Spiral Lane Markings: A Review of Lane Discipline

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Abstract
Roundabouts are quite effective as junction control measures; reducing crashes by eliminating certain conflict points and managing capacity by virtue of its self-regulating ability. Amongst other forms of circulatory carriageway markings, spiral markings have been acknowledged as a way of reducing a driver's decision-making responsibilities and leading drivers to their choice exit lanes hence improved safety. Conversely, signalization becomes imperative as it offers an equitable means of controlling right-of-way at all arms of the roundabout especially where problems of unbalanced flows exist. Considering these issues a question comes to mind; "what proportion of drivers contravene the principles of lane discipline which several authors claim to be the highlight of spiral markings?" It was on this premise that this research was borne with specific objective of observing the lane discipline at a roundabout. This was achieved by installation of video cameras at strategic locations around the circulatory carriageway of the roundabout, with an observational study (survey); analysis of same, considering class of vehicles, traffic and light conditions being carried out. The transgressions observed were classified as minor and major transgressions and full lane changes; analyzed using simple statistical analysis. Following an hourly average for a three-day period, there were 33%, 23%, 17% car transgressions and 55%, 43%, 42% truck transgressions at unsaturated, partially saturated and saturated periods respectively. It was therefore concluded that there are more transgressions at unsaturated periods and transgressions generally are of the minor form, trucks are more involved in the observed transgressions, and that transgressions increase when roundabouts get busier which was quite a surprising finding as the reverse was expected.
Keywords: Roundabout, Transgression, Traffic, Markings.

1. INTRODUCTION

Lane markings over the years have been adopted as a way of providing guidance to road users so as to influence drivers' behaviour in order to reduce incidences on the road. However, at intersections there are greater accident propensities as the conflict points would be higher than what is obtainable on straights; a standard signalized crossroad having one lane per approach has 32 potential conflict points while a roundabout with comparable characteristics would have 8 conflict points (Gross et. al, 2013), hence the adoption of roundabouts at appropriate locations though the decision should be reflected upon the volume of pedestrian activity along such locations. In order to make these roundabouts safer – reducing these potential conflicts, the idea of spiral markings was introduced in the U.K around 1978 to improve safety and capacity by guiding drivers to their chosen exit without changing lanes (McCann, 1996). This novel approach was geared towards influencing driver behaviours and improving lane discipline which would inadvertently improve safety at roundabouts.

Even before the modernization of circular intersections by the then Road Research Laboratory in the 1960s (TRL, 2008), roundabouts were adopted for deflecting travel speed of drivers to suit the prevalent conditions of the environment, freeway terminal interchanges, balancing delays at minor roads and several other reasons according to the dynamics of the design elements of intersections. Apart from capacity worries, the issues of safety have been prominent; hence the need for detailed design of these roundabouts paying attention to factors like entry deflections which are aimed at deflecting the travel path of a driver thereby reducing travel speed and impact energies in the event of an incident.

LITERATURE

1.1 Types of Roundabouts

These rotary intersections are of different forms, any of which could be adopted to suit the design considerations of the road. These considerations could be estimated traffic flow, proportion of right turning traffic, available land area, number of entries to the intersection and so on. The various types of roundabouts are: Normal roundabout which features a kerbed central island with a diameter greater than 4m and flared approaches to allow multiple entry lanes; Mini-roundabouts on the other hand do not have a kerbed central island but a flush or slightly raised circular road marking with a diameter less than 4m. The compact roundabout differs slightly from the normal roundabout in that it has single lane entries and exits on each arm with non-flared approaches making room for pedestrian and cyclist activities (DfT, 2007).

Variants of these three main categories of roundabouts are; double roundabout (combination of two roundabouts), grade separated roundabout (having at least one arm at a different level), signalized roundabout (normal roundabouts with traffic signals installed on one or more approach roads). For sake of capacity and safety concerns at roundabouts, modifications are being made to the geometric design and operation of roundabouts, of such modifications are; Flower roundabout, C-Roundabout (Cyclist roundabout), Target roundabout and Turbo roundabout, with the latter receiving lot more attention.

1.2 Safety Considerations

Attention is paid to certain details when selecting the best suited form of intersection at the road geometric design stage as it affects efficiency and cost of operation, road safety, speed, and capacity. Therefore adequate design of the best suited intersection can be used to manipulate these issues especially safety, since intersections typifies potential conflict locations; conflicts would inadvertently impact negatively on capacity and other issues therewith.

Apart from its aesthetic, congestion-, and pollution-reduction benefits; the latter owing to fewer stops, less idling time and better uniform acceleration, roundabouts are heralded for good safety records accruing from positive impacts recorded since its adoption over signalised intersections with head-on and high-speed right angled collisions precluded.

Basically, there are three categories of conflicts at intersections varying according to their degree of severity, and they are as follows (Gross et al., 2013):

a. Queuing conflicts: These are caused by a vehicle running into the rear side of another vehicle queuing on the approach or entry, typically a rear-end shunt. This could possibly be caused by the inattentiveness of the following driver hence reducing the reaction time to the stimulus produced by the lead driver.
b. Merge and diverge conflicts: These are caused by the joining or separation of two streams of traffic leading predominantly to sideswipes and could cause more severe accidents than queuing conflicts.
c. Crossing conflicts: These are caused by the two streams of traffic crossing each other at angles more dangerous than that of merge and diverge conflicts typically head-on and right-angled collisions resulting mostly to fatal accidents.

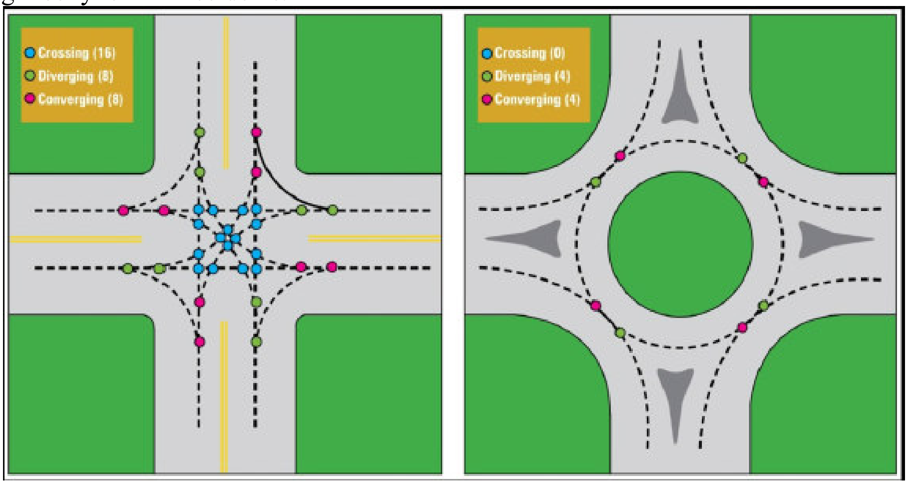


Figure 1: Conflict points for a signalised and rotary intersection. (Gross et al., 2013)

The figure above shows that roundabouts have just about 8 conflict points (0 crossing, 4 diverging, and 4 converging) as against crossroads having 32 conflict points (16 crossing, 8 diverging, and 8 converging). Roundabouts eliminate the possibility of crossing conflicts since all movements are deflected and the priority rule applies; by so doing, the most severe forms of crashes are eliminated. Accidents at roundabouts are mainly slight accidents.

In the United States where concerted efforts are being made to replace traffic signalized junctions with roundabouts, using the procedure of Empirical Bayes; Persaud et al. (2001) revealed a 40% reduction in crash severities, 80% reduction in all injury accidents, and incapacitating injury accidents had a highly significant reduction of about 90%. These figures most certainly hold true considering that Empirical Bayes protocol takes into account traffic volume variations and regression to the mean which usually accompanies changes in operational measures along the roadway; secondly, the figures obtained are quite similar to that of IIHS (2000) and most recently DoT (2008).

Lalani (1975) reported the study conducted by Transport and Road Research Laboratory at 78 sites all over Britain where priority control junctions had been replaced with roundabouts as follows; reduction in accident severity from 25 to 18%, whereas total accidents had reduced by 31%.

Accidents at roundabouts however can be categorised into five types, albeit some of them are not mutually exclusive (Maycock and Hall, 1984; Lenters, 2004). The various categories are:

i. Entering-Circulating accidents: These are accidents concerning collisions between vehicle entering the roundabout and one circulating within the roundabout.

ii. Approaching accidents: These are accidents involving vehicles on the approach to the roundabout where a following vehicle runs into the back of the lead vehicle or when vehicles are changing lanes indiscriminately along the circulatory carriageway. These two follow the forms of merge and diverge, and queuing conflicts respectively as explained by DoT (2000).
iii. Single-vehicle accidents: These are accidents involving a vehicle in conflict with some elements of the roundabout layout – kerbed Central Island, Splitter Island or street furniture.
iv. Pedestrian accidents: These are accidents involving vehicles and pedestrians.
v. Other accidents: This category includes accidents which occur relatively less often – collision involving circulating vehicles, collision involving circulating vehicles and exiting vehicles, and other miscellaneous accidents which do not clearly fit into any of the four categories above.

Maycock and Hall (1984) further expressed that from a total of 780 accidents recorded, the accident frequencies followed the order; Single-vehicle (30%), Approaching (25.3%), Entering-circulating (20.3%), Other (18%) and Pedestrian (6.4%). Thompson (2009) gave some explanation to these forms of accidents at roundabouts and concluded that at large roundabouts on high-speed roads where such speeds have been maintained for quite a reasonable time, drivers may not be able to reduce their speeds sufficiently early. This would result to drivers crossing the yield line leading to entering-circulating accidents. Single-vehicle accidents could also occur when drivers run into landscape elements in the central island. Thompson (2009) therefore suggested adequate deflection, roundabout island visibility, and other speed management techniques at the approach. He further opined that when traffic-flow patterns change, situations could arise where few gaps are available for entering traffic because of high circulatory volumes which would give entering-circulating accidents higher propensity. Furthermore, approaching accidents could occur as a result of a following driver focusing on circulating traffic and assuming that the lead driver would accept the critical gap only to realise the otherwise too late.

The foregoing is a strong proof that roundabouts are safer than other forms of intersections though according to IIHS (2013), roundabouts have outstanding safety advantages at the same time driver confusion is an implicit pitfall; a survey carried out disclosed that signs and pavement markings were not clear-cut as to what is expected of drivers especially at points of exit. Waddell et al. (2009) and McCann (1996) had similar opinions.

1.3 Circulatory Lane Markings

Montella (2011) identified that lane markings were contributory factors in 51.8% of the total crashes; missing or ineffective markings brought drivers to a dilemma as to which stream has the right-of-way. However, there exists a school of thought according to Kinzel (2003) which acknowledges a "laissez-faire approach" that specifies no markings within the roundabout; hence the circulating roadway is seen as a wide area where drivers jockey for positions. Evidence has shown that the "guidance approach" which specifies enforced lane discipline which typically tries to match drivers' choice of circulating lane with his exit lane would uphold the safety record of roundabouts as it is seen as being more salutary than other intersection types in terms of traffic safety and operation; reducing the number of fatalities (Ogden, 1996; Bird, 2001; Persuad et al., 2001; Elvik, 2003; Bie et al., 2008).

Provision of roadway infrastructure without a predetermined and enforceable avenue of controlling activities and incidences, if there be any, jeopardises the primary intention of delivering a safe, sustainable and efficient means of moving people and freight between points of interest. Therefore with the provision of well geometrically designed roundabouts, for sake of safety and other attendant concerns, road markings are commonly adopted to foster the safety as well as enhance the efficient use of the road thereby improving capacity (Thompson, 2009). According to the Institute of Transportation Engineers (1982); road markings serve to guide, regulate and channelize traffic into the correct position on the street or highway, to serve as a psychological barrier and supplement other traffic control measures for which roundabouts particularly mini-roundabouts which are adopted in street design are recognised as one by the Institution of Highways and Transportation (2005). They are also useful for regulating the direction of travel, overtaking and lane changing; conveying information to motorists about where certain manoeuvres are either required, permitted or restricted without them getting their eyes off the roadway; identifying potential hazards like road narrowing, railway crossings and most importantly identifying a driver's safe and legal limits along his choice lane in order to foster lane discipline (Freedman et al., 1988).

DfT (1997) specifies four primary structures of road markings which may be applied on the circulatory carriageway at roundabouts; these include:

A. Concentric markings: Concentric markings basically are circular markings of extended radii from the kerbed central island; making traces around the circular carriageway which are equidistant to the locus (kerbed Central Island) forming adjacent lanes as much as the carriageway width can allow for.

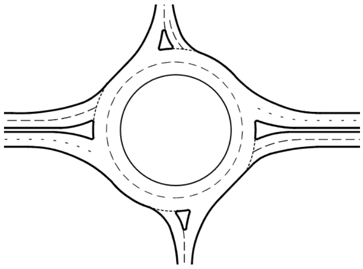


Figure 2: Concentric Markings (DfT, 1997)

B. Partial concentric markings: These also are circular markings though have interrupted traces equidistant from the kerbed central island; more like broken lines while the former are solid lines. According to DfT (2003) they can help resolve the issue of perplexity of drivers where rotary intersection has a wide carriageway by providing drivers clearly defined lanes within which to proceed around the junction reducing the probability of drivers especially those on the offside approach lane being forced towards the kerbed central island.

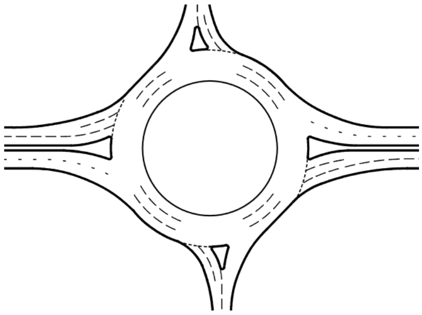


Figure 3: Partially concentric markings (DfT, 1997)

C. Concentric-Spiral (Alberta) markings: This is a kind of hybrid marking with the aim of directing traffic on the outermost circulating lane(s) to the next exit by way of lane drop – merging a typically concentric marking to the centre line on exit lanes. On multi-lane roundabouts, it helps drivers approaching their desired exit understand what is expected of them.

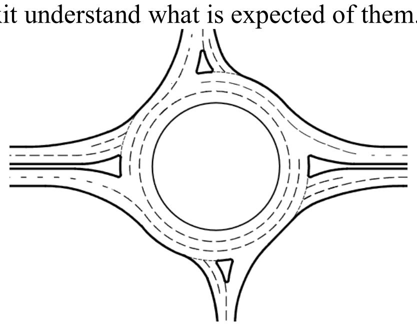


Figure 4: Concentric-Spiral (Alberta) markings (DfT, 1997)

D. Spiral markings: This system is best suited at large roundabouts; it involves a technique of lane gain and drops around the circulatory carriageway, giving drivers distinct guidance on how to get off at their desired exit lane. The markings could develop from the central island or from hatched markings on the central island.

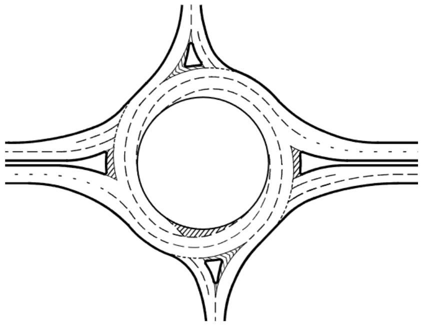


Figure 5: Spiral markings (DfT, 1997)

Kinzel (2003) acknowledged that "roundabouts offer drivers explicit guidance and simple decision-making responsibility (Ogden, 1996)" applies only to single-lane roundabouts, however for multi-lane roundabouts, the driver on the approach is left to answer such questions as; what lane should I maintain while entering the roundabout? Should/can I switch lanes along the circulatory carriageway? Can I exit from my current circulatory lane? Kennedy (2008) suggested that spiral markings are very helpful at large complex roundabouts, aiding drivers to select appropriate lanes and guide them through to exit.

The goal of spiral marking technique is to reinforce the driver lane guidance by giving an unmistakable set of priorities for traffic circulating and exiting the roundabout (Wong et al., 2012); thereby making it easy to obey the rule "traffic travelling more than half the circulatory carriageway must approach from the splitter-side lane while traffic travelling less than half the circulatory carriageway to their exit must approach from the kerb-side lane" (Land Transport Safety Authority, 2001). This rule promotes a more balanced lane utilization and higher discipline. Bie et al. (2008) in his comparison between concentric markings and concentric-spiral (Alberta) markings, identified that with the latter, there was reduction in the absolute use of the inner circulating lane which is an indication of ineffective lane discipline (when all drivers want to enter and circulate on the inner circulatory lane regardless of the priority rule).

Giving a thought to this, it could be naturally concluded that if such benefits accrued from spiral-concentric markings, definitely so much more would be achieved with spiral markings which offer a harder measure of lane discipline.

1.4 An Offshoot of Spiral Markings

In the quest for safer intersections, roundabouts were developed. Evaluations revealed performance challenges, then lane markings around the circulatory carriageway were promoted. Spiral markings amongst other forms of roundabout markings have been suggested by professional literature world over. For sake of capacity and safety concerns at roundabouts, modifications are being made to the geometric design and operation of roundabouts, of all of such modifications, turbo roundabout has received lot more attention.

Turbo-roundabouts principally were developed in 1996 from the concept of spiral markings by Lambertus Fortuijn (Fortuijn, 2009). Turbo-roundabouts have the trappings of a conventional roundabout with spiral-markings rather in an advanced detail. Geometrically, turbo-roundabouts as seen in figure 6, consists of two (or more in the case of rotor-turbo-roundabout) homocentric circles having an axial displacement equal to the width of a circulatory lane of the roundabout. Grabowski (2012) suggests that vehicles are induced into the inner lane and subtly guided to the next exit thereby eliminating weaving manoeuvres. It is more like a mandatory use of the inner lane with no flexibility in lane change along the circulatory carriageway because of the mountable lane dividers. The turbo-roundabout is characterised by the following (Grabowski, 2012; Fortuijn, 2009):

a. Forced spiral lane markings with associated mountable lane dividers guiding drivers' path to exit lanes; avoiding possibilities of weaving.
b. Reduction of potential conflict points to 10 against 16 of a dual lane roundabout; eliminating two crossing conflicts and four merge and diverge conflicts.
c. Lower driving speeds at entry and while circulating.

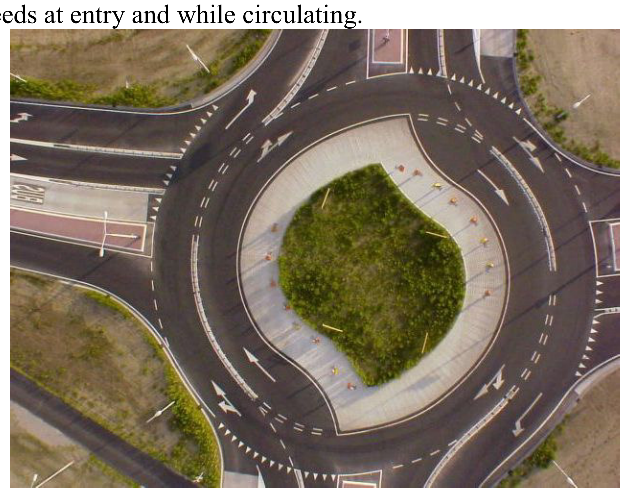


Figure 6: Typical four arm turbo-roundabout [driving on the left] (Source: Google)

1.5 Role of Traffic Signals

The discussion so far has been centred more on safety than on capacity as such. Considering a roundabout with disproportionate traffic flows at all arms; it would be difficult for drivers on the minor arm to enter into the circulatory carriageway for sake of the gaps which are rather too critical. If the situation at such a junction worsens, traffic at the minor arms would experience unending delays because the drivers at the major arm would usurp their right-of-way. By implication, queues would continue to build up at the minor arm until the lead driver takes the chance; accepting the very critical gap at the expense of his safety. The scenario as above, paints a picture of an overloaded junction, running above capacity as it were. In which case, the roundabout has lost its ability to "self-regulate"; by mere observation, the problem with some roundabouts in the light of the foregoing could be inadequate coordination of traffic from all arms especially at peaks, which could probably be as a result of increase in traffic volume after design and construction of the roundabout.

For such reasons, the modern roundabout features a combination of road markings and traffic signals geared towards increasing capacity, providing better queue balance, reducing speed, and improving safety of cyclists. Signalizing roundabouts helps reduce critical queues since in Urban Traffic Control (UTC) networks, green times could be biased to favour arms with longer queues; capacity can be improved but with a complementary physical improvement possibly road markings (Hallworth, 1992).

1.6 Trucks at Roundabouts

Whilst roundabout design is characterized by lots of trade-offs; deciding between capacity and safety optimization while considering its appropriateness in terms of location and cost (DfT, 2007), large vehicles; the likes of combination trucks having kingpin to centre of rear tandem axle ranging between 25.5 and 40.5 (AASHTO, 2011) constitute challenges at the design phase. The basic problem here is a decision between adequate deflection of the vehicles by the central island, and widening of the circulatory carriageway to accommodate longer wheelbases; alongside other measures like fully traversable or partially traversable (truck aprons) central islands, use of adjacent lane, etc. (Waddell et. al., 2009).

A study conducted by Lenters (2007) of two roundabouts in United States, recommends that trucks perform better at roundabouts operating under the "laissez-faire approach". Gingrich and Waddell (2008) went further to suggest that enlarging the geometry with extra lanes may be required to assist the trucks on the outer circulatory carriageway.

2. METHODOLOGY

Several works have laid claim to the fact that there is improved discipline with spiral lane markings at roundabouts, but the extent of this positive achievement is yet to be ascertained. Hence the research question; "what proportion of drivers contravene the principles of lane discipline which spiral lane markings stand for?" The research approach, therefore, would be one geared towards determining trends and frequencies of lane indiscipline. Research is a continuum and can never be exhaustive, in the light of this and within the boundaries of unavoidable limitations, site observation was adopted a method for achieving the aim of this research.

2.1 Survey site

The Sheriffhall roundabout, Edinburgh city, Scotland was selected for this survey because it is quite a large and busy one; serving varying traffic volumes at different times of the day. It is located along A720 Edinburgh by-pass, connecting six A-class roads – A7(North), A7(South), A6106 Millerhill road, A6106 Old Dalkeith road, A720(East) and A720(West) all of regional and local importance. It is the only at-grade roundabout along the Edinburgh by-pass having significant queuing at peaks.

2.2 Method

A before-after survey would have been best suited for this research as it would have been possible to establish the level of discipline before the spiral lane marking was introduced, and compare it with the situation after its introduction but DfT (2001) specifies a three year observation period before a scheme and after the scheme to determine adequate measure of effectiveness; time being a limiting factor here makes it impossible to adopt this method.

Four video cameras were mounted at strategic points around the Sheriffhall roundabout being the selected study site. The cameras were mounted for 9 days; from 31st January to 8th February, 2015 between the hours of 04:00 to 22:00 daily, this was done to monitor the manoeuvres made around the circulatory carriageway. Specifically, the cameras were mounted at A720 (East) – exiting the roundabout, A720 (East) – entering the roundabout, A720 (West) – entering the roundabout, and A7 (South) – exiting the roundabout; at the coordinates 55.900496,-3.091383; 55.900203,-3.091161; 55.900101,-3.093236, and 55.899451,-3.092413 respectively.

The entire video recording amounted to a 648-hour footage which was too voluminous; hence the recordings of Monday, Friday and Saturday only were analyzed as this was found to be a fair representation of all other days accounting for difference in traffic patterns, and driver behaviour. The recording of one camera was disregarded for this study because it captured traffic exiting the roundabout; the scope of this research, however, is limited to considering the entering and circulating traffic.

The factors that were considered for this research included: Vehicle class (Any vehicle with 2 axles and 4 wheels was classified as car while vehicles with more than 2 axles and 4 wheels as trucks); Traffic condition (divided into saturated, unsaturated, and partially saturated); Light conditions (divided into daytime and dark).

Speed was not considered because the roundabout has good geometric design that enables adequate deflection of traffic. Weather conditions remained practically unchanged.

Based on these assumptions and the scope of this study, three different classifications of lane transgressions were defined; 25% transgression (minor trespass), 50% transgression (major trespass), and >75% transgression (lane change).

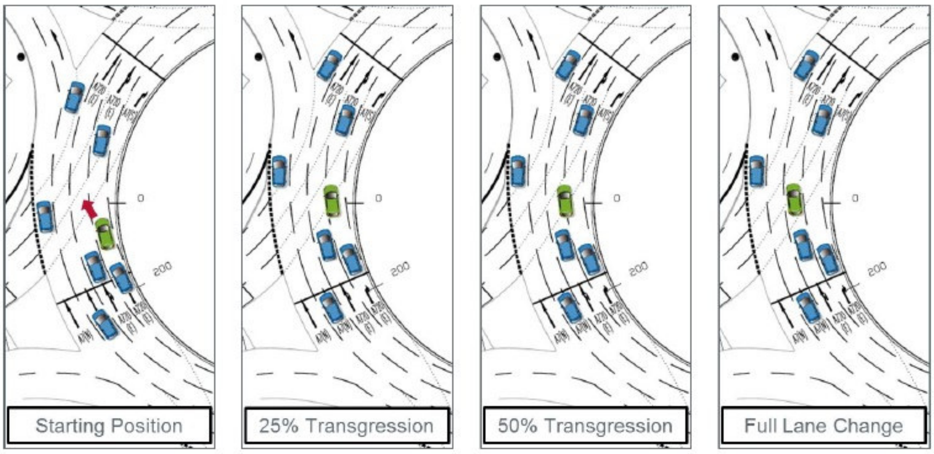


Figure 7: Lane transgression definition.

Vehicles under these categories were identified and recorded accordingly, following a one-hour interval. Hence the observations were recorded in vehs/hr. The analysis of transgressions in relation to traffic flow was discretized into car and truck traffic flows independently, so that the findings here could lend itself for use at other roundabouts considering the dynamics of car/truck composition of road sections. Whereas a combined analysis of both flows would also be relevant, it would not have been achieved here for sake of the way data was extracted from the video recording; estimating the traffic count in terms of Passenger Car Units (PCU) which would have aided in analysing transgressions according to a combined flow would be prone to avoidable errors, and would have required greater time.

3. RESULTS AND DISCUSSION

Generally, the traffic count showed a higher evening peak during weekdays and about a uniform traffic distribution between morning and evening peaks (07:00-18:00) on Saturday. Secondly, Saturday traffic count surprisingly had a lower truck composition. It was observed that on Monday, transgressions were 21% (σ =0.5) and 34% (σ =4.3) by cars and trucks respectively, following an average of the hourly transgressions from the three cameras; whereas that of Friday was 22% (σ =1.2) by cars and 38% (σ =10.0) by trucks, and Saturday, 18% (σ =1.4) by cars and 52% (σ =5.1) by trucks. It then becomes obvious that there are more transgressions by trucks than cars.

At peak periods, there was appreciable growth in lane transgressions though it was not proportional to the traffic volume; however, at off-peak periods, the lane transgression rate was almost proportional to traffic volume. The increase in lane transgression at peak periods was mainly of the minor category; this was due to the fact that drivers at these times entered and circulated along the roundabout in a channelized manner having lower "degrees of freedom" for manoeuvre. The major transgression and lane change at peak times occurred mostly during the amber signal stage with most drivers trying to beat the traffic signal while approaching the circulatory carriageway.

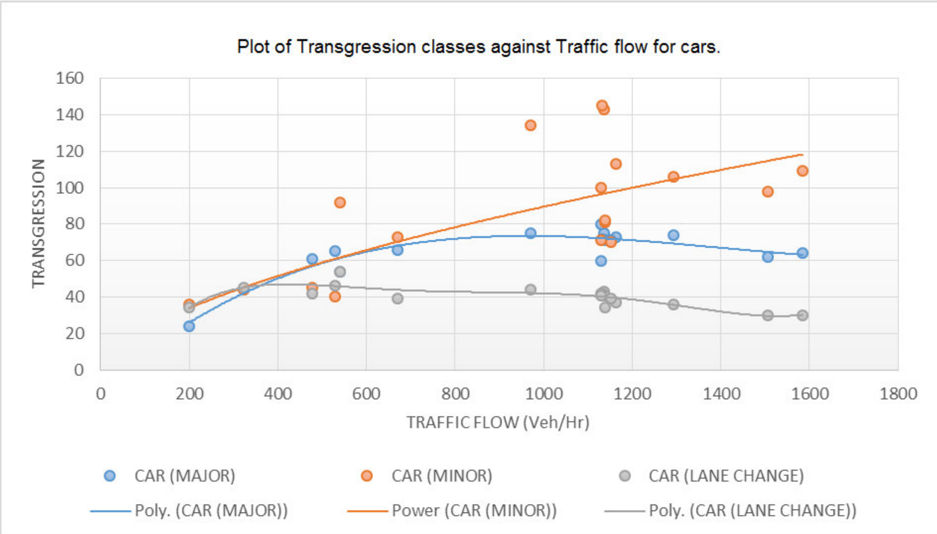
3.1 Transgression by traffic condition

Following the definitions of the factors considered, the traffic conditions were found to be; unsaturated: 19:00-06:00, partially saturated: 11:00-14:00, and saturated: 07:00-10:00, and 15:00-18:00 for weekdays. On Saturday, unsaturated: 19:00-06:00, partially saturated: 07:00-08:00, and saturated: 09:00-18:00. It can therefore be concluded that there was 32% (σ =0.020), 18% (σ =0.020) and 19% (σ =0.013) car transgressions during weekdays at unsaturated, partially saturated, and saturated periods respectively; 53% (σ =0.060), 32% (σ =0.082), and 33% (σ =0.091) truck transgressions during weekdays at unsaturated, partially saturated, and saturated periods respectively. On Saturday, there was 34% (σ =0.022), 28% (σ =0.064), and 14% (σ =0.005) car transgressions at unsaturated, partially saturated, and saturated periods respectively; and truck transgressions for unsaturated, partially saturated, and saturated periods was 56% (σ =0.034), 54% (σ =0.082), and 50% (σ =0.078) respectively.

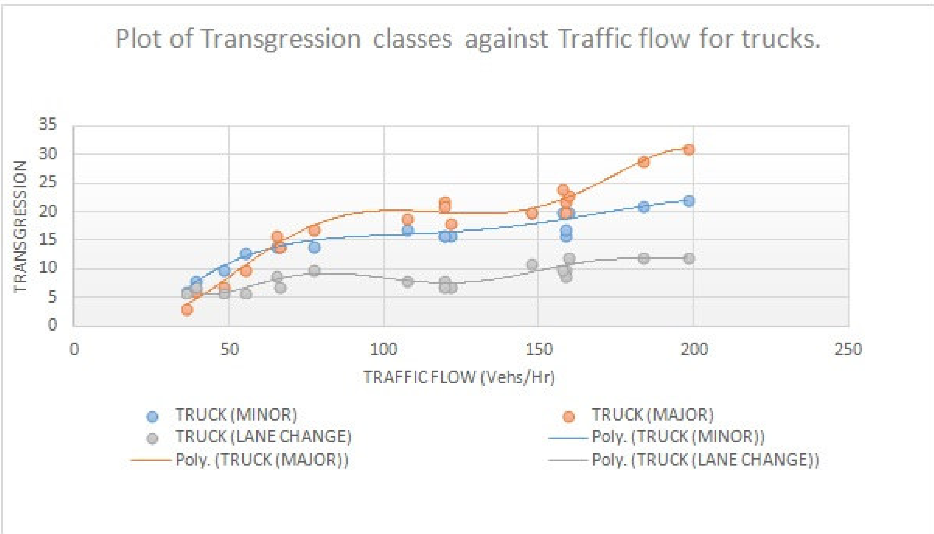
There is thus, good evidence to suggest that higher transgressions occur at unsaturated period, less at saturated periods and least at partially saturated periods. At unsaturated periods, drivers seeing less cars on the road feel it is safer to risk these manoeuvres, but when the traffic starts building up (partially saturated), streams of traffic appear more like channelized fluids making certain manoeuvres difficult for sake of the vehicles travelling at the same pace on parallel lanes, hence a reduction in the perceived safety leading to reduced transgressions.

When saturation is reached, transgression rises slightly because more cars arrive at the roundabout, most of which for sake of the traffic signals make unnecessary manoeuvres thereby increasing the number of transgressions. It could be inferred that the increase in traffic volume increases frequency of minor transgressions and the traffic signals increases the frequency of lane change considering the rush associated with peaks and the nature of manoeuvres identified above; this does not obviate other possible explanations for this increase.

Relationships were found between the three classes of transgression and traffic flow by combining the number of transgressions by vehicle class based on average of the three-day count data and frequency of transgressions of each category of transgression. The trend lines for the scatter plot were selected based on an R^2 value close to unity. For cars, minor transgressions reached maximum at about 1136veh/hr around which point it also dropped by 50% (143 down to 70) then rose again to 109 at 1584veh/hr. Major transgressions reached maximum at 1130veh/hr following a gradual increase and decreased gradually to 64 at 1584veh/hr, and lane change attained maximum at flow of 541veh/hr, and decreased gradually to 30 at 1584veh/hr being the maximum observed flow rate, as seen below.



For trucks, all three transgressions (Major, Minor and Lane change) rose gradually to maximum at a maximum observed flow rate of 198veh/hr, as seen below.



There appears to be a critical zone between flow rates of 147-158veh/hr considering the density of all three transgressions within such short range whereas such a critical zone was observed between flow rates of 1130-1165veh/hr for the cars.

3.2 Transgression by light condition

From the foregoing, further explanation need not be given for light conditions because the dark hours were within the unsaturated periods. The circulatory carriageway was proper illuminated at night and was sufficient enough to lead drivers safely to their exits without unnecessary weaving, though the dark hours made drivers with risk proclivities feel safer.

3.3 Transgression by vehicle class

As already mentioned, trucks were involved in the transgressions more than cars with about 61% transgression and almost twice that of cars at some instances. This could be as a result of the deflection caused by the rotary island and the length of the trucks which made it difficult for the drivers to negotiate the roundabout and also maintain their lanes.

4. CONCLUSION

Roundabouts as earlier stated are quite effective as junction control measures; reducing crashes by eliminating certain conflict points, and managing capacity by virtue of its self-regulating ability. This concept developed by Transport Research Laboratory has become very convenient for traffic engineers especially now that traffic crashes and congestion are a major issue. Inasmuch as this concept has become globally accepted, it has faced criticisms. Studies have shown that drivers who find it difficult to find their way around it seem not to appreciate its benefits.

Amongst other forms of circulatory carriageway markings, spiral markings have been acknowledged by many as a good way of reducing the number of decisions a driver at a roundabout makes, leading drivers safely to their choice exit lanes hence promoting safety. Spiral markings however, would only play a perfect role in executing these claims if vehicles are introduced in an orderly manner into the circulatory carriageway, especially at large roundabouts with unbalanced flows. It is along this line of thought that roundabout signalization becomes imperative as it offers an equitable means of controlling right-of-way at all arms of the roundabout according to traffic flow or pre-set plans.

Following extensive and established literature, the question, "what proportion of drivers contravene the principles of lane discipline which several authors claim to be the highlight of spiral markings?", found probable answers. With the specific objective of observing the lane discipline at a busy roundabout (Sheriffhall roundabout), the results held that there were more transgressions by trucks than by cars and the possible causes have been discussed, similarly more transgressions apparently occurred during weekends and of all three categories of transgression, minor transgression occurred the most at all times. Generally, more transgressions occurred at unsaturated periods while the frequencies at partially saturated and saturated periods were almost the same.

In conclusion, for car transgressions, with increasing traffic flow, the major transgression and lane change increased slightly then reduced gradually while there appears to be a steady increase in minor transgressions with increased flow. Truck transgressions on the other hand, though increased with increasing flow, was relatively steady at mid-range possibly at partially saturated periods. It could then be said that transgressions increase when roundabouts get busier since more vehicles are introduced into the roundabout all of which having the potentials of transgressing.

5. RECOMMENDATIONS

Judging from the results and analysis, truck aprons and truck margin could help trucks negotiating the roundabout, preventing sideswipes, and reducing transgressions. Since there are higher transgressions at unsaturated times, intelligent road studs synchronized with the traffic signal should be a common feature at roundabouts because it serves as further enforcement of lane discipline and would come in handy at night and poor weather conditions. It could be solar powered or hard wired, installed on the lane markings and comes on only when a particular stream has right-of-way.

Turbo-roundabouts, where it is possible to retrofit or at new road layouts, would enforce lane discipline at a higher degree. With these, it would be very absurd to change lanes depending on the employed design parameters. A hybrid of complementary turbo-roundabout and intelligent road studs with the studs installed on the mountable lane dividers would perform better.

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