibration and validation, the study explored various access management scenarios, assessing their safety implications using SSAM. The findings demonstrated that SSAM, when integrated with VISSIM, serves as a viable tool for evaluating the safety impacts of proposed access management strategies. This capability positions SSAM as a complementary approach to traditional crash-based and field-based conflict analysis, offering a proactive and simulation-driven methodology for assessing future transportation infrastructure implementations (Kim et al., 2018).

2.4. Research at Intersections in Nepal

In Nepal, numerous studies have employed microsimulation software to analyze and propose geometric improvements at various intersections, addressing the growing challenges of traffic congestion and safety. Acharya (2020) conducted a comprehensive study of the New Baneshwor intersection, evaluating seven distinct scenarios aimed at reducing conflict points by restricting vehicle movements in both the main and service lanes. This study highlighted the potential of targeted geometric modifications to enhance intersection efficiency and safety. Similarly, Ranjeet (2019) utilized the VISSIM microsimulation model to assess performance improvements at the same intersection by introducing an underpass. The study focused on key performance indicators such as level of service (LoS), travel time, and delay, demonstrating the effectiveness of infrastructure interventions in mitigating congestion and improving traffic flow. Suwal (2017) examined the operational performance of Prithvi Chowk in Pokhara using VISSIM, focusing on delay as a primary metric. The study evaluated four alternatives: reducing the diameter of the central island, restricting southbound traffic, implementing a four-phase signal system, and permitting right turns from northbound traffic. These scenarios provided valuable insights into the potential benefits of geometric and operational modifications in enhancing intersection performance. Pandey (2016) applied SIDRA Intersection 8.0 to assess the current performance of the Itahari roundabout, analyzing metrics such as degree of saturation, delay, and LoS. The study explored various improvement scenarios, including geometric enhancements and the implementation of a metering concept, offering evidence-based recommendations for optimizing roundabout operations. In a safety-focused study, Shrestha (2016) analyzed conflicts at the Satdobato intersection in Kathmandu using a combination of VISSIM and the Surrogate Safety Assessment Model (SSAM). The study evaluated nine alternatives to assess their impact on safety performance, underscoring the utility of microsimulation and conflict analysis tools in identifying and mitigating potential safety risks. These studies demonstrate the growing reliance on microsimulation software in Nepal to evaluate intersection performance and propose evidence-based solutions.

3. Objectives and Contribution

This study investigates technically feasible intersection improvement alternatives by evaluating both operational and safety-related performance measures under Nepal's heterogeneous traffic condition. A review of existing literature indicates that previous research in Nepal has primarily addressed either operational efficiency or safety concerns at intersections, without integrating both aspects into a comprehensive framework. Consequently, a gap remains in the development of holistic countermeasures that simultaneously enhance traffic flow and mitigate safety risks. To address this gap, this study conducts a analysis combining operational performance and safety assessment. Furthermore, this research introduces the concept of a turbo roundabout in Nepal, a novel approach not previously explored in local transportation studies.

4. Methodological Framework

The methodological framework for this study comprises several critical stages: development of a base model, calibration and validation, and evaluation of various intersection improvement scenarios. A robust dataset, specifically collected for this analysis, serves as the foundation for model development. Multiple improvement alternatives were systematically modeled to assess their operational and safety impacts under heterogeneous traffic conditions. The calibrated and validated model was further adapted for forecast traffic, a ten-year traffic, enabling a comprehensive evaluation of long-term intersection performance. The subsequent sections provide a detailed account of the data collection methodology, model development procedures, and analytical approach employed in this study. Figure 1 shows overall methodological approach for this study.

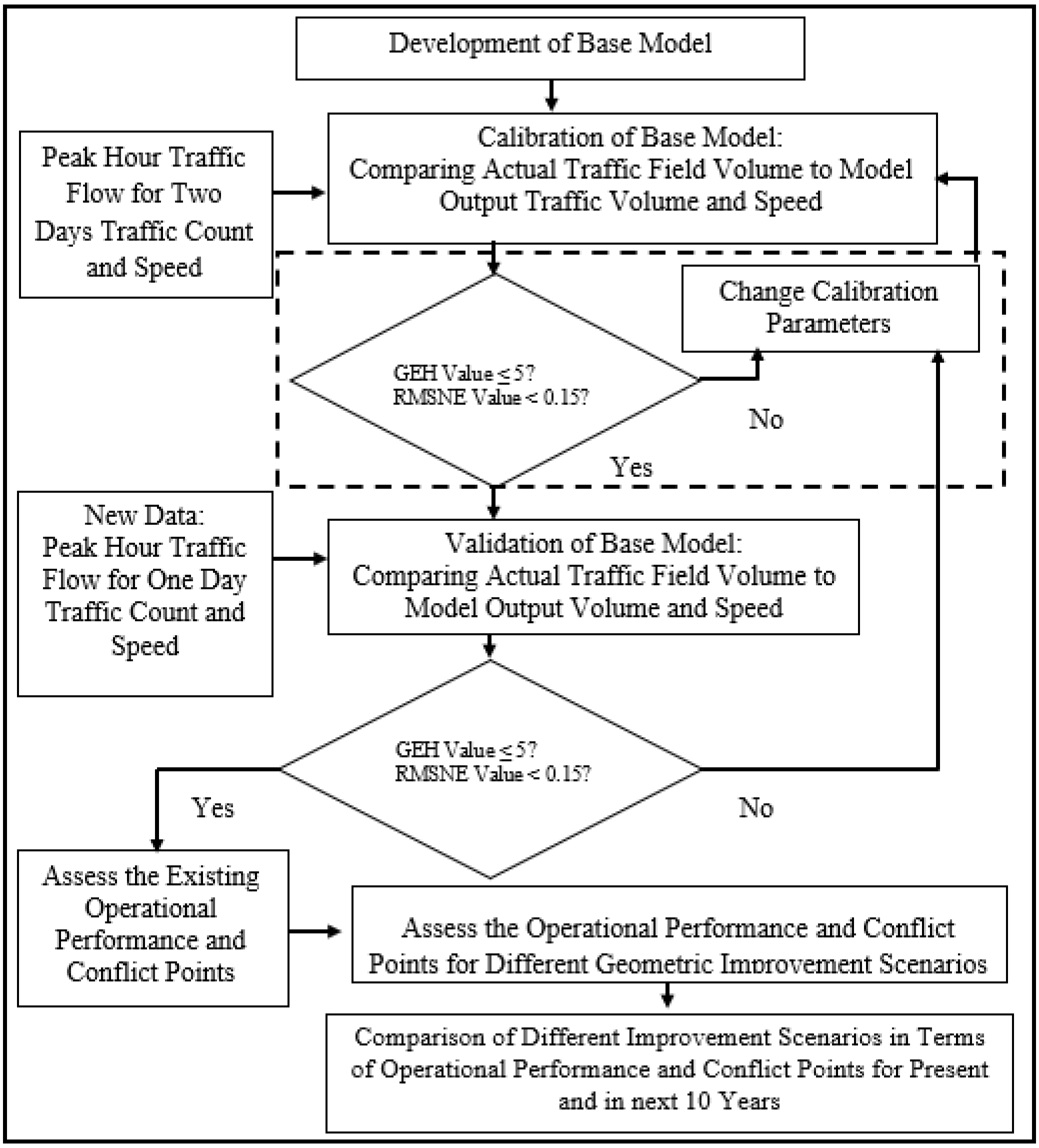


Figure 1. Research approach

4.1. Data Collection

4.1.1. Primary data

This study involved the systematic collection of primary data on roundabout geometry, traffic volumes, pedestrian movements, and vehicle speeds to support a comprehensive operational and safety analysis. Geometric data were obtained through detailed field surveys, measuring key parameters such as the number of lanes, entry and exit lane widths, and the diameter of the central island. To capture traffic and pedestrian flow, video-based data collection method was conducted over three consecutive working days. Cameras were strategically placed to record continuous traffic and pedestrain volume. The recorded footage was then analyzed to classify and quantify vehicle and pedestrian movements accurately. Vehicle speed data were collected using a radar gun, with a sample of 50 vehicles per category, including two-wheelers, three-wheelers, four-wheelers light, and four-wheeler heavy vehicles. This sample size aligns with the standard error threshold recommended by Mathew, ensuring statistical reliability (Mathew 2019). Speed measurements were conducted during peak traffic hours to reflect prevailing traffic conditions. These empirical data were instrumental in calibrating and validating the VISSIM microscopic traffic simulation model (Shrestha 2022).

4.1.2. Secondary data

For the initial reference, calibration parameters were adopted from article published by Siddharth and Ramadurai (Siddharth and Ramadurai, 2013). The Passenger Car Unit (PCU) factors, as recommended by the Department of Roads (DoR) in the Nepal Road Standard were used to convert different vehicle types into equivalent passenger car units (DoR, 2013). The standard values of traffic performance were sourced from the Indo-HCM, providing a reliable benchmark for performance evaluation in the context of Indian and South Asian road networks (Indo-HCM, 2017). The traffic growth rate utilized in this study was derived from the Kamal-Dhalkebar-Pathlaiya Detailed Design Report, prepared by the Department of Roads and funded by the World Bank (KDP Design Report, 2021). This report provided the basis for calculating future traffic growth, which was determined using historical traffic data and observed trends in traffic volume increases over the years.

4.2. Traffic Projection

The study was conducted for both the existing operational scenario and a projected scenario i.e., for the next 10 years. Traffic data were forecasted using Equation 1, as outlined in the Flexible Pavements Design Guideline (DoR, 2021). Adopted traffic growth rate is presented in the Table 1.

$$P^n = A(1+r)^n \quad (1)$$

Where,
P^n: Future traffic in n years i.e., in next 10 years
A: Present traffic
r: Traffic growth rate
n: Number of years

Table 1. Adopted traffic growth rate

Vehicle Type	Traffic Growth Rate (%)
Truck	3.09
Bus	3.14
Car	5.91
Motorcycle	8.74
Utility Vehicle	2.81
4 Wheel Drive	5.91
Tractor	3.99

Source: Source: (KDP Design Report, 2021)

4.3. Modelling and Analysis

4.3.1. Development of base model

The microsimulation base model for the roundabout intersection was developed using PTV VISSIM 2023 (SP 5), incorporating the geometric and traffic characteristics specific to the study area. The geometric parameters included the number of lanes, lane widths, and the radius and width of the circulatory roadway. Traffic characteristics consisted of traffic and pedestrian volumes, as well as vehicle speeds. The development of the base model followed a systematic sequence of steps: first, the geometry was coded to accurately represent the physical layout of the roundabout; next, vehicle data were input, which included vehicle types and their respective characteristics; vehicles were then routed through the intersection, considering their movements and interactions within the network. Subsequently, speed profiles were generated for different vehicle categories to reflect realistic traffic conditions. Finally, nodes were placed at strategic data collection points to capture relevant output data for analysis.

4.3.2. Model calibration

The developed roundabout intersection model was calibrated using the initial two days average peak hour traffic counts using a trial-and-error method. This involved iteratively adjusting calibration parameters to achieve the best possible match between actual field measurements and model outputs. PTV VISSIM offers two car-following models: Wiedemann 74 and Wiedemann 99. Wiedemann 74 is suited for urban traffic, while Wiedemann 99 is designed for freeway conditions (PTV Group, 2023). Since the study area is urban, the Wiedemann 74 model was used.

The model calibration procedure involves several steps, which are summarized as follows:

- Selection of appropriate Measures of Effectiveness (MOE).
- Identification of suitable model parameters for calibration.
- Initial calibration based on the default parameters in VISSIM.
- Modification of selected parameters until the model's output closely replicates field measurements.

Traffic volume calibration was based on the Geoffrey E. Havers (GEH) statistic recommended by the Washington State Department of Transportation (WSDOT, 2021). As per the WSDOT, 2021 threshold values for GEH statistics are shown in Table 2.

Table 2. Threshold GEH values

GEH statistics	Guidance
< 3	Acceptable fit
3 to 5	Acceptable: For Local Roadway Facilities
> 5	Unacceptable

The GEH statistic was calculated using the equation 2;

$$\text{GEH} = \sqrt{\frac{2(m-c)^2}{(m+c)}} \tag{2}$$

Where,
m: Simulated output volume (Vph)
c: Traffic volume based on field data (Vph)

No queue formation was observed in the study area, even during peak hours, so queuing was not considered for model calibration and validation. Speed was used as a secondary calibration parameter, and the Root Mean Squared Normalized Error (RMSNE) was employed to measure the percentage deviation of the simulated data from the observed data. An RMSNE of less than 0.15 is considered acceptable for traffic model calibration (FDOT, 2014). Mathematically, RMSNE can be expressed as shown in equation 3;

$$\text{RMSNE} = \sqrt{\frac{1}{n}\sum_{i-n}^{n}\frac{(yi,sim-yi,obs)^2}{yi,obs}} \tag{3}$$

Where,
n: Total number of traffic measurement observations
yi, sim and yi, obs: Simulated and observed data

4.3.3. Model validation

After calibration of the model, it needs to check by new set of data to know its accuracy and replicability of the real-world scenario known as model validation. In this study, the calibrated model was validated using the new set of data i.e. day three peak hour traffic volume and speed by checking its compliance with the GEH statistics and RMSNE statistics thresholds.

4.4. Alternatives for Improvement of Roundabout

To enhance operational efficiency in terms of capacity, delay reduction, level of service, operational speed, and safety—quantified by the number of potential conflicts—three alternative improvement alternatives were systematically evaluated. The assessment of these alternatives was conducted in accordance with geometric design standards aligned with the Department of Roads' planned upgrades for the Kamala-Dhalkebar-Pathlaiya section of the East-West Highway. The evaluation incorporated both existing traffic conditions and projected traffic demand over a ten-year horizon to ensure long-term effectiveness. The following sections provide a detailed examination of the proposed improvement alternatives.

Alternative I: Geometric Improvement as per Upgradation Plan

In Alternative I, the existing geometric elements were improved, and the analysis was conducted based on the Department of Roads' upgradation plan. The geometric parameters used in this alternative are listed in the Table 3.

Table 3. Adopted geometric parameters

Item		**Units**
Traffic Island Radius		30.00 m
No. of approaches		3 nos.
Number of Lane		4 Main Lane + 1 Service Lane + 1 Cycle Lane
	Lahan Leg	3.50 x 2 m
Approach Road width (Main Lane)	Bardibas Leg	3.50 x 2 m
	Janakpur Leg	10.5 m
	Lahan Leg	6.50 m
Approach Road width (Service Lane)	Bardibas Leg	6.50 m
	Janakpur Leg	5.75 m
Shoulder Width		2.5 m
Median Width		4 m
Cycle Lane Width		2 m

Alternative II: Improvement of Existing Roundabout Using Metering Concept

Metering refers to the implementation of traffic control measures to regulate the rate of vehicles entering freeway sections through use of traffic signals, coordinated with occupancy detectors installed on the mainline. The primary objective of metering is to optimize traffic flow, maintaining vehicle movement at or near free flow speeds and maximizing roadway capacity. In this study, various aspects of traffic operational performance and safety were analyzed for the enhanced geometric design that incorporates the metering concept, with a particular emphasis on prioritizing through traffic on the East-West Highway.

Alternative III: Improvement of Existing Roundabout as a Turbo Roundabout

In a turbo roundabout, vehicles select their destination lanes based on their intended turning movements prior to entering the circulatory section. This design effectively reduces conflicting paths, thereby minimizing conflicts at weaving and merging areas, which enhances traffic safety and improves speed, Level of Service (LoS), and capacity. This study proposes and analyzes a three-legged turbo roundabout. The turbo face is oriented towards the Bardibas leg to prioritize through traffic on the East-West Highway, as this route represents the predominant flow of traffic.

5. Result and Discussion

5.1. Traffic Composition

The analysis of traffic composition reveals that motorcycles constitute the largest proportion of vehicles i.e., 58.95%, followed by cars (8.38%), buses (7.71%), and trucks (7.51%). Four-wheel drive and utility vehicles account for 5.97% and 3.82%, respectively. Bicycles represent 4.56%, while tractors (1.74%) and three-wheelers (1.34%) have the lowest shares. Figure 2 depict the traffic composition of the study location.

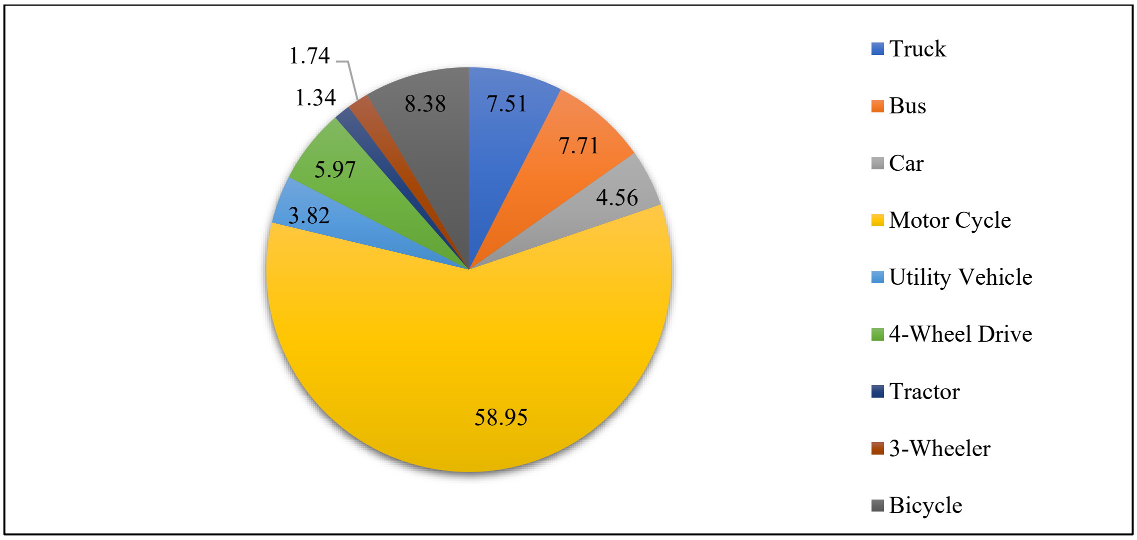


Figure 2. Traffic composition

5.2. Calibration of Model

Traffic volume and speed distribution data from two day's peak-hour periods were used for model calibration. The calibration was assessed using **GEH** and **RMSNE** statistical measures to ensure accuracy. The calibrated driving behavior parameters are presented in **Table 4**.

Table 4. Calibrated driving behavior parameters

Parameters		**Calibrated value**
Look Ahead Distance	Max (m)	140
	Min (m)	20
Look Back Distance	Max (m)	120
	Min (m)	20
Wiedemann 74		
Average standstill distance (m)		1
Additive part of safety distance		0.2
Multiplicative part of safety distance		0.6
Lane Change		
Min. clearance (front/rear) (m)		0.3
Safety distance reduction factor		0.4

The maximum GEH statistics obtained for traffic volume calibration was 1.08 which was less than GEH statistic's maximum threshold value i.e. 5 (WSDOT, 2021). Table 5 represents the calibration of traffic volume.

Table 5. Calibration of traffic volume using GEH statics

Simulation period (s)	Links/Route/Movement	VISSIM Volume in Vph	Field volume in Vph	GEH statistics
3600	Janakpur to Bardibas	232	240	0.52
3600	Janakpur to Lahan	165	173	0.62
3600	Bardibas to Lahan	302	321	1.08
3600	Bardibas to Janakpur	195	196	0.07
3600	Lahan to Bardibas	297	314	0.97
3600	Lahan to Janakpur	207	204	0.21

The maximum RMSNE statistics obtained for speed calibration was 12% which was less than RMSNE statistic's maximum threshold value i.e. 15%. (WSDOT, 2021). Table 6 represent the calibration of speed.

Table 6. Calibration of speed using RMSNE statistics

	Speed (Kmph)		
Vehicle category	Simulated avg. speed	Field measured avg. speed	RMSNE
Two-Wheeler	21.42	24	0.07
Three-Wheeler	13.23	15	0.12
Four-Wheeler Light	18.32	20	0.08
Four-Wheeler Heavy	17.79	16	0.11

5.3. Validation of Calibrated Model

Third day peak hour traffic volume were used to validate the base model, and the GEH statistics were calculated to assess the model's performance. Table 7 presents the validation results for traffic volume.

Table 7. Validation of traffic volume using GEH statistics

Simulation period (s)	Links/Route/Movement	Vissim volume in Vph	Field volume in Vph	GEH statistics
3600	Janakpur to Bardibas	215	224	0.61
3600	Janakpur to Lahan	200	209	0.63
3600	Bardibas to Lahan	319	335	0.88
3600	Bardibas to Janakpur	219	218	0.07
3600	Lahan to Bardibas	344	366	1.17
3600	Lahan to Janakpur	226	228	0.13

In addition, for the validation of the model, speed data from the third day's peak-hour traffic was also utilized, with the validation assessed using RMNSE statistics. The results of the validation for average speed are presented in Table 8.

Table 8. Validation for speed using RMSNE statistics

Vehicle category	Speed (Kmph)

	Max	Min	Simulated avg. speed	Field measured avg. speed	RMSNE
Two-Wheeler	26.29	14.56	24.42	25	0.12
Three-Wheeler	16.72	12.52	15.45	16	0.14
Four-Wheeler Light	23.09	18.87	21.56	22	0.09

5.4. Comparative Analysis for Base Year Traffic

The operational and safety performance of the three alternatives was compared to identify and recommend the best option for the base year traffic conditions. Operational performance was assessed based on LoS, delay, operational speed, and capacity, while safety performance was evaluated by analyzing the number of conflicts. The comparative results are discussed in the following subsections.

5.4.1. *Analysis of the level of service and delay*

In the analysis for base year traffic, improvement alternative III (Turbo Roundabout) was identified as the most effective option among the three proposed alternatives, achieving a LoS of B and an average delay of 10.44 seconds. This was followed by alternative II (Metering Concept), which also achieved an LoS of B with an average delay of 14.05 seconds, and alternative I (Improvement of Existing Geometry), which resulted in an LoS of C and an average delay of 16.22 seconds. Alternative III was found to be the best option because its design allows vehicles to choose their lanes based on their intended turning movements before entering the roundabout. This approach facilitates smoother traffic flow and reduces vehicle interactions within the circulatory area compared to the other alternatives. Table 9 presents the LoS and Delay of the intersection for base year traffic.

Table 9. LoS and delay of the intersection for base year traffic

Alternatives	**LoS**	**Delay (Sec)**
Existing	LoS E	44.99
Alternative 1	LoS C	16.22
Alternative 2	LoS B	14.05
Alternative 3	LoS B	10.44

5.4.2. Analysis of operational speed

Alternative III showed the best operational speeds for three-wheelers, light four-wheelers, and heavy four-wheelers, with speeds of 26 km/h, 44 km/h, and 32 km/h, respectively. However, Alternative II offered the best speed for two-wheelers at 60 km/h. This was because Alternative II allowed free-flow traffic in the east-west direction while using traffic lights to control the Janakpur approach leg. Figure 3 shows the anticipated average operational speeds for different alternatives under base year traffic scenario.

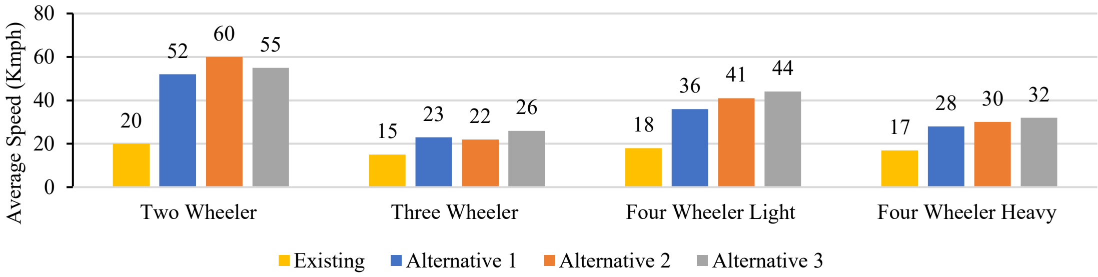


Figure 3. Average operational speed (Kmph) for base year traffic

5.4.3. Analysis of capacity

As shown in Figure 4, Alternative III had the highest capacity, recorded 3,883 PCU/hour. Alternative II followed with a capacity of 3,716 PCU/hour, while Alternative I had a capacity of 3,586 PCU/hour. The increased capacity of Alternative III is due to the turbo roundabout design, which allows vehicles to choose their destination lanes before entering the circulatory section. This design minimizes delays from turning movements, leading to greater overall capacity compared to the other alternatives.

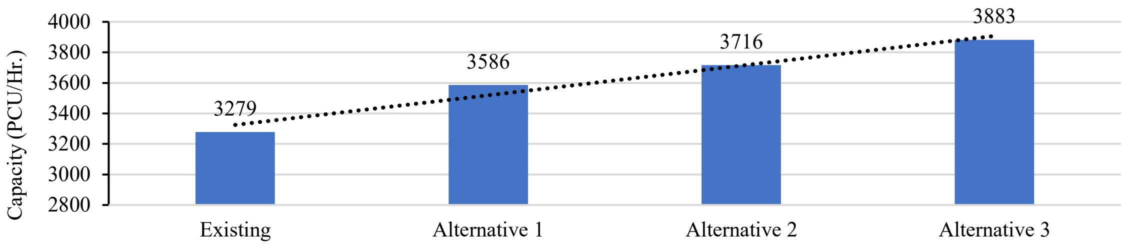
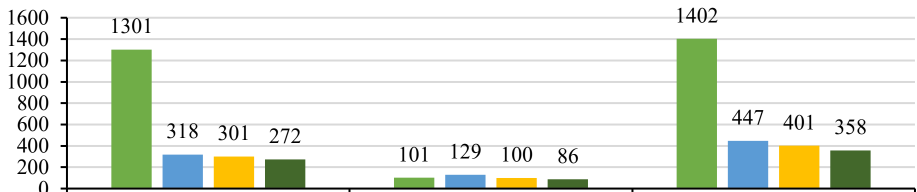


Figure 4. Base year capacity of dhalkebar roundabout

5.4.4. Analysis of conflicts

In terms of total conflicts observed at the roundabout, Alternative III was identified as the most effective among the three improvement options, recording a total of 358 conflicts per hour. This figure includes 272 rear-end conflicts and 86 lane change conflicts. Alternative II followed with a total of 401 conflicts per hour, consisting of 301 rear-end conflicts and 100 lane change conflicts. Alternative I had the highest incidence of conflicts, totaling 447 per hour, which included 318 rear-end conflicts and 129 lane change conflicts. Alternative III was observed as the best option because the turbo roundabout design allows vehicles to maneuver at slower speeds and select their specific paths prior to entering the circulatory section. This design effectively reduces weaving and merging phenomena within the roundabout, resulting in fewer conflicts compared to the other alternatives. Figure 5 depict the conflicts for the different alternatives.



	Rear End	Lane Change	Total
Existing	1301	101	1402
Geometric Improvement	318	129	447
Metering Concept	301	100	401
Turbo Geometry	272	86	358

Existing Geometric Improvement Metering Concept Turbo Geometry

Figure 5. Conflicts analysis for base year traffic

5.5. Comparative Analysis for Forecasted Traffic

The operational and safety performance of the three alternatives was compared to identify and recommend the best option for the forecasted year traffic conditions as well. The comparative results are discussed in the following subsections.

5.5.1. Analysis of the level of service and delay

In the analysis of forecasted traffic, Alternative III (Turbo Roundabout) demonstrated as most effective improvement, achieving a LoS of C with an average delay of 16.65 seconds. Alternative II also reached an LoS of C, with a slightly higher delay of 18.02 seconds, while Alternative I give a LoS of D and an average delay of 27.62 seconds. The superior performance of Alternative III is primarily due to its design, as stated in the section 5.3.1. Table 10 details the intersection's LoS and delay for the base year.

Table 10. LoS and delay of the intersection for forecasted traffic

Alternatives	**LoS**	**Delay (Sec)**
Existing	LoS F	61.23
Alternative 1	LoS D	27.62
Alternative 2	LoS C	18.02
Alternative 3	LoS C	16.65

5.5.2. Analysis of operational speed

Alternative III achieved the highest operational speeds for three-wheelers and heavy four-wheelers, with speeds of 23 km/h and 21 km/h, respectively. In contrast, Alternative II provided the higher speeds for two-wheelers and light four-wheelers, reaching 46 km/h and 37 km/h, respectively and this superior performance of Alternative II is due to the free-flow conditions for east-west through traffic, as highlighted in the base-year analysis. Figure 6 illustrates the average operational speeds for each vehicle category under each alternative in the forecasted traffic scenario.

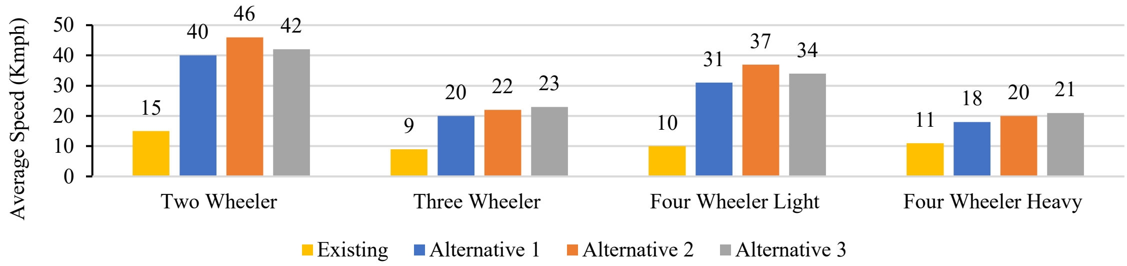


Figure 6. Operational speed for forecasted traffic

5.5.3. Analysis of capacity

As illustrated in Figure 7, Alternative III achieved the highest capacity i.e., 4529 PCU/hour, followed by Alternative II with 4207 PCU/hour, and Alternative I with 4060 PCU/hour. The enhanced capacity of Alternative III is due to the incorporation of the turbo roundabout design, as mentioned in the base-year analysis.

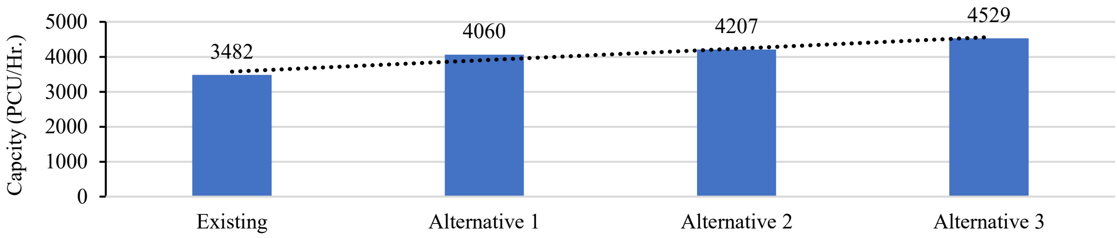
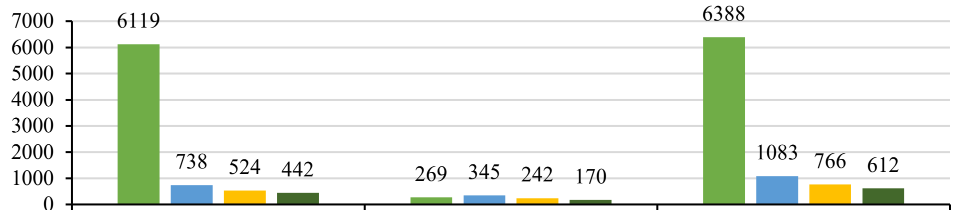


Figure 7. Roundabout capacity for forecasted traffic

5.5.4. Analysis of conflicts

Alternative III was identified as the most effective amoung three improvement options, with a total of 612 conflicts per hour, including 442 rear-end conflicts and 170 lane-change conflicts. Alternative II followed with 766 conflicts per hour, comprising 524 rear-end and 242 lane-change conflicts. Alternative I had the highest number of conflicts, totaling 1083 per hour, with 738 rear-end conflicts and 345 lane-change conflicts, as shown in Figure 8. Alternative III was considered the best option due to the turbo roundabout design, as discussed earlier in the section 5.3.4.



	Rear End	Lane Change	Total
Existing	6119	269	6388
Geometric Improvement	738	345	1083
Metering Concept	524	242	766
Turbo Geometry	442	170	612

Figure 8. Conflicts scenario for forecasted traffic

6. Conclusion and Recommendations

This study was carried out to identify the best geometric improvement option for existing and forecasted traffic in next 10 years of Dhalkebar three-legged roundabout. Operational and safety performance evaluation was conducted under three improvement scenarios: alternative I with geometric improvement as per DoR`s upgradation plan, alternative II with metering concept, and alternative III with turbo roundabout. Numerical results show:

- For the base-year traffic scenario, Alternative III featuring the turbo roundabout was identified as the most effective solution among the three alternatives. It resulted in an 18.42% increase in capacity, a 76.79% reduction in delay, and a 74.46% decrease in conflicts compared to the existing scenario. Additionally, it contributed to higher average speeds and an improvement in the Level of Service (LoS) relative to the current conditions.
- For the forecasted traffic scenario, Alternative III with the turbo roundabout was found to be the most effective among all three alternatives. It demonstrated a 30.06% increase in capacity, a 72.80% reduction in delay, and a 90.41% decrease in conflicts compared to the existing scenario. Furthermore, it resulted in higher average speeds and an improvement in the Level of Service (LoS) relative to current conditions.

This study does not consider options for grade-separated improvements, the construction costs of different geometric changes, or the severity of traffic conflicts. Additionally, the study focused mainly on the roundabout and its performance. However, to gain a depth understanding of traffic conditions, it's important to consider a overall network analysis. Therefore, it is recommended that future studies can look at grade-separated improvement options, analyze construction costs, and assess the severity of traffic conflicts across the entire network.

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