PERFORMANCE EVALUATION OF TURBO-ROUNDABOUT IN HETEROGENEOUS TRAFFIC CONDITION OF DHAKA, BANGLADESH

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ABSTRACT

Turbo-roundabouts have gained recognition as efficient intersection designs in developed countries, exhibiting improved capacity and performance compared to conventional intersections. However, the applicability and effectiveness of Turbo-roundabouts in developing countries remain largely unexplored. This study aims to fill this knowledge gap by assessing the capacity and performance of a Turbo-roundabout and comparing it with a four-legged intersection and a typical roundabout commonly found in developing countries like Bangladesh. A four-legged intersection in Dhaka city was selected for the study, where the traffic is non-lane-based, and both motorized and non-motorized vehicles share the same roadway, making the traffic characteristics heterogeneous. Data was collected on two consecutive weekdays during peak hours. VISSIM, a microsimulation software, was used for modeling the intersection, which was calibrated and validated to replicate the field condition. Later, The capacity and performance metrics such as vehicle travel time, delay, and level of service were measured for each type of intersection through simulation. Turbo-roundabouts outperform both four-legged intersections and regular roundabouts, reducing vehicle travel time by 29% and 16%, respectively, and decreasing delay by 65% and 43%, respectively. Moreover, it improved the level of service as well. This research contributes to understanding transportation planning and management in developing countries by shedding light on the potential benefits and limitations of implementing Turbo-roundabouts.

Keywords: *Intersection capacity, Four-legged intersection, Roundabout, Turbo-roundabout, VISSIM*

1. INTRODUCTION

Traffic flow management as one of the aspects of urban transport is an important issue for providing sustainable and efficient mobility in developing countries. The growing population, rapid urbanization, and motorization nowadays put great strains on the existing transport networks, resulting in traffic congestion problems (Saleh et al., 2023). This congestion affects the economy significantly as it increases travel timing and cost, lowers productivity levels, and contributes to air and noise pollution and hence, innovative solutions are needed to tackle traffic problems (Riyad et al., 2020).

Dhaka, the capital of Bangladesh, stands as the most important cultural, economic, and scientific hub of Eastern South Asia. It attracts a significant number of people each year from every corner of the country, ultimately earning the distinction of being the most densely populated built-urban area globally (Hossain, 2022). However, the existing non-sustainable traffic infrastructure is inadequate to keep up with the traffic demand generated due to the rising population. Adding to the challenge, the limited space available to accommodate this growing traffic demand is exacerbated by non-lane-based, heterogeneous traffic, where both motorized and non-motorized vehicles share the same roadway, only worsening the overall traffic scenario (Junaed et al., 2022). The increasing gap between traffic demand and supply leads to increasing traffic congestion, especially at junctions. During peak hours, both the major and minor roads of road intersections experience a surge in traffic volume, directly affecting the intersection's capacity and overall traffic safety. Consequently, finding a sustainable solution to this persistent issue becomes imperative.

Traditionally, on roads with high traffic volume, signalized intersections are employed (Demir & Demir, 2020). However, in Dhaka, most of the intersections are manually controlled by traffic police in an un-engineered manner, failing to meet the traffic demand (Rahman et al., 2012). A viable alternative is roundabouts, first introduced in the UK in 1966 to efficiently and safely control traffic flow at unsignalized intersections (Robinson et al., 2000). Later, it gains popular in many developed countries such as the USA, Australia, France, and others. As single-lane roundabouts struggled with large traffic volumes, the concept of multilane roundabouts was introduced in most European countries, becoming a crucial component of their traffic network (Elhassy et al., 2021; Kittelson & Associates, 2024). Over time, the design of these roundabouts has evolved, and among many present-day substitutes for conventional multilane roundabouts, Turbo-roundabouts have emerged as one of the most innovative forms of unsignalized circular intersection. They are designed to enhance flow and mitigate accidents without compromising efficiencies. The primary advantage lies in eliminating entering and exiting conflict points by directing drivers to merge into physically separated spiral lanes, ensuring they are guided to their designated direction before entering the intersection (Giuffrè et al., 2010). Studies have shown that depending on the road geometry, Turbo-roundabouts can reach up to a 70% reduction in accident frequency and more than 90% reduction in the number of fatalities (Silva et al., 2011), attributed to the reduction of conflict points and the homogenization of speed profiles (Silva et al., 2015).

Recently, the Turbo-roundabout has attracted the interest of transportation engineers and urban planners due to its ability to offer a more flexible and convenient alternative to regular intersections. However, there exists a significant gap in the study of its ability to operate effectively and efficiently in the heterogeneous, non-lane-based traffic conditions of developing countries. This study addresses this gap by evaluating the performance of Turbo-roundabout and comparing its performance with typical roundabouts and an existing manually controlled four-legged intersection in Dhaka, using microsimulation software VISSIM.

2. LITERATURE REVIEW

Several studies consistently indicate an enhancement in road safety performance when a double-lane roundabout is converted to a Turbo-roundabout. Giuffrè et al. (2010) demonstrated that the safety benefits are due to a reduction in the number of conflict points, which can be achieved by placing kerbs that prevent lane changes on entries, circulatory carriageways, and exits. Furthermore, by enforcing deflection levels that guarantee the adoption of safer speeds, raised lane dividers prevent the practice of straight trajectories. Using a potential accident rate model based on potential conflict, Mauro et al. (2010) assessed Turbo-roundabouts' safety improvement. Considering numerous crash typologies, including rear-end collisions at entry, loss of vehicle control, failure to yield, and circulating-exiting collisions, the results showed that Turbo-roundabouts reduce overall crash rates by 40–50% and injury crashes by 20–30%. A more recent study supported this finding and demonstrated the usefulness of Turbo-roundabouts in urban contexts with high traffic volume from pedestrians and two-wheelers (Mauro et al., 2015). The Surrogate Safety Assessment Model (SSAM) software and microsimulation techniques were used by (Vasconcelos et al., 2014) to develop a comparative performance analysis of single-lane, multilane, and Turbo-roundabouts. The findings indicate that the Turbo-roundabout performs best out of the three solutions examined. Despite being more severe, it tends to have fewer conflicts than the single-lane roundabout. In terms of capacity, Yperman et al. (2003) used the microsimulation program PARAMICS to examine how well a three-lane conventional roundabout and a double-lane Turbo-roundabout operated. They found that the Turbo-roundabout had a capacity that was 12%–20% higher. Engelsman et al. (2007) directly compared the capacities of Turbo-roundabouts and double-lane conventional roundabouts using the Multilane Roundabout Explorer Dutch capacity model. The findings indicated that, in situations where traffic flow did not surpass the 3,500 pcph threshold, Turbo-roundabouts were consistently more effective than conventional roundabouts. According to the authors, Turbo-roundabouts can increase capacity by 25% to 35% when compared to traditional roundabouts. (Fortuijn, 2009) discussed how multilane roundabout capacity is affected by the circulatory lane's utilization ratio. The author concluded that each circulatory lane of a Turbo-roundabout would have an optimal utilization ratio due to the presence of raised lane dividers, resulting in improved performance and increased capacity. It was found that capacity values in the Netherlands were at least 30% greater than those in the US. Although an extensive review has been found on the performance of a Turbo-roundabout, there is not enough information on how a Turbo-roundabout might behave in mixed traffic conditions. Hence, this paper focuses on the behavior of a Turbo-roundabout in a four-legged intersection in Dhaka, Bangladesh, where both motorized and non-motorized vehicle prevails, and then compares the obtained result with the performance of a four-legged intersection and a traditional roundabout.

3. METHODOLOGY

This paper evaluates the performance of Turbo-roundabouts under non-lane-based heterogeneous and oversaturated traffic conditions. An existing four-legged intersection situated at Uttara, Dhaka, Bangladesh, was selected, where each approach is comprised of two lanes with shoulder, and traffic police manually control the signals. The existing four-legged intersection was modelled and simulated in the VISSIM microsimulation software, which was later replaced by typical roundabout and Turbo-roundabout. Subsequently, a performance analysis was conducted and variations in vehicle travel time, delay, queue length, and intersection level of service of these three intersection types was compared to determine the most effective performer.

3.1 Data Collection

A four-legged intersection at the convergence of Sonargaon Janapath and Gareeb-e-Nawaz Ave (23.874342881705758, 90.3908052750194) was selected for the study. The intersection, depicted in Figure 1, accommodates a mix of motorized and non-motorized vehicles with a non-lane-based traffic flow and lacks access control, making the traffic flow heterogeneous. Vehicle volume data were gathered from video recordings during peak hours (9.00 a.m. - 9.30 a.m.) over two consecutive weekdays. Additionally, three successive cycle lengths were observed to derive signal timing parameters such as phase sequence, cycle time, and green time. For analysis, 15 minutes of recorded data were multiplied four times to establish hourly volumes. The Northbound traffic volume was recorded at 1294 veh/hr, Southbound at 856 veh/hr, Eastbound at 788 veh/hr, and Westbound at 1140 veh/hr. Furthermore, vehicle turning ratio and vehicle composition at the intersection were determined from the video recordings. Table 1 presents the vehicle composition within the traffic.

Figure 1: Study Intersection

Table 1: Vehicle Composition within traffic

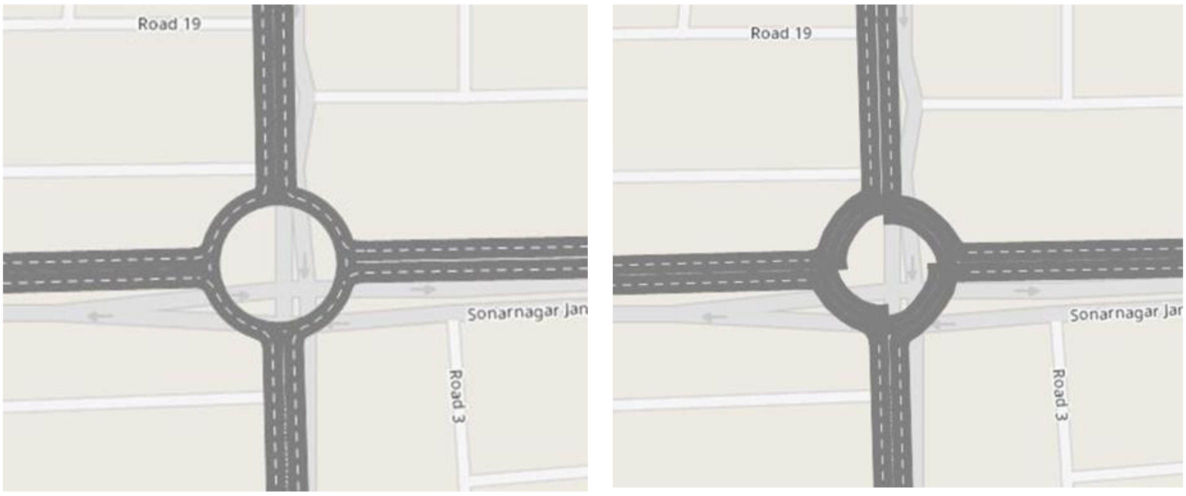
Vehicle type	**Vehicle Volume (%)**			
	Northbound	**Southbound**	**Westbound**	**Eastbound**
Bicycle	13	13	14	6
Rickshaw	36	40	21	38
CNG	10	11	6	10
Car	23	21	32	25
Leguna	9	10	14	11
Light commercial vehicle (LCV)	1	1	4	2
Bus	1	0	6	3
Truck	1	1	1	1
Motorbike	6	3	2	4

3.2 Microsimulation Modelling

A microscopic model of the study intersection was developed within PTV VISSIM 2023. The traffic conditions in the study area exhibited heterogeneity, characterized by absence of lane discipline, non-lane-based traffic flow, and lack of access control. As VISSIM outperforms other simulation tools in modeling complex road networks with traffic control, this software is well-suited for modelling heterogeneous traffic scenario (Mashrur et al., 2022). The geometric model of the intersection was developed in VISSIM based on field data (Figure 2). Considering the varied vehicle composition in the study area, the vehicle distribution for each approach was derived from field data and integrated into the model. Signal control parameters - such as cycle length, green, red, and amber timings for each approach, were incorporated into the software using VISSIG. While the default driving behavior of VISSIM creates a homogeneous traffic condition, so to replicate the actual field condition, the model needs to be calibrated. Calibration of the model involved adjusting default driving parameters to mirror the real traffic conditions. Subsequently, a validation of the model was conducted using different set of data. Calibration and validation processes utilized Geoffrey E. Haven (GEH) statistics and visual assessments to ensure accuracy, with a GEH value below 5 indicating a good fit (Junaed et al., 2022; Mitkas & Politis, 2020). The GEH values for each approach of the calibrated and validated model are presented in table 2 and 3, respectively.

Subsequently, a performance evaluation of the validated model for the existing four-legged intersection was conducted. Following this, the four-legged intersection was replaced by a typical roundabout and a Turbo-roundabout (see Figure 3), and their performance was also measured. Data on vehicle travel time, delay, and level of service at each intersection type were collected from the software after simulation and the results were then compared.

Figure 2: Four-legged intersection model in VISSIM



(a) **(b)**

Figure 3: (a) Typical and (b) Turbo-roundabout model in VISSIM

Table 2: Calibration of the model using GEH statistics

Traffic Approach	Field Volume (veh/hr)	Model Volume (veh/hr)	GEH
Northbound	1294	1260	0.95
Southbound	856	834	0.76
Eastbound	788	786	0.07
Westbound	1140	1110	0.89

Table 3: Validation of model using GEH statistics

Traffic Approach	Field Volume (veh/hr)	Model Volume (veh/hr)	GEH
Northbound	1124	1098	0.78
Southbound	1020	1044	0.75
Eastbound	1108	1078	0.91
Westbound	864	846	0.62

4. RESULT AND DISCUSSION

Vehicle travel time, vehicle delay and intersection level of service were the key parameters to evaluate the performance of the intersections in this study. Comparing the result across intersection types, it was evident that the Turbo-roundabout outperformed both typical roundabout and the existing four-legged intersection. Vehicle travel time and delay was lowest at Turbo-roundabout. Moreover, the intersection level of service was also superior at the Turbo-roundabout, while the existing intersection exhibited the lowest level of service. Overall, the typical roundabout outperformed the four-legged intersection, while the Turbo-roundabout exhibited superior performance compared to the typical roundabout.

4.1 Vehicle Travel Time

The comparison of vehicle travel time is illustrated in Figure 4. Travel time decreased by 14 percent and 29 percent when typical roundabouts and Turbo-roundabouts replaced four-legged intersections.

Furthermore, there is a 16 percent reduction in vehicle travel time when the Turbo-roundabout substitutes the typical roundabout.

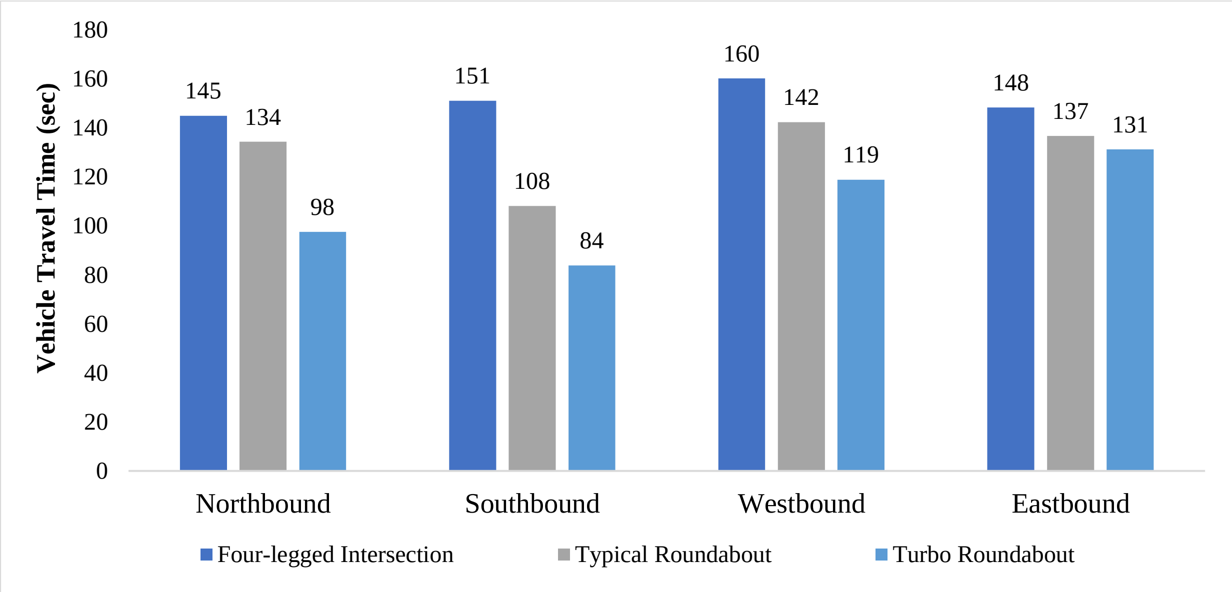


Figure 4: Comparison of vehicle travel time

4.2 Vehicle Delay

The comparison of vehicle delay is depicted in Figure 5. Vehicle delay reduced by 38 percent and 65 percent when typical roundabouts and Turbo-roundabouts replaced four-legged intersections. Furthermore, there is a 43 percent reduction in vehicle travel time when the Turbo-roundabout substitutes the typical roundabout.

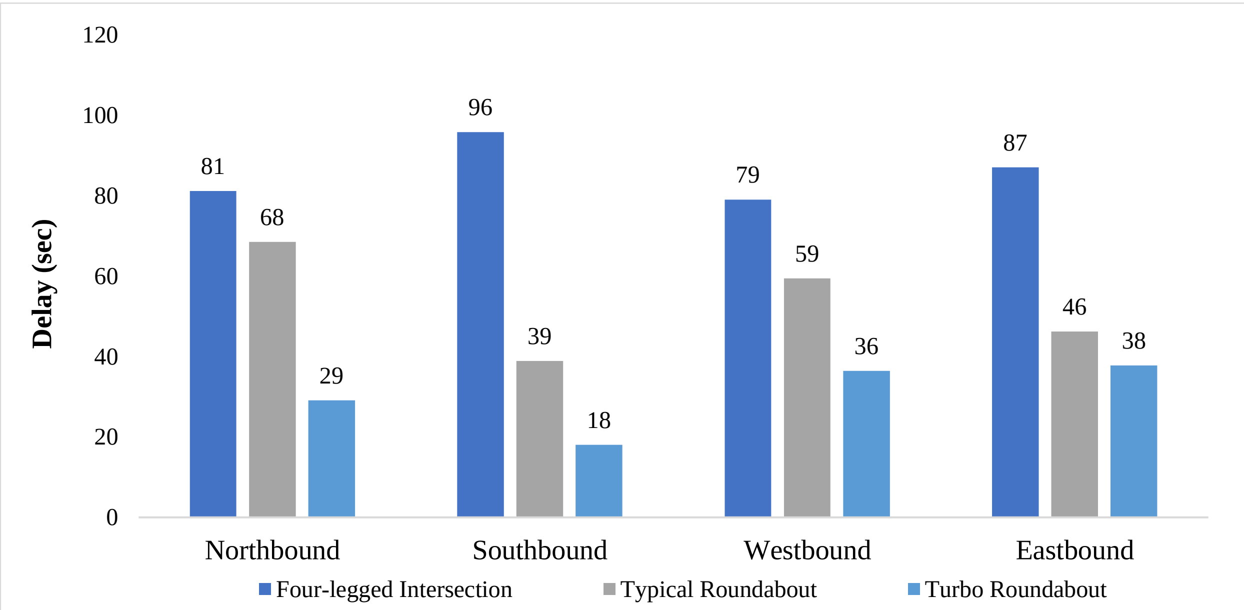


Figure 5: Comparison of delay at the intersection

4.3 Level of Service of Intersection

The Turbo-roundabout exhibits the highest level of service among the three intersections, followed by the typical roundabout, with the four-legged intersections demonstrating the lowest level of service. At the four-legged intersection, all approaches indicated an 'F' level of service, which progressed to 'E' and 'F' with the introduction of the typical roundabout. Subsequently, with the Turbo-roundabout, the level of service improved to 'C' and 'D'. Table 4 provides a comprehensive overview of the level of service across all approaches within these three intersection types.

Table 4: Level of service of intersection

Traffic Approach	Four-legged Intersection	Traditional Roundabout	Turbo Roundabout
Northbound	F	F	C
Southbound	F	E	C
Westbound	F	E	D
Eastbound	F	F	D

5. CONCLUSIONS

This research focused on evaluating the performance of Turbo-roundabout in heterogeneous traffic conditions. From the analysis, it can be observed that Turbo-roundabouts outperform both typical roundabout and existing four-legged intersection by a significant margin. The novelty of this research lies in evaluating the suitability of Turbo-roundabouts, commonly implemented in developed nations, within the context of heterogeneous traffic conditions prevalent in developing countries, where three or four-legged intersections are predominant. The findings underscore the strong performance of Turbo-roundabouts in such traffic scenarios, particularly in cities like Dhaka, suggesting their suitability as alternatives to traditional intersections to enhance traffic conditions.

Despite their potential to enhance traffic flow, the practical replacement of existing intersections with Turbo-roundabouts poses challenges. However, considering Bangladesh's development trajectory, the extension of major cities offers an opportunity for transportation planners to consider incorporating Turbo-roundabouts as viable alternatives. Also, it is important to note that this study utilized the student version of PTV VISSIM, which has limitations, notably restricting simulations to ten minutes. Employing a more comprehensive version, such as the full or academic edition, could yield more meaningful and in-depth insights into the performance of Turbo-roundabout.

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