OPTIMISING THE PERFORMANCE OF ROUNDABOUTS IN DAR ES SALAAM CITY

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ABSTRACT

Intersections are one of the major bottlenecks that aggravate congestion in road networks; effective control of which is an important strategy in improving traffic flow. While developing countries have found it hard to adopt sophisticated means of intersection control, they have also not optimised the performance of roundabouts. This paper reviews the performance of roundabouts, which have become increasingly popular in recent years, as simple and low cost forms of intersection control. The performance of three major roundabouts in Dar es Salaam has been analysed and results show that roundabouts can accommodate high traffic volumes without causing excessive delays. The results also show that low-cost improvements on roundabouts, involving minor adjustments in geometry and improved traffic management, can significantly improve their operational performance.

Keywords: Traffic control, intersection control, roundabouts

INTRODUCTION

Congestion has emerged as one of the main challenges facing the highway mode of transport resulting in economic losses to nations and hitting hard on the developing countries' productivity as they struggle to develop their economies. Traffic control is one of the most important components of managing traffic as an efficient operation could increase road capacity at a very low cost and there are beneficial environmental impacts in terms of reduced delay and congestion, and improved air quality. Intersections have a disproportionate effect on the overall safety and capacity of highways as they serve traffic in opposing or conflicting directions. Intersections constitute one of the major bottlenecks in road networks and aggravate congestion; effective control of intersections therefore forms an important strategy in improving traffic flow. An effective intersection control would maximize capacity, minimize delays and minimize conflicts (TRL, 1994).

Due to shortage of trained professionals and the limited resources in developing countries, traffic signals are often left unrepaired. They also continuously consume the scarce and costly electrical energy. It is therefore wise for developing countries to use solutions which require minimal maintenance and resources (such as roundabouts) where possible. Roundabouts provide high capacity, cause little delay in the off-peak period and require no technical maintenance or energy supply. Their strength lies in their ability to reduce the number of vehicular conflicts at intersections thus enhancing intersection capacity and safety. There are additional intangible benefits of roundabouts such as their traffic calming effect, getaway feature and aesthetics (Oketch *et al*., 2004). As a result of the foregoing, use of modern roundabouts as a viable traffic control measure (instead of traffic signal or priority intersection) is increasing in many jurisdictions in Tanzania and other developing countries.

Although the use of roundabouts is on the rise in Tanzania, their adoption as a common form of intersection is hindered by the general lack of an evaluation of their operational performance that would facilitate an objective comparison between them and other intersection control strategies. This paper reviews the performance of roundabouts in Dar es Salaam as one of the major types of intersection control. Since traffic control interacts with engineering design, the best solution to improve traffic flow usually involves a combination of physical redesign and control. This study also aimed at demonstrating the application of low-cost improvements on roundabouts, involving minor adjustments in geometry and improvement in traffic management, to improve the operational performance of roundabouts.

1 Introduction of the Modern Roundabout

The modern roundabout was developed in the United Kingdom in 1963 to rectify problems associated with traffic circles by adopting a mandatory “give-way” rule at all circular intersections, which required entering traffic to give way, or yield, to circulating traffic (FHWA, 2000). The introduction of flare and deflection concepts further assisted roundabouts to prevail as one of the most popular, safe and convenient traffic-control options in Europe and Australia (Sisiopiku and Oh, 2001). In addition, smaller circular intersections were proposed that required adequate horizontal curvature of vehicle paths to achieve slower entry and circulating speeds (FHWA, 2000). The modern roundabout represents a substantial improvement, in terms of operations and safety, when compared with older rotaries and traffic circles (Brown, 1995; Todd, 1991; Jacquemart, 1998).

2 Roundabout Performance Analysis

An operational analysis produces two kinds of estimates: (1) the capacity of a facility, i.e., the ability of the facility to accommodate various streams of users, and (2) the level of performance, often measured in terms of one or more measures of effectiveness, such as delay and queues. 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”. While capacity is a specific measure that can be defined and estimated, level of service (LOS) is a qualitative measure that characterizes operational conditions within a traffic stream and their perception by motorists and passengers. To quantify level of service, the HCM defines specific measures of effectiveness for each highway facility type (TRB, 2000). 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. Roundabout approach capacity is dependent on the conflicting circulating flow and the roundabout’s geometric elements (FHWA, 2000).

Basically, two main approaches can be seen among the various approaches currently used in the world to make capacity estimations. They are; (i) gap acceptance approach, and (ii) empirical approach. The empirical approach has been used in UK (Kimber, 1980) and Germany (Brilon *et al*., 1997) while in Australia (Troutbeck, 1991) and the HCM 2000, use the gap acceptance approach. The gap acceptance approach is mainly based on theory and driver behaviour is represented by vehicle-to-vehicle interaction. The empirical approach is based on statistical regression and driver behaviour is represented by the relation between geometric elements and road performance.

Geometry parameters that affect capacity are inscribed diameter, number of entry lanes, average entry lane width, number of circulating lanes, entry radius, entry angle, “flaring” as short lanes and bypass lanes (Akcelik, 2011). The results of the extensive empirical British research indicate that approach half width, entry width, average effective flare length and entry angle have the most significant effect on entry capacity (FHWA, 2000).

3 Comparative Performance of Roundabouts

While traffic signals have been effective, they sometimes create more problems than they solve especially when improperly implemented. Unnecessary stops and delays lead to drivers’ discomfort, and extra fuel consumption and emission. In addition, there is increased likelihood of accidents due to speeding and violation of traffic signals. Minor streets also suffer excessive delay mostly due to right turning movements even where traffic on the major street is low (Manage *et al*., 2003).

Sisiopiku and Oh (2001) compared the performance of roundabouts with four leg intersections under yield control, two- and four-way stop control, and signal control for various traffic conditions using the SIDRA package. Roundabout capacities are found to be higher than capacities of signal controlled intersections with two- and three-lane approaches for any proportion of right-turning traffic volume. Polus and Vlahos (2005) found that when constructed where geometric and traffic conditions are appropriate, roundabouts can potentially provide advantages over conventional intersections in terms of capacity, delay, queue length, emissions, safety, and aesthetics.

Manage *et al*. (2003) found evidence of significant reduction in accidents experienced at intersections converted from traditional traffic control to roundabouts. A before and after study of installation of 73 roundabout sites in Victoria state in Australia that was carried out in 1981 revealed that there was a large percent reduction in number of accidents after roundabout installation (AUSTROAD, 1993). Another study carried out by Tude (1990) studied accidents from 1981 to 1987 at 230 roundabouts and 60 control sites (non-roundabouts) in New South Wales, Australia. A significant overall reduction in crashes was observed at roundabouts while during the same time period, the control sites experienced significant increases in accident rates annually. These results show that roundabouts perform better than other types of intersections when safety is concerned.

Brabander *et al*. (2005) analyzed the effect on road safety of 95 roundabouts that were built in Flanders between 1994 and 1999. The study found that roundabouts are most effective on intersections of a main road with a high speed limit (90 km/h) and an adjacent road with a lower speed limit (50 or 70 km/h). The empirical analysis reveals a reduction of 34% (varying between 15% and 59%) for the total number of injury accidents, 30% (7%–45%) for light injury accidents, and 38% (27%–72%) for serious injury accidents. Several German studies, including the before-after studies carried out by Brilon *et al*. (1993) and Pohl (1995), show that roundabouts provide lower accidents rates and lower accident severity than other intersections types.

Persaud *et al*. (2001) evaluated changes in motor vehicle crashes following conversion of 23 intersections from stop sign and traffic signal control to modern roundabouts. A before-after study was conducted which estimated highly significant reductions of 40 percent for all crash severities combined and 80 percent for all injury crashes. Reductions in the numbers of fatal and incapacitating injury crashes were estimated to be about 90 percent.

Schoon and van Minnen (1994) studied 181 Dutch intersections converted from conventional controls (traffic signals or stop signs) to modern roundabouts and reported that crashes and injuries were reduced by 47 and 71 percent, respectively, with the more severe injury crashes being reduced by 81 percent. Troutbeck (1993) reported a 74 percent reduction in the rate of injury crashes following conversion of 73 roundabouts in Victoria, Australia. A thorough review of the literature was conducted by Elvik *et al*. (1997), who concluded that converting from yield, two-way stop, or traffic signal control to a roundabout reduces the total number of injury crashes by 30 to 40 percent. Reduction in the number of pedestrian crashes was in the same range. In general, numerous studies suggest that modern roundabouts are safer than other methods of intersection traffic control and that their installation should be strongly promoted as an effective safety treatment for intersections.

A study carried out by Andras (2002) on the effects of small roundabouts on emissions and fuel consumption showed an average decrease in CO emission by 29%, NOx emission by 21% and fuel consumption by 28% per car within the influence area of the considered junction.

METHODOLOGY

The simulation software used for this study is aaSIDRA (Signalized and un-signalized Intersection Design and Research Aid), also known as SIDRA, version 2.1. SIDRA uses an empirical gap-acceptance method to model roundabout performance that takes into account both the roundabout geometry and driver behaviour. The software is capable of analyzing signalized intersections (actuated and fixed-time), un-signalized intersections including two-way stop-controlled, all-way stop-controlled, and yield-controlled intersections, and roundabouts. Akcelik (2008) observed that driver behaviour, characterized by gap acceptance parameters, is one of the major determinants of capacity. The SIDRA default roundabout critical gap and follow-up time values are not fixed and are estimated as functions of the roundabout geometry, circulating flow and entry lane flows. The SIDRA capacity model may also be calibrated to better reflect road and local driver characteristics. Consequently, the roundabout analysis conducted in this study has been calibrated for local driver characteristics using default critical gap and follow-up times (Akçelik and Associates, 2002; 2005). Input data to aaSIDRA, which was used in analyzing the roundabouts, included traffic volumes for each approach to the roundabout and the flow rate for each directional movement. Volumes are expressed in passenger car vehicles per hour (vph), for a 15 minute analysis period.

The key performance measures that are typically used to estimate the performance of a given roundabout are capacity, degree of saturation, delay, queue length and Level of Service (LOS). Each measure provides a unique perspective on the quality of service at which a roundabout will perform under a given set of traffic and geometric conditions (Kimber, 1980). Table 1 shows the Highway Capacity Manual (HCM) delay limits as used by the aaSIDRA software to determine each LOS.

Table 1: Level of Service criteria for roundabouts

LOS	Control Delay per Vehicle (Sec)
A	≤ 10.0
B	10.1 – 20.0
C	20.1 – 35.0
D	35.1 – 55.0
E	55.1 – 80.0
F	> 80.0

Source: TRB (2000)

This paper has assessed the performance of roundabouts on major roads in Dar es Salaam city using three roundabouts namely:

- The Uhuru roundabout; which joins the Msimbazi and Uhuru roads. It is a four arm roundabout with the Uhuru road having two lanes and the Msimbazi road having four lanes (with only two being effectively used).
- The Bandari roundabout; which is a three arm roundabout joining the Sokoine, Msimbazi and Bandari roads, each with two lane approaches.
- The Kawawa roundabout; which joins the Kawawa and Kigogo roads. It is a four arm roundabout with the Kigogo road having two lanes and the Kawawa road having four lanes.

The geometric layouts of the three roundabouts are depicted in Figures 1 to 3 and their basic dimensions are summarized in Table 2.

Table 2: Geometric dimensions of the three roundabouts

Roundabout	Approach half width (m)	Island diameter (m)	Circulatory roadway width (m)	Number of circulation lanes
Kigogo	3.5	30	10	2
Bandari	3.5	42	7	1
Uhuru	3.5	28	5	1

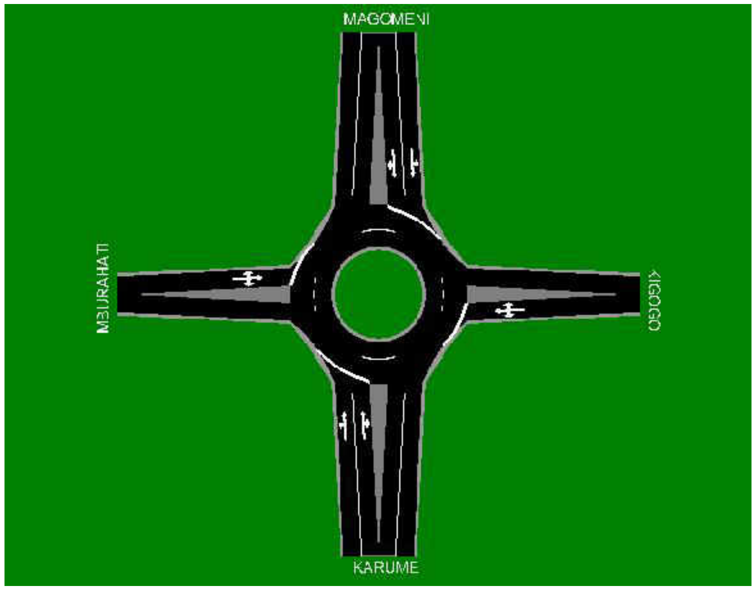

Figure 1: *Layout of the Kigogo roundabout*

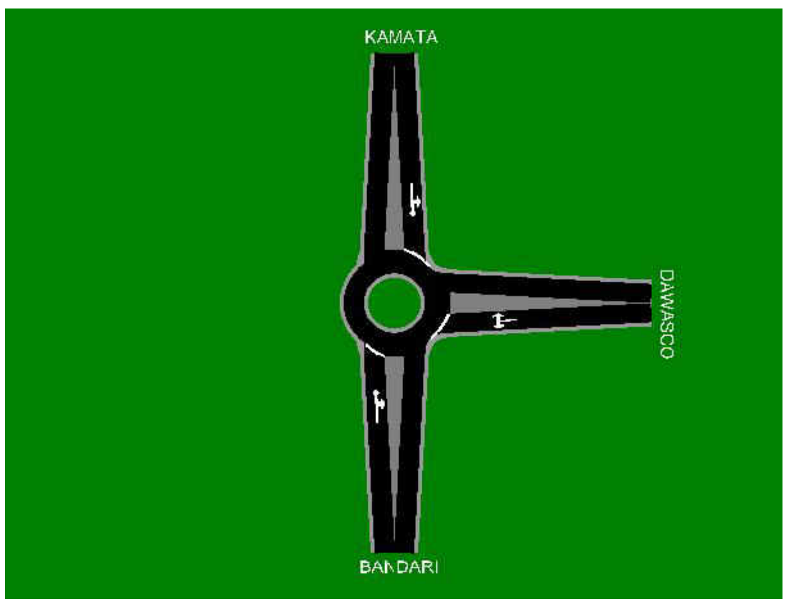

Figure 2: *Layout of the Bandari roundabout*

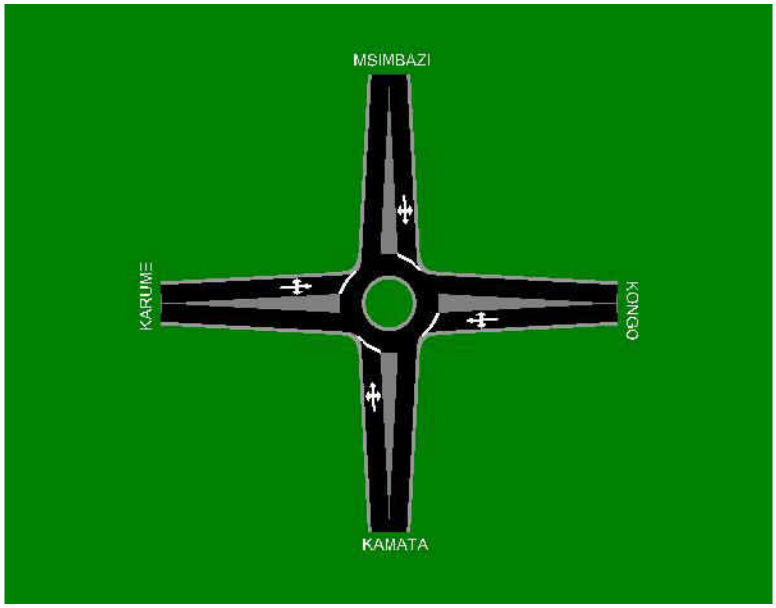

Figure 3: *Layout of the Uhuru roundabout*

RESULTS AND DISCUSSION

1 Performance of the Roundabouts

Tables 3 to 5 provide the performance indicators for the three roundabouts as a result of the analysis of field data using aaSIDRA.

The following observations were made regarding the Kigogo roundabout:

- There are roadside activities near the roundabout which affect its performance.
- Drivers approaching the roundabout were observed to safely negotiate into and through the roundabout. However, physical observations showed that safety was compromised in some cases as some drivers did not yield to traffic already in the circulation roadway.
- The roundabout is operating at a very good LOS 'A'. Few vehicles approach the roundabout from Kigogo and Mburahati approaches and hence the effect of entry to circulating flow is very low leading to the high LOS of the roundabout.

The following observations were made regarding the Bandari roundabout:

- Heavy vehicles affected the performance of the roundabout during peak hours (note the LOS 'C' on Bandari approach which has most of the heavy vehicles).
- Safety is compromised by poor drivers' behaviour as some entering vehicles do not yield to traffic already in the circulation roadway.

The roundabout operates at a good LOS 'B'.

Table 3: Performance indicators for the Kigogo roundabout

Approach/ Movement No	Turn	Demand Flow (vph)	Cap. (vph)	Deg of Satn (v/c)	Av. Delay (sec)	LOS	95% Back of Queue (m)	Av. Speed (kph)
KARUME								
1	L	287	500	0.574	3.6	A	37	36.5
2	T	1023	1782	0.574	3	A	37	36.9
3	R	6	10	0.6	9.5	A	37	34.1
Approach		**1316**	**2292**	**0.574**	**3.2**	**A**	**37**	**36.8**
KIGOGO								
4	L	67	543	0.269	7.8	A	10	34.6
5	T	58	543	0.269	7.8	A	10	34.6
6	R	21	543	0.269	7.8	A	10	34.6
Approach		**146**	**543**	**0.269**	**7.8**	**A**	**10**	**34.6**
MAGOMENI								
7	L	18	47	0.383	1.9	A	19	37.6
8	T	827	2140	0.386	0.7	A	19	38.3
9	R	298	771	0.387	6.7	A	19	35.1
Approach		**1143**	**2958**	**0.386**	**2.3**	**A**	**19**	**37.5**
MBURAHATI								
10	L	278	559	0.78	17.2	B	53	29.9
11	T	24	559	0.78	17.2	B	53	29.9
12	R	134	559	0.78	17.2	B	53	29.9
Approach		**436**	**559**	**0.78**	**17.2**	**B**	**53**	**29.9**
Roundabout		**3041**	**6351**	**0.78**	**5.1**	**A**	**53**	**35.7**

The following observations were made regarding the Uhuru roundabout:

- Some of the approaches to this roundabout have been shown to have a reasonable level of service although they experience higher demand than other approaches. This is due to entry-circulation relationship where approaches with lower demand volume have experienced very long delays and queue lengths. Entry capacity decreases if the circulation flow increases as there are then fewer opportunities for waiting vehicles to enter the circulation.
- Locking of the roundabout does occur as drivers become impatient and enter the roundabout. The heavy vehicles also cause locking due to the difficulty they encounter in manoeuvring.
- Small businesses around the roundabout reduce the circulation width thus affecting the performance of the roundabout. In addition, the businesses attract a large number of pedestrians crossing the roundabout.
- The bus stop along the Kongo approach (which is near the roundabout) affects the performance of the roundabout since vehicles leaving the roundabout have to slow down and sometimes stop and wait for minibuses to drop and pick passengers.
- Msimbazi road is a 4-lane road but only two lanes are used as the outer

lanes are used for commercial acitivities and by the minibuses that provide public transport. As a result, the LOS along KAMATA and Msimbazi approaches is very poor.

- The overall LOS of the roundabout is 'F' calling for some measures to improve the performance of the roundabout.

2 Simulated improvement of the Uhuru Roundabout

The above analysis has shown that the Uhuru roundabout needs to be improved. The following simple improvements were considered:

- Clearing lanes and re-routing of minibuses; Although Msimbazi road is a four lane road, the existing situation does not allow it to perform as a four lane road due to pedestrian activities along the road. One lane in each direction along the KAMATA approach is also used for parking minibuses. The minibuses were re-routed (to Lumumba and Shaurimoyo or Kawawa roads) to allow the two lanes to also serve traffic. The bus stop at the exit along Kongo approach was also moved further away from the roundabout so as to allow vehicles from the roundabout to exit the roundabout at the desired speed.

Change in layout of the roundabout; Layout changes were possible on Uhuru roundabout which is old and big and was not designed as a small modern roundabout. The circulation roadway is improved by decreasing the island diameter from 28 m to 20 m so as to allow for circulation width of 10 m i.e. two circulation lanes.

Table 4: Performance indicators for the Bandari roundabout

Approach/ Movement No	Turn	Demand Flow (vph)	Cap. (vph)	Deg of Satn (v/c)	Av. Delay (sec)	LOS	95% Back of Queue (m)	Av. Speed (kph)
BANDARI								
1	T	806	1247	0.966	26.5	C	295	21.6
2	L	399	1247	0.966	26.5	C	295	21.6
Approach		**1205**	**1247**	**0.966**	**26.5**	**C**	**295**	**21.6**
CITY CENTRE								
3	T	615	1095	0.9	17.2	B	172	23.8
4	R	371	1095	0.9	17.2	B	172	23.8
Approach		**986**	**1095**	**0.9**	**17.2**	**B**	**172**	**23.8**
KAMATA								
5	L	197	1081	0.603	3.6	A	42	28.4
6	R	455	1081	0.603	3.6	A	42	28.4
Approach		**652**	**1081**	**0.603**	**3.6**	**A**	**42**	**28.4**
Roundabout		**2843**	**3424**	**0.966**	**18**	**B**	**295**	**23.6**

Figure 4 shows the improved layout of the Uhuru roundabout as modelled in aaSIDRA and Table 6 shows the new performance indicators following the improvement of the roundabout. With simple and low-cost operational and geometric improvements, the roundabout will operate at a Level of Service 'B' and there will be an increase in the overall travelling speed to 26.4 km/h from the low of 6.5 km/h. The new geometry of the roundabout can satisfactorily handle the traffic and there will therefore be no need to deploy the costly Traffic Police Officer (TPO) to guide traffic during peak periods as is the case now.

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Table 5: Performance indicators for the Uhuru roundabout

Approach/ Movement No	Turn	Demand Flow (vph)	Cap. (vph)	Deg of Satn (v/c)	Av. Delay (sec)	LOS	95% Back of Queue (m)	Av. Speed (kph)
KAMATA								
1	L	95	386	0.896	63.5	E	116	7.5
2	T	105	386	0.896	63.5	E	116	7.5
3	R	146	386	0.896	63.5	E	116	7.5
Approach		**346**	**386**	**0.896**	**63.5**	**E**	**116**	**7.5**
KONGO								
4	L	130	1063	0.912	18.7	B	187	9.1
5	T	683	1063	0.912	18.7	B	187	9.1
6	R	156	1063	0.912	18.7	B	187	9.1
Approach		**969**	**1063**	**0.911**	**18.7**	**B**	**187**	**9.1**
MSIMBAZI								
7	L	185	489	1.19	392.7	F	959	3.3
8	T	249	489	1.19	392.7	F	959	3.3
9	R	148	489	1.19	392.7	F	959	3.3
Approach		**582**	**489**	**1.19**	**392.7**	**F**	**959**	**3.3**
KARUME								
10	L	97	1021	0.794	10	A	102	9.5
11	T	656	1021	0.794	10	A	102	9.5
12	R	58	1021	0.794	10	A	102	9.5
Approach		**811**	**1021**	**0.794**	**10**	**A**	**102**	**9.5**
Roundabout		**2708**	**2960**	**1.19**	**102.2**	**F**	**959**	**6.5**

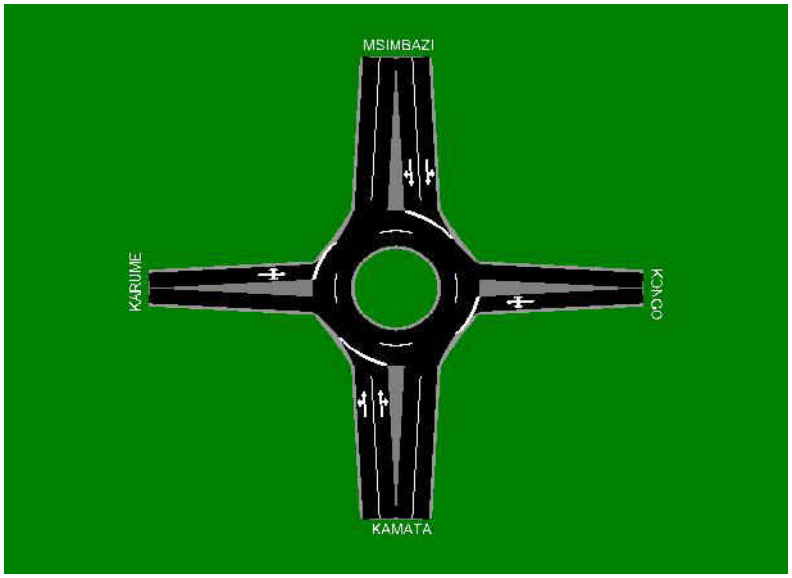

Figure 4: *Modelled improved layout of the Uhuru roundabout*

Table 6: Performance indicators for the improved Uhuru roundabout

Approach/ Movement No	Turn	Demand Flow (vph)	Cap. (vph)	Deg of Satn (v/c)	Av. Delay (sec)	LOS	95% Back of Queue (m)	Av. Speed (kph)
KAMATA								
1	L	95	805	0.43	14.1	B	19	28.1
2	T	105	805	0.43	14.1	B	19	28.1
3	R	146	805	0.43	14.1	B	19	28.1
Approach		**346**	**805**	**0.43**	**14.1**	**B**	**19**	**28.1**
KONGO								
4	L	130	986	0.983	32.5	C	254	22.1
5	T	683	986	0.983	32.5	C	254	22.1
6	R	156	986	0.983	32.5	C	254	22.1
Approach		**969**	**986**	**0.982**	**32.5**	**C**	**254**	**22.1**
MSIMBAZI								
7	L	185	1087	0.535	13.5	B	33	28.3
8	T	249	1087	0.535	13.5	B	33	28.3
9	R	148	1087	0.535	13.5	B	33	28.3
Approach		**582**	**1087**	**0.535**	**13.5**	**B**	**33**	**28.3**
KARUME								
10	L	97	1038	0.781	6.4	A	70	31.4
11	T	656	1038	0.781	6.4	A	70	31.4
12	R	58	1038	0.781	6.4	A	70	31.4
Approach		**811**	**1038**	**0.781**	**6.4**	**A**	**70**	**31.4**
Roundabout		**2708**	**3916**	**0.983**	**18.2**	**B**	**254**	**26.4**

CONCLUSIONS

- Roundabouts have proved to accommodate large traffic volumes without causing excessive delays as shown by the Kigogo and Bandari roundabouts. Despite experiencing high traffic volumes, the Kigogo roundabout has been observed to operate at an overall Level of Service 'A'. The Bandari roundabout is also experiencing high traffic volumes with a large number of heavy vehicles but operates satisfactorily at the overall Level of Service 'B'.
- The Uhuru roundabout operates at a very poor level of Service 'F' due to poor traffic management and inadequate geometric layout to provide the necessary capacity. Improvement of the geometric layout of the Uhuru roundabout and traffic management around the roundabout has been found to largely improve the performance of the roundabout. The performance of a roundabout can therefore largely and cheaply be improved by improving traffic management and geometric layout.
- Physical observation shows that locking of the roundabout is mostly caused by poor drivers' behavior. The safety of roundabouts is also reduced by drivers who do not slow down and yield when entering roundabouts.

RECOMMENDATIONS

- Measures should be taken to discourage all roadside activities near roundabouts which attract a large number of pedestrians. Re-routing of public transport and heavy vehicles as well as moving bus stops further away from roundabouts should be considered as a way of improving roundabouts' performance. Where necessary, heavy vehicles should only be allowed to enter low traffic roundabouts and during off-peak periods.
- Since minor adjustments in the geometry of a roundabout can result in significant improvement in its safety and operational performance, such measures should be considered especially on traditional roundabouts which have large central islands that can be reduced to small modern roundabouts' sizes.

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