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Assessment of Turbo and Multilane Roundabout Alternatives to Improve Capacity and Delay at a Single Lane Roundabout Using Microsimulation Model Vissim: A Case Study in Ghana

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Abstract A single lane roundabout characterized by long queues during morning and evening peak periods was chosen as our study site. The objective of this study was to 1) Model and calibrate the vissim simulation model for the roundabout and 2) to model roundabout alternatives to improve capacity and assess the delay. A two hour video data collection was undertaken on a typical morning peak from which the traffic demand and turning movement data were extracted. The vissim micro simulation model was calibrated using the west approach as the target and the analysis was done for the existing single lane roundabout. A Turbo roundabout and a conventional double lane roundabout alternatives were also assessed. The capacity of the single lane roundabout was estimated as 2990 pcu/h and was performing at an ICU level of service H. Average Delay on the west approach was 232 seconds. The intersection capacity was 4392 pcu/h when the turbo roundabout alternative was assessed. Westbound vehicles experienced average delay of 87 seconds (inner lane) and 74 seconds (outer lane). The capacity of the conventional double lane roundabout was estimated to be 3690 pcu/h. The turbo roundabout concept will deliver a comparatively higher capacity and could be the most effective alternative to reduce congestion and delay.

Keywords: *capacity, delay, micro simulation, vissim, turbo roundabout*

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1. Introduction

Roundabouts are very useful as Traffic calming devices at intersections but have very limited capacity especially where on more than one leg the flows approach capacity. In recent years, research by traffic and road engineers has been focused on the design of new types of roundabouts with the main aim of increasing capacity. The single lane roundabout was turned into double lane roundabout in the quest for higher capacity and more recently the innovation of the "Turbo roundabout" by Bertus Fortuijn, in 1996 [1]. The turbo roundabout has been a success since its implementation in the Netherlands and other European nations. According to [2], turbo roundabouts have higher capacity than conventional roundabouts.

In many towns and cities of Ghana, roundabouts have become part of the cultural heritage and monuments: For instance Yaa Asantewaa roundabout in Ejisu, Harper road roundabout in Kumasi Ashanti region, Dankwa Circle roundabout, Kwame Nkrumah Circle roundabout in Accra, Habour roundabout, PTC roundabout in Takoradi all represent a part of the long tradition and history of the cities some with statutes of prominent statesmen and women. Most of these roundabouts have also become locations of extreme congestion in the morning peak and evening peaks in their cities and towns. Indeed roundabouts contribute to congestion in most cities and urban areas in Ghana. Unfortunately however, when these priority control systems operate under congested conditions the practice has been to leave them as they are for several years, redesign and reconstruct into interchanges and over-passes and a few have been turned into signalized intersections. In cities such as Accra and Kumasi for example, Kwame Nkrumah Circle, Sankara Circle and Sofoline Roundabout have all been reconstructed into grade separated interchanges. Though the choice of grade-separated intersections over roundabouts will lead to increase in capacity, the cost of construction including space availability is very high. Even though theses roundabout seem to be a nuisance during the peak periods, at off peak periods they work very well as traffic calming devices, facilitate turning movement in the network and also have social value as they represent the great history of the nation. It is unclear why engineers and planners in Ghana do not pursue alternatives to increase the capacity using other higher capacity roundabout options, signalization of roundabouts et cetera. One thing is sure though that the practice of modeling and simulation of intersections including roundabouts is at the infant stages or in most cases nonexistent. Lack of tools and capacity may explain the lack of modeling but with the advent of computers and various software tools, the time has come to explore new approaches to finding improved solutions to single lane roundabout capacity improvement.

1.1. Objectives of the Study

This paper seeks to improve the capacity of single lane roundabouts using “The turbo roundabout” concept and the conventional two-lane roundabout as alternatives. The turbo roundabout has not yet been implemented or contemplated in Ghana, this paper hopes to contribute to understanding how such a roundabout could be introduced and also how a micro simulation based approach could be employed in seeking alternatives for a roundabout. The objectives of this study was to 1) Model and calibrate the vissim simulation model and 2) to model roundabout options to improve capacity and minimize delay.

2. Literature Review

Roundabout is an unsignalised intersection with a circulatory roadway around a central island with all entering vehicles yielding to the circulating traffic [3]. Compared with other traditional at-level intersections, roundabouts respond more efficiently to multiple functions such as traffic regulation, traffic calming, urban regeneration and landscaping. Roundabouts are particularly popular for enabling fluid traffic operations with increased safety [4]. However, driver indecision and misunderstanding of the driving rules can lead to weaving conflicts and accidents in the circulatory carriageway. These accidents, although not usually severe, are frequent and often affect normal traffic flow [5].

The most original and basic form of roundabouts is the single-lane roundabout. According to DHV Group and Royal Haskoning (2009) Single lane roundabouts offer a capacity of 2000 through to 2700 pcu/h [6]. Because of its small diameter, traffic cannot queue on the roundabout, and therefore the right-hand rule cannot be applied on the roundabout: circulatory traffic must have priority [1].

The conventional multi-lane roundabouts are most often implemented for intersections on which the traffic demand are so high, that the single lane roundabout will not be able to serve the traffic demand in terms of capacity. Although concentric two-lane roundabouts have good performance levels, the international experience over the years shows some functional problems [5].

According to a report from the Queensland Department of Main Roads (QDMR) in Australia as cited by [2] multilane roundabouts have the problem of increase in vehicles cutting across lanes and higher potential for sideswipe collisions. This is as a result of increase in vehicle path curvature. The publication "Roundabouts: An Informational Guide" [4] discusses this same problem.

Fortjuin (2009a) also talks about the problem of lane changing on the multilane roundabouts: “A driver in the left-hand access lane (assuming a right-hand rule of the road) has to change lanes over a very short distance on the roundabout in order to exit. The position becomes even worse if there are two exit lanes: a serious conflict situation then arises if the driver in the outside roundabout lane wishes to continue along the roundabout, since the layout of the concentric roundabout means that other drivers have no way of knowing whether he intends to continue round the roundabout or to exit” [2].

A third drawback of the multilane roundabout is that the poor usage of the inner lane by drivers eventually affects the capacity [2]. Additionally the conventional multi-lane roundabouts have the disadvantage of drivers negotiating them at higher driving speeds. The number of conflict points is higher as a result of the introduction of lane changing (weaving) movements. In order to overcome these, the challenge was to develop a roundabout with the same capacity or higher than the two-lane roundabout, but with the same safety features as the single-lane roundabout [2]. This led to the innovation of the turbo roundabout.

2.1. Turbo Roundabout

In 1996, the turbo-roundabout concept emerged in the Netherlands by Bertus Fortuijn, a researcher from the University of Delft, who aimed at solving the existing problems in the multilane conventional roundabouts [5]. The challenge was to develop a roundabout with the same or a higher capacity than the two-lane roundabout, but with the same safety features as the single-lane roundabout [2]. The first turbo roundabouts were installed in 2000 in the Netherlands, a report from [6] mentions that by the year 2007, 70 of them were in operation. Countries like Poland, Germany, Finland, Norway and Slovenia have also implemented this roundabout type. South Africa has recently implemented the concept by constructing its first turbo roundabout aimed at improving safety and enhancing the capacity of the intersection [7].

2.1.1. The concept

Within the circulatory lane of the turbo roundabout, vehicles are forced to move spirally, following a specific path depending on their destination and are prevented from changing lanes. This is achieved by physically separating the lanes using mountable curbs (lane dividers) [8]. Unlike conventional roundabouts which vehicles gets to the yield line before setting the trajectory to exit from one of the intersection legs, drivers depending on their intended destination are forced to choose lanes by physical lane separation even dozens of meters from circle [2,9].

In a turbo roundabout, right-turn vehicles from the minor road are requested: i) to drive along the outer entering lane; ii) to get onto the outer circulating lane; iii) to address to the leg close to that they come from. Through vehicles (and left-turn vehicles) have to choose the inner entering lane, to get onto the inner circulating lane and then they are able to maneuver to the required exit [9]. One feature worthy of mentioning is that, U-turn manoeuvres from every direction are not allowed on several variants of turbo roundabouts [10].

2.1.2. Design Features

According to [2] every turbo roundabout must have the following ten (10) features as depicted by Figure 1:

a) An additional lane, inserted opposite of one or more entry.
b) Traffic merging with the circulatory stream should yield to traffic in at most two lanes.
c) Provision of well applied spiral alignment enhances smooth flow on roundabout.
d) Mountable raised lane dividers to make lane changing uncomfortable.
e) Each segment of the roundabout includes one lane on which drivers can choose whether to exit or to continue round the roundabout.
f) At least two exit legs are two-lane.
g) The diameter of the roundabout is kept small.
h) Approach legs are at right angles to the roundabout;
i) Roundabout shields cut off view of horizon
j) Mountable aprons offer sufficient width for long vehicles to use the roundabout.

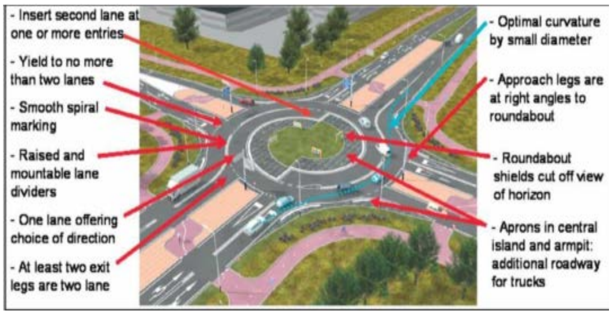

Figure 1. Characteristics of Turbo roundabouts [2]

The turbo roundabout answers three problems of the concentric two-lane roundabout: (a) Safety is enhanced as sideswipe collisions and collision speeds are reduced since vehicles are deflected at a small radius. Driver Speed through turbo-roundabout might be expected to closely approximate that of a single-lane roundabout with a similar central island diameter [10]. (b) The number of conflicts in multilane roundabouts is reduced as weaving and cut in conflicts are dealt with. (c) There is improvement in the capacity since a turbo roundabout allows the traffic flow to be distributed over the different lanes by the introduction of the spiral lane marking by arrow marking, signposts and lane selection signs. The inner circulatory lanes are properly utilized and this marks for a high capacity [2,11].

Turbo roundabouts can be distinguished into seven main forms namely Egg or Oval roundabout, Basic turbo roundabout, Spiral roundabout, Knee roundabout, Rotor roundabout, Stretched-knee roundabout and Star roundabout [2]. According to CROW (2008) as cited by [2], the types that lack features e) and f) above are called partial turbo roundabouts.

The main forms mentioned above can be modified into other forms by reducing the number of entry lanes in an approach from two or three to one, as occurs in the Egg roundabout. This is because the extra lanes are going to be underutilized if the traffic volume is low [2]. These variations are necessary because of the differences in the distribution of traffic volume over the approaches of the intersection. The factors that determine the most suitable type are saturation level, average delay time, spatial need and investment costs [6].

2.2. Roundabout Capacity

The Highway Capacity Manual (HCM) defines the capacity of a facility as “the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions” [3]. The capacity of each entry to a roundabout is the maximum rate at which vehicles can reasonably be expected to enter the roundabout from an approach during a given time period under prevailing traffic and roadway (geometric) conditions [4]. According to [12], capacity is the main determinant of the performance measures such as delay, queue length and stop rate and their relationship are often expressed in terms of degree of saturation. This explains how relevant capacity estimation of highway facility is. The entry capacity of roundabouts depends on two factors which are; the circulating flow on the roundabout that conflicts with the entry flow, and the geometric elements (width of the entry and circulatory roadways, or the number of lanes at the entry) of the roundabout [4].

International studies have shown that roundabouts perform better in terms of capacity than signalised intersections. Hummer (2004) mentions that “Traffic-analysis software also typically shows that single-lane roundabouts that remain below capacity reduce delays compared to signalised intersections handling the same volumes” [13]. However, conventional multi-lane roundabouts offer greater capacity than single lane roundabouts.

The DHV Group and Royal Haskoning report gives a summary of both practical and theoretical capacities of various roundabout types using the ‘conflict load’ method [6]. They reported a practical and theoretical capacity (all entries combined) for single lane roundabout as 2000 pcu/h and 2700 pcu/h respectively. Similar, the Basic turbo roundabout was reported to have overall practical capacity as 3500 pcu/h and a 3800 pcu/h theoretical capacity.

2.2.1. Turbo and Conventional Roundabouts Capacities

The recent emergence of turbo roundabouts has called for various studies comparing its performance in terms of capacity with that of conventional multi-lane roundabouts. Many researches are of the view that turbo roundabouts have higher capacity than the conventional roundabouts though most of these studies are theoretically based [10].

Fortuijn (2009a) concludes that capacity of turbo roundabouts are higher because, the spiral lane marking, combined with raised lane dividers, result in better usage of the inner circulatory lane [2]. Bulla and Castro (2011) used micro simulation software to develop a research which resulted in a 7% increment in capacity of the turbo roundabout compared with the multi-lane roundabouts [14]. Another research by [11] concluded using micro simulation tool Paramics that, the capacity of a two-lane turbo roundabout exceeds that of a three lane classical roundabout by 12 to 20% with the capacity at its highest when traffic is equally distributed among the four approaches. Mauro and Branco (2010) reported that turbo roundabouts could be expected to have superior capacity to a conventional roundabout with a similar number of traffic lanes, though the difference might be small for balanced traffic situations [15].

There are other studies that seem not to consent to most of the studies reporting improvement in capacity with regards to turbo roundabouts. Silva et al (2013) reported a 3% decrease in capacity of an existing conventional roundabout when changed to a turbo roundabout [5]. Recent Portuguese researchers [5,8] share the view that most of the researches used methods that do not address the complex interactions between traffic streams of multilane roundabouts. Yperman and Immers (2003) calibrated their micro simulation model Paramics upon the Swiss roundabout capacity model [11]. Vasconcelos et al (2012) argue that the Bovy model is regression-based and is unable to guarantee accurate capacity predictions when the geometry and conditions of operations are outside its calibration domain [9]. Moreover, regression models do not account for the traffic flow theory of determining and accepting gaps upon entering the intersection [16]. Engelsman and Uken (2007) using ‘quick-scan model’ called the Meerstrooksrotondeverkenner (multilane roundabout explorer), estimated capacity increment of turbo roundabouts in their studies [17]. Even though this model takes into account the effect of both separated lanes and pseudo conflicts, its linear structure, does not take into account multilane roundabout properties in a good way [18]. Mauro and Branco (2010) developed an analysis which was based on gap acceptance theory [15]. Unlike most empirical models, models based on this theory can handle the lane split in turbo roundabout but are disadvantaged when it comes to pseudo conflicts and influence of heavy vehicles [18].

3. Methodology

3.1. Description of Study Site

The N6 Highway roundabout intersection at KNUST has four legs, two of which are dual carriageway roads (East and West legs). These two lane carriageways taper into single lane roundabout from about 80m to the approach yield line. The other legs are single carriageway roads with low to medium traffic. The traffic demand on the dual carriageway is very high and often peak traffic queues block adjacent intersections located 200 - 300m downstream of the yield line for both approaches on the dual carriageway. Within 30m of the intersection the approach grades are less than 3% and therefore the terrain is considered flat.

3.2. Field Data Collection

The following sets of data were required for calibrating and analyzing the performance of the roundabout namely; Geometric data, Flow rate data, Demand data, Queue length data and Delay data.

The geometric data of the roundabout was extracted from aerial photos and image obtained from Google Maps. The photo was scaled to the actual measurements in the field on the computer using the vissim simulation tool. The inscribed circle diameter and the approach lane width were all measured. The roundabout has four legs with single lane as entry and exits with an inscribe diameter of 38m. The geometric data collected in the field for modeling is presented in Table 1.

Table 1. Basic geometric parameters of the single lane roundabout

Parameter	Approach			
	SB	WB	EB	NB
Entry radius	28m	52m	24m	15m
Entry width	4m			
Approach width	3.5m			
Departure width	3.5m			
Inscribed circle diameter	35m			
Flare length	8m			

The geometric design also includes a truck apron, raised splitter islands, a non-mountable central island and crosswalks. Figure 2 shows a typical morning peak condition of the study area.

Figure 2. Typical morning peak condition of the study area (Westbound approach)

Traffic demand at the intersection were obtained from counts derived from simultaneous video recordings of the four approaches. A video camcorder was placed at an elevated position on a tripod at a point such that the target approach could be observed and also the flows from the three other approaches and turning movements could be observed. The recording was done for two hours to include the morning peak hours. The period of the recording was from 7:00am-9:00pm on a typical Tuesday, evening peak traffic could not be taken because of poor lighting. Prior to the recording, the yield lines were marked, queue markers were also installed on all approaches. Care was taken to ensure that the approaches had no bottlenecks that impede traffic flow. The entire recording was made inconspicuous to road users to prevent biased data resulting from driver interference. During the measurements pedestrian traffic was very small and therefore was ignored in this study.

Flow Rate

Flow rate data that is the number of vehicles per analysis time period were obtained for the morning AM peak. The flow rate data includes turning movements, entering flow rate and entry capacity. The entering flow rates are the movements that actually entered the inside circles of the roundabouts per analysis period.

The entry capacity was measured downstream of the queued vehicles on the target approach by counting the number of vehicles passing the yield line during the saturated period. The segment of road from which capacity is measured should have a queue ideally lasting for a full hour; however, reasonable estimates of capacity can be obtained if the queue lasts only 0.5 hour [19]. The east approach was the subject approach since it had the longest queue lasting for over one hour during the morning AM peak.

Demand Data

Whenever you want to measure capacity of at a roundabout there must be congestion and queueing. In the presence of congestion a measure of only the turning movements represents only capacity constraint volume. The true demand consist of capacity constrained volume and the arrivals at the back of the queue in the target lane. In order to get a measure of the true demand the queue length and the turning movement were abstracted every 15-minute time period. It was also necessary to record the vehicle mix since the presence of a high percentage of heavy goods vehicles and trucks can affect queue length and lane changing.

A vehicle composition table was created based on the field data. The traffic mix was grouped into Cars, Medium trucks and Large vehicles according to the Ghana Highway Authority vehicle classification [20]. The cars were made up of the taxi, pickups and saloon cars. The medium trucks were the “trotro” or the mini buses and the trucks consist of the long bus and the heavy goods vehicles.

The recorded volume of vehicles were converted into passenger car units by adopting the passenger car equivalent (PCE) values of 1.0 for Car, 1.7 for Medium and 2.5 for large vehicles from a traffic studies in Kumasi [21].

Queue length data

Prior to the main data collection, the reconnaissance survey revealed the extent of the queue. The length of the queue was so long that a count of the vehicles in queue per 60 seconds from the downstream to the upstream wasn’t feasible. Queue markers were made on the roadway edge by taking distances from the yield line. This helped to monitor the length of the queue from the roundabout. The control marks were 20m intervals up to the upstream of the queue. When the queue got pass the last control mark, the queue length was determined by measuring the length beyond the mark and adding it to the distance of the mark from the beginning of the queue.

Delay data

Delay is the difference between the time it takes a vehicle to traverse a certain distance in queued condition (real travel time) and the travel time over the same distance in an ideal condition (ideal travel time). The ideal travel time is the time that would be reached if there were no other stops or vehicles in the network. The floating car method was used to measure the field delay. Three survey personnel took the data during the floating car survey: The driver, one passenger who acted as an observer of the actual elapsed time of passing control points and the last person recorded the time as mentioned by the time keeper. The driver drove within the traffic stream overtaking and allowing himself to be overtaken whenever necessary over the delay segment. The travel time of the floating car from a control point within the queue to various control points established within the study area was measured. The ideal travel time was estimated with the assumption that the vehicle was travelling at the speed limit over the same distance. The measured delay in seconds was averaged over the measurement taken during the period.

3.3. Intersection Alternatives

This study undertook an evaluation of the performance of the existing singlelane roundabout condition after calibration and modeling of vissim. Using the calibrated vissim, a comparative assessment of the turbo (Egg turbo roundabout) and conventional multilane roundabout was carried out. The objectives was to see the effectiveness of replacing the single lane roundabout in order to improve the degree of congestion at the intersection.

Egg Turbo Roundabout

The egg turbo roundabout was proposed to increase capacity of the intersection by removing the bottleneck sections of the east and west approaches and introducing an extra lane making it a double lane entry and exit for the east and west approaches. The single lane entries and exit of the north and south approaches have been maintained just as they were. However, the south approach has been realigned for it to be perpendicular to the intersection. The Egg turbo roundabout has been proposed based on the existing traffic distribution which shows heavy traffic flow on the east and west approaches and the light traffic flow on the north and south approaches. Figure 3 and Table 2 shows the layout and geometry of the turbo roundabout respectively.

Figure 3. Turbo roundabout layout

Table 2. Turbo Roundabout Geometry

Element		Dimension (m)
Inner Lane	Inner radius	12.00
	Outer radius	17.15
Outer Lane	Inner radius	17.45
	Outer radius	22.45
Inner Lane	Start width	5.30
	End width	5.00
	Average width	5.15
Outer Lane width		5.00
Lane divider width		0.30
Distances between outer center points		5.35
Distances between inner center points		5.05

Conventional Double Lane Roundabout

This alternative was also considered to replace the existing single lane with the aim of increasing the capacity of the roundabout. It has the similar approach entries and exits like the turbo roundabout option. The only difference between the two is the "forced spiraling traffic flow on the circulatory lanes of the turbo roundabout which is not on the conventional double lane roundabout. Figure 4 and Table 3 shows the layout and geometry of the multilane roundabout respectively.

Figure 4. Multilane roundabout layout

Table 3. Multilane Roundabout Geometry

Element	Dimension (m)
Outer radius	21
Inner radius	12.5
Carriageway width	8.5
Entry curve	12
Exit curve	15
Entry single lane	3.5
Exit single lane	3.5
Entry two lanes	7.0
Exit two lanes	7.0

Building the Roundabout Model in VISSIM

Figure 5. Existing roundabout modeled in vissim

The existing single lane roundabout was modeled in VISSIM by the help of an aerial image of the site as shown in Figure 5. Unlike macro simulation tools which use links and node connections, VISSIM traffic network uses links and connectors connections making it flexible to model different roundabout geometries. This is why it was opted for to be able to model the peculiar geometry of the turbo roundabout. The network was built by loading the aerial image into the vissim model and scaling it. The links which represent roadway were drawn over the image and were connected by connectors to allow for continuing traffic. Figure 6 shows the modeled roundabout in wireframe with blue and pink lines representing links and connectors respectively.

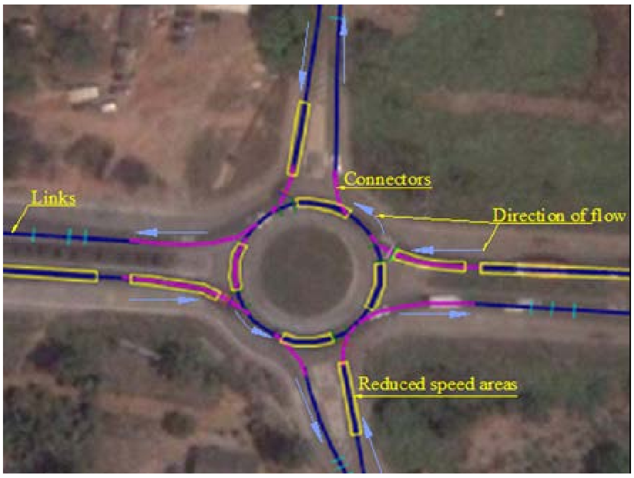

Figure 6. Wireframe model of existing roundabout

Desired speed distribution and Reduce speed areas

A desired speed distribution of 80km/h with a lower limit of 75km/h and an upper bound of 110km/h was used to model all the approach vehicular movements as soon as they enter the network. The roundabout drive through speed for both single and turbo roundabout was set at 20km/h with an upper and lower limit of 25km/h and 15 km/h respectively. However, the drive through speed for the conventional double lane roundabout was set as 30km/h having an upper and lower limit of 37km/h and 25 km/h respectively.

Reduce speed areas of length of about 14m were placed at the entrance of each roundabout approach. Vehicles that find themselves within this area are assigned a desired speed of 25km/h with an upper and lower limit of 30km/h and 25km/h respectively.

Priority rule

Figure 7. Priority rules on the single lane roundabout

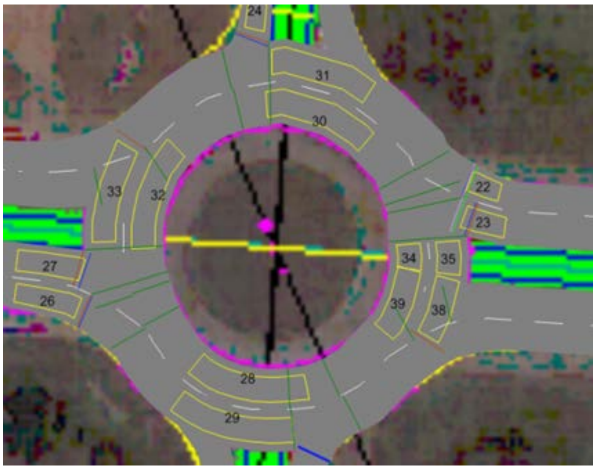

Figure 8. Priority rules on the multilane roundabout

The right of way at the roundabout entry was modeled using the “priority rules” function in VISSIM. Any vehicle that encounters the green lines (conflict markers) on the major roads has priority over those that encounter the red lines (stop lines) on the minor roads. Figure 7 and Figure 8 show the positions of the priority rules on the single lane and multilane roundabout respectively. As described in the VISSIM 5.30-05 User Manual, the priority rules were set up to obtain results similar to real world data [22].

Two parameters are included in the “priority rule”, which are “minimum gap time” and “minimum headway” (distance). For multi-lane roundabouts both the exterior and interior lanes were coded with different minimum gap time and minimum headway values.

It is worth mentioning that all the vehicle classes measured from the field were converted into passenger cars as mentioned earlier for the purposes of the simulation. A vehicle composition of 100% passenger cars was therefore used to run all the simulations to simplify the simulation and analysis process in Vissim. Table 4 depicts the various headways and critical time gap used for the simulation.

Table 4. Priority rules for the simulation

	Eastbound/Westbound		**Northbound/Southbound**	
Roundabout Type	**Headway**	**Critical time gap**	**Headway**	**Critical time gap**
Single lane	3.5m	2.7s	2m	2s
Multi-lane	3.5m (outer lane)	2.7s (outer lane)	2m (outer lane)	2s (outer lane)
	3.8m (inner lane)	3.2s (inner lane)	2.6m (inner lane)	2.9s (inner lane)
Turbo roundabout	3.5m	2.7s	2m (outer lane)	2s (outer lane)
			2.6m (inner lane)	2.9s (inner lane)

Note: The inner and outer lanes represent the lanes of the circulatory roadway.

Error checking and Calibration of vissim model

After building the roundabout, the network was examined for errors and completeness. The FHWA guideline volume 4 mentions that, the error checking stage ensures a working model so that the calibration process doesn’t result in distorted parameters to compensate for unnoticed coding errors[19]. Errors were checked by reviewing Software errors, Input Data and Animation.

The network was subsequently calibrated after satisfactorily checking for the errors. The model was calibrated using field data. The two parameters considered for the calibration process were the delay and queue length data obtained from the field. Various parameters within the model were varied until the simulated queue length and delay values on the target approach (Eastbound) of the roundabout matched what was obtained on the field to an acceptable level.

Vissim Run Considerations

The time period decided for this study was 3600 simulation seconds. However, the vissim student version used for the simulation process had a limitation of 600 simulation seconds maximum. Due to this limitation, the flow rates measured were converted to hourly flow rate using simple proportion.

The simulation run was therefore performed for 600 seconds with a warm up period of 300 seconds. The warm up period is very necessary in simulations because the network is not saturated at the start of simulation. In order words, the simulation starts with zero vehicles within the network and takes time to fill the network completely with vehicles. Data collected before saturation is attained will not reflect the field condition. Data collected within the first 5minutes of simulation was therefore excluded from the analysis.

Due to the stochastic nature of the vissim model, 10 simulation runs were performed with each run performed with a different random seed number. The measured data like delay and entry flow from each simulation run was recorded and averaged over the 10 simulations runs. This was done to reduce the impact of the stochastic nature of the vissim model on the results. Figure 9 shows a snapshot of vissim simulation.

Figure 9. VISSIM simulation snapshot

Capacity measurement

Vissim just like other micro simulation does not provide a value called “capacity”. In order to measure the entry capacity of the approaches of the proposed intersections, the east and west approaches were increased to create queue upstream of the yield lines. Capacity was measured as the maximum possible flow rate through the entry points of the approaches during the saturated condition. This was made possible by using the “data collection tool” in vissim to collect the traffic entry flow downstream of the queue at the yield line.

Delay and queue measurement

The delay segments which are based on travel time sections created on the network were used to measure the delay of every vehicle that pass the start section of the travel time section created. A delay segment 1 was created on the westbound approach which started from a point 326m from the yield line and ended on the yield line. Another Delay segment 2 was also created which started from the same point as delay segment 1 and ended from a point 450m from the start point.

The maximum and average queue was measured by using queue counters tool. This tool was drawn at the yield line of the westbound approach to measure the maximum and average queue. Vissim calculates the maximum queue length as the maximum of the current queue length measured upstream every time step whiles the average queue length is the arithmetical average of the current queue length measured upstream every time step [22].

Data Processing

The raw data output from vissim was analysed by the help of Microsoft Excel. The calibration parameters were assessed to determine their degree of closeness with the parameters measured on the field. Statistical Hypothesis testing which employs the analysis of variance (ANOVA) was used to assess the difference between the calibration parameters from the field and simulation observation.

4. Results and Discussions

4.1. Calibration Results

The existing roundabout was calibrated by using two performance measures namely queue length and delay. The subject approach for the calibration was the westbound approach. It was chosen as the subject approach because of the long queue and delay observed during the morning peak. We present the calibration results of the study.

Delay

The field delay on the westbound approach was estimated to be 253 seconds for delay segment 1 and 256 seconds for delay segment 2. After the calibration process, the simulation model estimated the delay to be 232 seconds and 235 seconds for the delay segment 1 and delay segment 2 respectively. These delay values are the averages of the number of runs performed as shown in Table 5.

Table 5. Delay results

	DELAY RESULTS (s)			
	Delay segment 1		Delay segment 2	
	Simulated	Field	Simulated	Field
Run 1	265	276	267	278
Run 2	221	269	224	276
Run 3	236	214	239	213
Run 4	253	-	256	-
Run 5	218	-	220	-
Run 6	197	-	200	-
Run 7	258	-	261	-
Run 8	215	-	218	-
Run 9	240	-	242	-
Run 10	219	-	221	-
Average	232	253	235	256

A single factor ANOVA tests at 95% confidence level were performed on the field and simulated delays to know if their means are the same. The results show that P-value (0.226) > α (0.05) and P-value (0.235) > α (0.05) in Table 6 and Table 7 respectively. We can therefore conclude that the observed values are close to the simulated values to an acceptable level and thus the delay is considered calibrated.

Table 6. ANOVA for delay segment 1

ANOVA

Source of Variation	SS	df	MS	F	P-volue	F crit
Between Groups	984.0169733	1	984.017	1.648086	0.2256	4.8443
Within Groups	9567.730768	11	597.066			
Total	7551.747742	12				

Table 7. ANOVA for delay segment 2

ANOVA

Source of Variation	SS	df	MS	F	P-volue	F crit
Between Groups	1010.713168	1	1010.713	1.57765	0.23512	4.8443
Within Groups	7047.106156	11	640.646			
Total	8057.819324	12				

Queue Length

The simulation model estimated a maximum queue length of 528m on the westbound approach which matches close to the maximum queue of 550m measured in the field. The model is therefore considered to be satisfactorily calibrated in terms of queue length. The long queue on this approach is related to the high traffic demand and the bottleneck created by the reduction in number of lanes from two to one about 80m before the vehicles get to the yield line. There is a high rate of inflow of traffic from the double approach lanes but a low discharge rate as vehicle get to the bottleneck zone as a result of the change in number of lanes from two to one.

Entry Flow

The entry flow rate of all the approaches after calibration compared with the field data are shown in Table 8.

Table 8. Entry flow rate for simulation and field data

	Simulation	Field	
APPROACH	Entry flow/(pcu/h)	Entry flow/(pcu/h)	GEH
North	305	404	5.2
South	401	596	8.7
East	1057	1220	4.8
West	1231	1472	6.6

A Geoffrey E. Havers GEH test statistic was conducted to compare the observed entry flow rate and the simulated entry flow rate. If the GEH is less than 5, the simulated flow is considered a good match to the observed flow. Further adjustments may be required if GEH is between 5 and 10. A GEH above 10 shows the possibility that there is a problem with the model or the data. Table 8 shows the GEH values for all the roundabout approaches. The GEH of the north, south and west approaches were 5.2, 8.7 and 6.6 respectively which lie between 5 and 10. However, GEH of the subject approach for the calibration was 4.8. Since the subject approach has a GEH less than 5, the model is considered to match the field condition at a satisfactory level. The model is thus considered to be calibrated in terms of entry flow.

4.2. Intersection Capacity Utilization (Level of Service)

After calibrating the simulation model, the existing single lane roundabout was estimated to be performing at level of service H as shown in Table 9. This was done by using the intersection capacity utilization method. Level of service H according to the ICU method means that, the intersection is 9% or greater over capacity and could experience congestion periods of over 2 hours a day.

Proposed Intersections Results

This section depicts the results of the proposed alternatives to the existing intersection. Two alternatives which are the Egg turbo roundabout and conventional double lane roundabout have been analysed. The capacity and delay of the alternatives are compared with that of the existing intersection.

Turbo Roundabout

The overall capacity of the turbo roundabout option showed a significant increment over that of the single lane roundabout after the simulation analysis. The overall capacity of the intersection at peak periods increased from 2990 pcu/h in the single lane roundabout to 4747 pcu/h in the turbo roundabout representing a 60% increment. There was an increase in the entry capacities from 1075 pcu/h to 2330 pcu/h on the east approach and 1246 pcu/h to 1962 pcu/h on the west approach. This increment can be attributed to the introduction of an additional lane making them double lane entries.

It is however interesting to note that the entry capacity of the minor roads (north and south approaches) of the turbo roundabout were reduced. The entry flow of north approach was reduced from 272 pcu/h in the single lane to 152 pcu/h in the turbo roundabout. The additional circulatory lane introduced increases the conflicting or circulating flow in front of the minor lanes which delays the vehicles waiting to make an entry. The vehicles on the minor roads making a left-turn or through movement now require a higher critical gap time and headways in two lanes at the same time before they can merge with the inner lane circulating flow.

The capacity result as compared with that of the single lane roundabout is shown in Table 10.

Table 9. Intersection Capacity Utilization (Level of Service)

Approach	Entry Capacity (pcu/h)	Entry Flow (pcu/h)	Volume/Capacity Ratio	ICU Value	LOS
North	272	596	219	630.3	H
South	397	404	102		
East	1075	2060	192		
West	1246	1472	118		

The queue and delay results also confirm an improvement in the performance of the intersection at peak periods when changed from single lane roundabout to turbo roundabout. The delay to travel time on the westbound approach was reduced from 232 seconds in the single lane roundabout to 81 seconds (inner lane) and 72 seconds (outer lane) in the turbo roundabout. Vehicles now experience less delay due to the introduction of an additional entry and exit lane to the major roads (east and west) which increases the rate of queue discharge. There was also a significant reduction (20%) in the maximum queue length from 528m in the existing condition to 443m in the turbo roundabout on the subject approach (westbound).

Table 10. Capacity of turbo roundabout compared with single lane roundabout

Roundabout Type	Approach	Approach capacity (pcu/h)	Roundabout Capacity All Approaches (pcu/h)
Single lane Roundabout	North	272	2990
	South	397	
	East	1075	
	West	1246	
Turbo Roundabout	North	152	4747
	South	302	
	East	2330	
	West	1962	

Conventional Double Lane Roundabout

The capacity of the conventional double lane roundabout option also resulted in a significant increment over that of the single lane roundabout after the simulation analysis. The overall capacity of the intersection at peak periods increased by 30% from 2990 pcu/h in the single lane roundabout to 3889 pcu/h in the double lane roundabout. The values are slightly higher than capacity values reported for single and double lane roundabouts. The difference could be attributed to limited simulation time in the student version Vissim software used for the work, differences in site conditions and probably the use of single target approach for the software calibration. The entry capacity of the east approach increased from 1075 pcu/h to 1505 pcu/h and that of the west was from 1246 pcu/h to 1588 pcu/h. The new double lane entries on these approaches contributed to this increase in capacity.

On the other hand, the entry capacities of the minor roads (north and south approaches) of the double lane roundabout also increased marginally. The south approach recorded a capacity increment from 397 pcu/h in the single lane to 493 pcu/h in the double lane roundabout. The capacity result as compared with that of the single lane roundabout is shown in the Table 11. The performance of the existing intersection in terms of queue and delay at peak periods improved when it was changed into a double lane roundabout. There was an appreciable reduction in the delay on the westbound approach from 267 seconds in the single lane roundabout to 173 seconds in the double lane roundabout. Vehicles on the major roads would experience less delay because of the new double lane entry which increases the rate of queue discharge.

Table 11. Capacity of double lane roundabout compared with single lane roundabout

Roundabout type	Approach	Entry Capacity (pcu/h)	Roundabout Capacity All Approaches (pcu/h)
Single lane Roundabout	North	272	2990
	South	397	
	East	1075	
	West	1246	
Conventional Two lane Roundabout	North	302	3889
	South	493	
	East	1505	
	West	1588	

When the simulation was done for the results of the queue length for single and double lane roundabouts, there was also a slight reduction (8%) in the maximum queue length from 528m in the existing condition to 487m in the double roundabout on the subject approach (westbound).

4.3. Discussions

It is worth comparing the results of the turbo roundabout and the conventional double lane roundabout since both have the same number of entry and exit lanes but differ in geometrical shape. The turbo roundabout recorded an overall capacity of 4747 pcu/h which is about 20% higher the conventional double lane roundabout's capacity of 3889 pcu/h. The result is in line with the publications made by [2,11] using micro simulation tool to conclude that capacity is increased in turbo roundabouts. This difference in capacity can be attributed to the reduction in conflict points and removal of weaving and cut-offs in the turbo roundabout which are eminent in the double lane roundabouts. Interestingly, whiles the east and west approaches of the turbo roundabout have higher entry capacities than the east and west approaches of the double lane roundabout, the opposite is recorded on the north and south approaches. The reason is that, vehicles on the east and west approaches that merge with the inner circulating flow when making a left or through movement, experience less delay because they find gaps in only one circulating lane in the turbo roundabout, as opposed to two circulating lanes in the conventional double lane roundabout. There is therefore proper utilization of the inner circulating lane of the turbo roundabout than the double lane roundabout.

Capacity results on the minor roads agree with the results from the studies published by [5] which states that the minor roads entry capacity depends strongly on the scale of left turn movements. The circulating flow at the entry points of the minor roads of the double lane roundabout is less than that of the turbo roundabout since entering vehicles on the westbound and eastbound approaches experience more delay. Thus the left-turn entering vehicles on the north and south approaches of the double lane roundabout can therefore easily find gaps than in the turbo roundabout. This reason explains the higher entry capacity on the north and south approaches of the double lane roundabout.

Furthermore, the performance measures in the turbo roundabout indicate an improvement over that of the conventional double lane roundabout. Vehicles on the westbound approach of the turbo roundabout experience delay to travel time of 81 seconds (inner lane) and 72 seconds (outer lane) whereas the delay on the double lane roundabout is 173 seconds. Moreover, the results show a longer average queue length in the subject approach of the double lane roundabout than in the turbo roundabout.

5. Conclusions and Recommendations

5.1. Conclusions

Based on the results of this study, the following conclusions have been drawn:

Most of the arterial roads in the urban areas in Ghana linked by conventional roundabouts are characterized by capacity deficit, long queues and delay during peak periods.

The turbo-roundabout is a new concept which was developed in the Netherlands with the aim of providing a solution to the capacity and safety problems in the conventional multi-lane roundabouts.

The introduction of mountable lane dividers on the turbo roundabout eliminates some conflicting paths and route choices and this increases safety and capacity. There is also proper utilization of the inner lanes which increases capacity.

The estimated overall capacity of the turbo roundabout, 4392 pcu/h is about a 70% increment of the capacity of the existing single lane roundabout. In as much as the conventional double lane roundabout has a capacity which is 40% higher than the existing single lane roundabout, the turbo roundabout's capacity is about 19% higher than the conventional double lane roundabout's capacity of 3690 pcu/h. A significant reduction in the delay and queue length of the subject approach (westbound) was also estimated when the turbo roundabout was analysed. This notwithstanding the results show slight reduction in the capacity of the minor roads of the turbo roundabout.

The geometry of the turbo roundabout and the conventional multilane roundabout shows that the spatial requirement (m^2) of the turbo roundabout is about the same as the conventional multilane roundabout.

It is important to note that the results cannot be generalized but applies to the specific study area. However, it is most likely to match closely to other intersections with similar traffic conditions.

Ultimately, the study shows that the turbo roundabout can be a sustainable solution with significant improvement of the capacity and performance of the intersection studied

5.2. Recommendations

The intersection was analysed using a single day data collected during the morning peak. In order to cater for the variability of traffic data, it is recommended, if possible, to collect field data for multiple days. Turbo roundabout concept is a recent innovation which hasn't been explored for roundabout capacity improvement in Ghana and other developing countries; therefore further research on this is encouraged.

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