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Characteristics of Drivers' Lane Choice at Large Multi-lane Roundabout

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Abstract: The use of modern roundabout as an intersection treatment is a popular choice. To increase the capacity, large multi-lane roundabout has been implemented to solve traffic congestions. Comparatively to small single-lane roundabouts, where many studies have been devoted to, the maneuver at multi-lane roundabout is a highly complex situation due to drivers' behavior in lane choosing. Little is known on the drivers' behavior at large multilane roundabouts. This paper aims to explore the drivers' lane choice behavior and its impact on the performance of large multi-lane roundabout. Traffic data were collected at three-lane roundabout on a normal day at peak traffic hours by using voice recorders and video cameras. Drivers' behavior had been characterized by assessing their lane choices from entry lanes to circulating lanes and from circulating lanes to exit lanes. Two models of drivers' lane choices were generated, the first representing reality and the second depicting standard roundabout lane discipline. Both models had been analyzed by using SIDRA Intersection software. Results indicated that the large number of lanes provides high freedom for drivers on their behavior which cannot be fully controlled. Also, drivers tend to follow the natural movement path to go through the roundabout correctly. Lane discipline marking is effective for multi-lane roundabout especially for roundabout with equal number of entry and circulating lanes in improving the traffic performance.

Keywords: Roundabout, large, multi-lane, drivers' behavior, lane choice, traffic performance

1. Introduction

Roundabout is a type of unsignalized at-grade intersection treatment that provides equal priority to all vehicles on the approaching legs where they have to give way to the circulating flow around a central island [1]. Six types of roundabout based on its size, location and number of circulating lanes have been distinguished in literature, which are mini-roundabout, rural single-lane roundabout, rural double-lane roundabout, urban single-lane roundabout, urban double-lane roundabout and urban compact roundabout [2]. Three types of roundabout are considered in Malaysia based on the diameter of inscribed circle (Di) and diameter of central circle (Dc), which are outlined in "Arahan Teknik (Jalan) 11/87" [3]. The three categories are mini-roundabout (Di < 25 m and Dc < 4 m), small roundabout (20 m < Di < 50 m and 4 m < Dc < 25 m) and conventional roundabout (Di > 50 m and Dc >25 m).

The design of roundabout is of a major concern throughout the world as it affects the performance of the intersection, particularly capacity, and the safety of drivers [4, 5]. For the intersection design, it should be taken into account the characteristics of drivers that they may behave based on their own habit, follow the "natural" movement paths and may get confused when surprised [3]. Drivers' behaviour at a roundabout has been characterised by gap acceptance, lane changing and speed [6, 7]. The freedom of drivers in their behaviour increases by increasing the number of lanes, which potentially have higher conflict points [6]. Roundabout must be designed to have sufficient number of entry, circulating and exit lanes to ensure that it can operate at a satisfactory level of service [1].

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Drivers' behaviour is also affected by driver's familiarity of the roundabout [8]. The driver's familiarity of the roundabout and their efficiency of negotiating around the roundabout can be improved by adopting lane discipline markings, particularly the approach lane markings. There are many guidelines have emphasised the need of the lane disciplines or lane markings for the roundabout. In Malaysia, Jabatan Kerja Raya (JKR) Arahan Teknik had stated that lane markings have a significant effectiveness to guide drivers at channelized intersections [3]. In USA, the importance of pavement markings and signing of a roundabout are highlighted in the Manual on Uniform Traffic Control Devices (MUTCD), where the recommendation is to relate to the geometric design and expected lane use. Markings on the entry and circulating lanes ought to complement each other to give a consistent message to road users and to prevent lane changing within the circulating lanes so as to exit the roundabout in a smooth way. Multi-lane roundabouts ought to have lane lines that would bring about good driver behaviour [9]. In Australia, Austroads underlined that lane direction arrows should be provided when the roundabout has more than one entry lane [1].

In fact, the drivers' behaviour directly affects the roundabout performance and can be examined by using software such as SIDRA, a lane-by-lane based tool. SIDRA Intersection software is very sensitive to the roundabout geometric parameters and it considers the drivers' behaviour [8]. Hence, understanding the drivers' behaviour by real observations, and the main cause and effect of relationship between the characteristics of roundabout geometry and the drivers' behaviour is highly needed [6]. To increase the capacity of roundabouts so as to ensure smooth and organised traffic flow, large roundabouts with multiple lanes are of great significance [7]. However, the studies conducted on the characteristics of large multi-lane roundabouts are limited [2, 7, 10] compared to many studies on mini to small single-lane roundabouts [4, 11-16]. To address this knowledge gap, this study attempts to characterise the drivers' behaviour at large multi-lane roundabouts through a traffic survey by exploring drivers' lane movement between entry lanes and circulating lanes and from circulating lanes to exit lanes, and their choosing entry lane and the effect of this behaviour on the roundabout traffic performance. The use of SIDRA Intersection to examine the influence of the drivers' lane choices on the roundabout performance is also deliberated.

2. Methodology

The focus of the present research is on drivers' lane choice at large roundabouts with more than one circulating lane. Traffic surveys were conducted at a large roundabout with three circulating lanes located along Kuching-Samarahan Expressway, Malaysia. The selected roundabout (Fig. 1) has four legs, where Leg 1, Leg 3 and Leg 4 have two entry and exit lanes, while Leg 2 has three entry and exit lanes. All legs have three circulating lanes. The inscribed diameter and lane width of this roundabout are 202.2 m and 3.7 m respectively. The roundabout does not have any lane markings showing any specific lane disciplines for each lane.

The traffic volume survey was conducted on Wednesday, 21 August 2019, during the morning rush hour from 6:45 to 8:45 am and evening rush hour from 4:15 to 6:15 pm. The highest one-hour volume for each survey period were determined as the peak hour. As the roundabout diameter is large, video recording of the traffic was set up at suitable locations and surveyors were stationed at all entry and exit lanes to record the vehicle plate numbers using voice recorders. Lane movement data were collected by recording vehicle plate numbers and their lane choices from each entry lane to circulating lanes and from circulating lanes to each exit lane.

To determine the turning movement count, the vehicle plate numbers at entry lanes had been paired with vehicle plate numbers at exit lanes. This was done for each lane so as to determine the entry lane choice for different lane disciplines. All vehicle volumes were converted to passenger car unit (pcu) using the equivalent pcu factors shown in

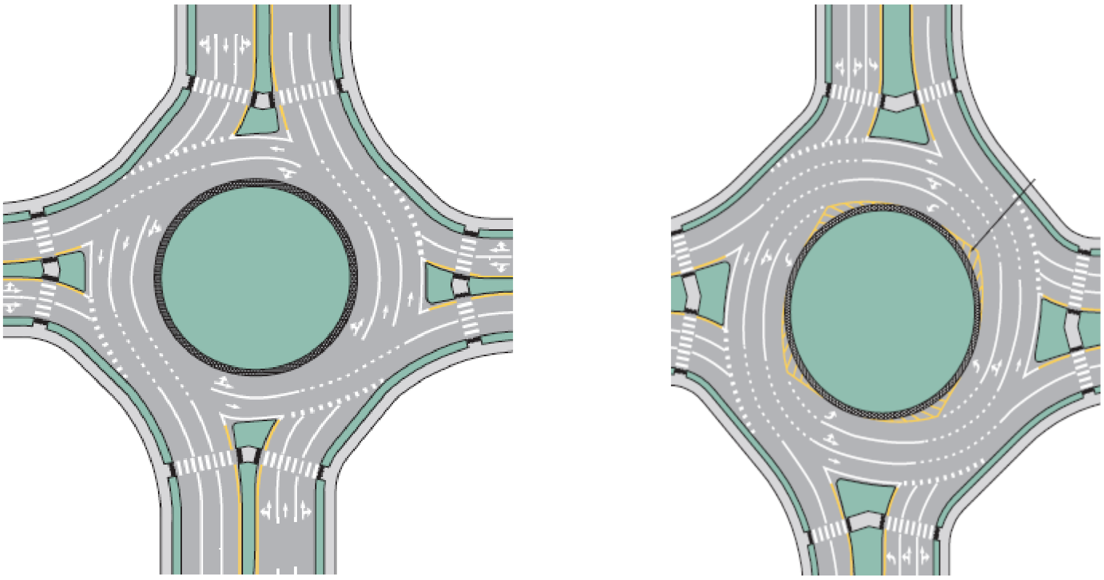
Table 1. The motorcyclist had been excluded from lane choices analysis due to the fact that experienced cyclists may feel reasonably comfortable in selecting the gap and movements at multi-lane roundabout which makes their exact lane choices unclear [1].

Fig. 1 - The selected large three-lane roundabout with four legs

Table 1 - Conversion factors to PCU [17]

Vehicle Type	Equivalent PCU Value
Passenger car	1.00
Motorcycle	0.33
Van	1.75
Medium lorry	1.75
Heavy lorry	2.25
Bus	2.25

The data were used to find the entry volumes to be input in SIDRA software. Two models of drivers' lane choice were generated and analysed. The first depicting the reality, where there are no specific lane disciplines with each lane having all movement types following the data collected from the site. The second model depicting roundabout rules according to MUTCD [9] and the field entry volumes had been modified based on this rule. Based on Fig. 2, the selected roundabout is assigned the following lane disciplines: (i) for legs with two-lane approaches (Legs 1, 3 and 4), the outer lane is for through and left movements and inner lane is for through, right and U-turn movements, and (ii) for leg with three-lane approach (Leg 2), the outer lane is for through and left movements, the middle lane is for through and right movements and the inner is for right and U-turn movements. (Note: The annotations and figures in Fig. 2 are based on vehicles driving on the right side of the road where circulating flow is in anti-clockwise direction while the present study is in the clockwise direction).



(a) (b)

Fig. 2 - MUTCD lane markings for (a) a combination of double-lane and three-lane roundabout; (b) a three-lane roundabout [9]

3. Results and Discussion

Data showed that the morning peak hour was from 7:00 to 8:00 am and evening peak hour was from 4:45 to 5:45 pm. Results are divided to three main parts: (i) drivers' turning movement lane choice at entry lanes; (ii) drivers' lane movement from entry to circulating lanes and from circulating to exit lanes; and (iii) the effect of drivers' lane choices on the traffic performance.

3.1 Drivers' Turning Movement Lane Choice

Fig. 3 shows the drivers' turning movement lane choice at the entry lanes during the morning and evening peak hours. It was observed that all the entry lanes have all the movement disciplines, which means some drivers chose the entry lane without following the roundabout driving rule. Generally, for left turn, higher volumes used the outer lane as the drivers needed to exit the roundabout in a short distance. However, for the rest of the movement disciplines, the distribution of lane choice was spread out between outer, middle and inner lanes.

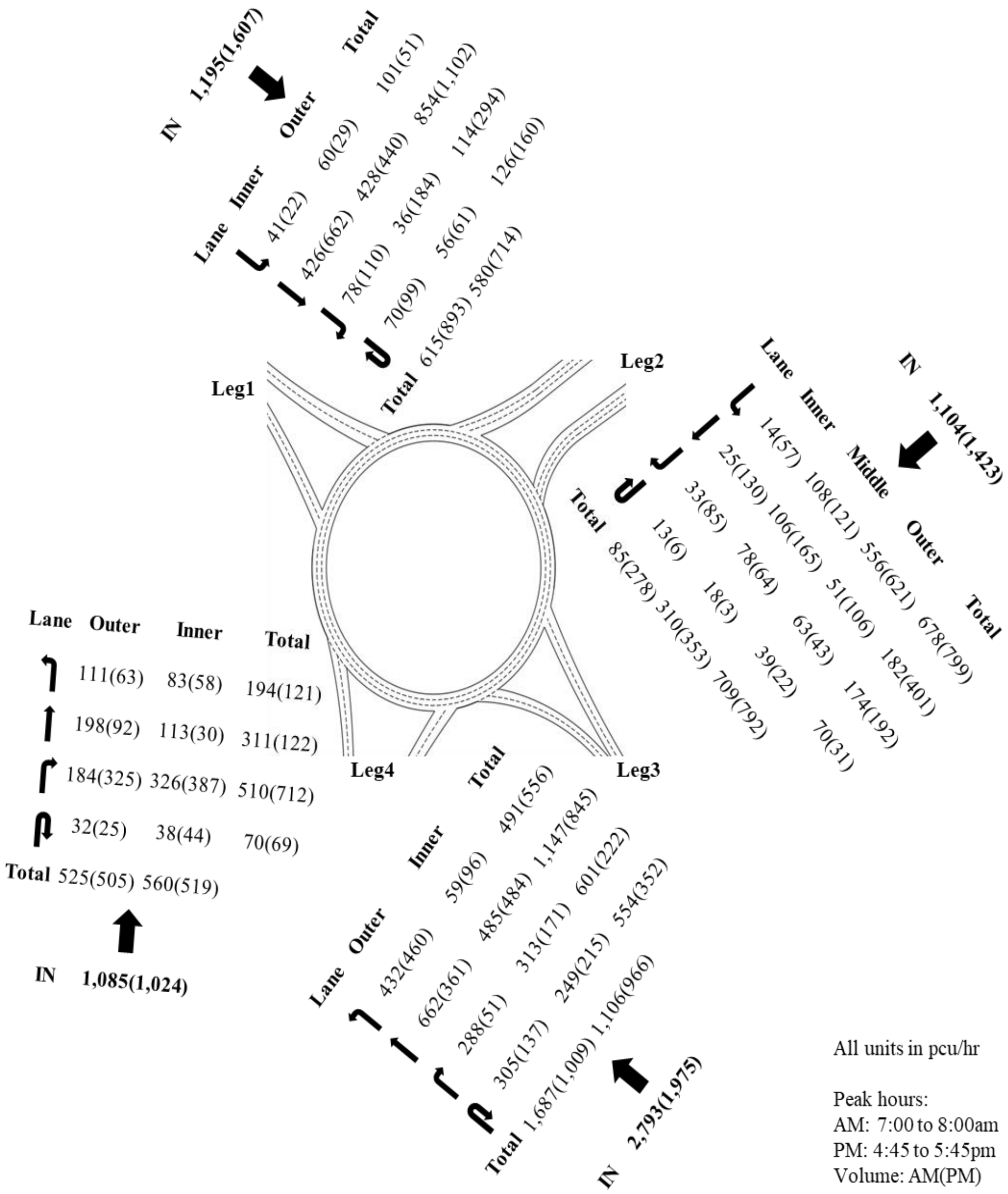


Fig. 3 - Turning movement count diagram for individual entry lanes during morning and evening peak hours

3.2 Drivers' Lane Movement

The drivers' lane movement from entry lanes to circulating lanes for morning and evening peak hours are presented in Table 2 and Table 3, respectively. For legs with two-lane approaches (Legs 1, 3 and 4), the outer lane drivers tended to select the middle circulating lane more than outer circulating lane due to their high right and through movements. The exception is for Leg 3 where higher percentage of the outer lane drivers moved into the outer circulating lane due to high left turn volume using the outer lane (refer to Fig. 3). For the inner lane, in the morning entry lane movement into circulating lanes were approximately equally distributed between middle and inner circulating lanes, except Leg 3. In the evening, more than 90 per cent of it was to inner circulating lane.

For Leg 2 with three-lane approach, the majority of outer entry lane drivers travelled onto the outer circulating lane, the middle lane drivers travelled onto the middle circulating lane and the inner entry lane drivers travelled onto the inner circulating lane. In other words, drivers selected the correct circulating lane due to their movements. This reflects that when the number of entry lanes is equal to the number of circulating lanes as it is at Leg 2, most of the drivers made their lane choices from entry to circulating lanes correctly based on their movements regardless of their exit lane choice. It is also noted that a very small volume of vehicles travelled from inner entry lanes to outer circulating lanes and vice versa. This driving behaviour is a safety issue as it creates more conflict points due to the lane change action at the high conflict zone of a roundabout.

Table 2 - Volumes and percentages of vehicles from entry lanes to circulating lanes for morning peak hour

From Entry Lane		To Circulating Lane (pcu/hr (%))			Total (pcu/hr (%))	Total (pcu/hr)
Leg No.	**Lane**	**Outer**	**Middle**	**Inner**		
Leg 1	Outer	169 (30)	387 (70)	1 (0)	557 (100)	1068
	Inner	2 (0)	207 (41)	302 (59)	511 (100)	
Leg 2	Outer	619 (99)	6 (1)	0 (0)	625 (100)	979
	Middle	5 (2)	261 (94)	12 (4)	278 (100)	
	Inner	0 (0)	3 (4)	73 (96)	76 (100)	
Leg 3	Outer	533 (52)	499 (48)	0 (0)	1032 (100)	2061
	Inner	0 (0)	88 (9)	941 (91)	1029 (100)	
Leg 4	Outer	130 (26)	378 (74)	0 (0)	508 (100)	951
	Inner	3 (1)	204 (46)	236 (53)	443 (100)	
Total (pcu/hr)		1461	2033	1565	5059	5059

Table 3 - Volumes and percentages of vehicles from entry lanes to circulating lanes for evening peak hour

From Entry Lane		To Circulating Lane (pcu/hr (%))			Total (pcu/hr (%))	Total (pcu/hr)
Leg No.	**Lane**	**Outer**	**Middle**	**Inner**		
Leg 1	Outer	211 (31)	462 (68)	6 (1)	679 (100)	1263
	Inner	0 (0)	53 (9)	532 (91)	585 (100)	
Leg 2	Outer	698 (100)	3 (0)	0 (0)	701 (100)	1278
	Middle	9 (3)	318 (97)	0 (0)	327 (100)	
	Inner	0 (0)	86 (34)	164 (66)	250 (100)	
Leg 3	Outer	671 (69)	307 (31)	2 (0)	980 (100)	1844
	Inner	0 (0)	62 (7)	802 (93)	864 (100)	
Leg 4	Outer	75 (15)	420 (84)	4 (1)	499 (100)	904
	Inner	0 (0)	39 (10)	366 (90)	406 (100)	
Total (pcu/hr)		1664	1750	1876	5290	5290

For the drivers' lane movement from circulating lanes to exit lanes, the field results are shown in Table 4 and Table 5 for morning and evening peak hours, respectively. For legs with two-lane exits, the outer exit lanes at Legs 3 and 4 were chosen by outer circulating lane drivers more than the middle lane due to the high left turn movements from the preceding legs, while at Leg 1, it was chosen by drivers from middle circulating lane more than outer lane because of the high through movement from the opposite leg. The inner exit lanes were chosen by drivers from inner circulating lane more than middle lane, except for inner lane at leg four in the morning. This is due to the high through movement from the facing legs.

For the leg with three-lane exit, outer exit lane was chosen by drivers from outer circulating lane, the middle exit lane was chosen mostly by drivers from outer and middle circulating lanes and insignificant percentage from inner lane, while there was insignificant percentage of drivers who chose the inner exit lane. The latter is as a result of having to cross multiple circulating lanes to make it to the inner exit lane in an extremely short distance, which poses safety issue due to having more conflict points.

Although there are no lane disciplines for any of approaches or circulating carriageway for the selected roundabout, most of drivers tended to follow the natural path and they made their lane choices based on the correct turning movement. By following the MUTCD lane markings, more than half of drivers at legs with two entry lanes made the full correct lane choices from entry to circulating to exit lanes. However, drivers at the leg with three entry lanes, only the outer entry lane drivers made the full correct lane choices. There was also small percentage of drivers who followed their own habits and they made their lane choices based on the empty lanes at middle and inner entry lane drivers.

This proved that the large number of lanes provides high freedom for drivers on their behaviour which cannot be fully controlled. The lane disciplines or lane markings might be effective at approaches, but drivers tend to change their lanes within the circulating lanes due to the large diameter size of the roundabout.

Table 4 - Volumes and percentages of vehicles from circulating lanes to exit lanes for morning peak hour

From Circulating Lane	To Exit Lane (pcu/hr (%))									Total (pcu/hr)
	Leg 1		Leg 2			Leg 3		Leg 4		
	Outer	Inner	Outer	Middle	Inner	Outer	Inner	Outer	Inner	
Outer	161 (22)	10 (2)	516 (95)	207 (55)	0 (0)	853 (79)	18 (1)	383 (68)	4 (5)	2,152
Middle	579 (78)	197 (42)	29 (5)	159 (43)	0 (0)	220 (21)	165 (14)	181 (32)	50 (57)	1,580
Inner	0 (0)	268 (56)	0(0)	7 (2)	0 (0)	0 (0)	1,019 (85)	0 (0)	33 (38)	1,327
Total per lane (pcu/hr (%))	740 (100)	475 (100)	545 (100)	373 (100)	0 (0)	1,073 (100)	1,202 (100)	564 (100)	87 (100)	5,059
Total (pcu/hr)	1,215		918			2,275		651		

Table 5 - Volumes and percentages of vehicles from circulating lanes to exit lanes for evening peak hour

From Circulating Lane	To Exit Lane (pcu/hr (%))									Total (pcu/hr)
	Leg 1		Leg 2			Leg 3		Leg 4		
	Outer	Inner	Outer	Middle	Inner	Outer	Inner	Outer	Inner	
Outer	163 (27)	14 (2)	290 (95)	36 (43)	0 (0)	915 (86)	18 (1)	609 (60)	50 (22)	2,094
Middle	439 (73)	244 (42)	16 (5)	41 (49)	0 (0)	152 (14)	214 (15)	400 (40)	79 (35)	1,582
Inner	0 (0)	326 (56)	0 (0)	7 (8)	0 (0)	0 (0)	1,183 (84)	0 (0)	99 (43)	1,614
Total per lane (pcu/hr (%))	602 (100)	583 (100)	307 (100)	83 (100)	0 (0)	1,066 (100)	1,414 (100)	1,008 (100)	227 (100)	5,290
Total (pcu/hr)	1,185		390			2,480		1,236		

3.3 The Effect of Drivers' Lane Choices on The Roundabout Traffic Performance

Table 6 shows SIDRA software morning and evening results of reality model and standard model traffic performance in terms of capacity and average delay. In both reality and standard models, the highest capacity at the outer lane (dominant lane) at the leg with three-lane approach, and at the inner entry lanes (dominant lanes) at legs with two-lane approach except inner lane at leg three. This is due to the high through movement volume from the adjacent leg which increases the circulating volume. The longest average delay at the outer lane at the leg with three-lane approach due to the high left movement volume. For legs with two-lane approach, the longest delay was in all outer lanes in reality model except outer lane at leg one at evening time due to the high through movement volume. However, the longest delay was in all inner lanes in the standard model due to the high total entry volume.

As the input for both models are the same except the entry volumes, the capacity and average delay calculations are very much affected by the way the volumes are assigned to each lane. Thus, if the lane-based volume is unknown and assumptions were made based on the appropriate lane disciplines, there is a potential to under or overestimate the capacity and average delay at roundabout with unequal number of entry and circulating lanes. On the other side, lane disciplines increase the capacity and reduce the average delay for roundabout with equal number of entry and circulating lanes.

Table 6 - Morning and evening traffic performance of reality and standard models

Leg No.	Entry Lane	Capacity (AM(PM) (pcu/hr))		Average Delay (AM(PM) (sec))	
		Reality Model	Standard Model	Reality Model	Standard Model
Leg 1	Outer	509(493)	422(421)	271.0(816.0)	481.6(324.3)
	Inner [d]	602(571)	512(588)	79.9(1020.0)	560.4(1626.7)
Leg 2	Outer [d]	592(530)	718(672)	373.2(903.3)	75.6(776.8)
	Middle	424(369)	490(447)	14.4(59.7)	5.8(10.2)
	Inner	397(363)	456(414)	6.4(21.4)	4.4(5.7)
Leg 3	Outer [dr]	882(701)	783(667)	1644.4(797.8)	854.7(682.7)
	Inner [ds]	755(675)	890(711)	843.6(780.9)	1519.3(882.5)
Leg 4	Outer	375(485)	322(278)	729.2(108.0)	413.4(18.8)
	Inner [d]	428(533)	406(513)	566.6(38.5)	1280.0(1053.6)

[d] Dominant lane in both models.
[dr] Dominant lane in reality model.
[ds] Dominant lane in standard model.

4. Conclusion

This research was conducted to investigate how drivers select their lanes at large multi-lane roundabout and how their lane choice affect the traffic performance in attempt to fill in the knowledge gap related to the characteristics of driver's behaviour at large multi-lane roundabout. Results indicated that the large number of lanes provided high freedom for drivers on their behaviour which cannot be fully controlled. However, when the number of entry lanes equal to the circulating lanes, most of drivers could make the correct movement from entry lane to circulating lane and from circulating lane to exit lane as drivers tend to follow the natural movement path. In the event that the number of entry lanes are lesser than circulating lanes, the middle circulating lane became common lane choice for both outer and inner entry lane drivers. Lane discipline marking is effective for multilane roundabout especially the roundabout with equal number of entry and circulating lanes in order to improve the traffic performance. Due to the input in the reality model and standard model, the roundabout performance varied greatly and standard model potentially under or overestimate the capacity and average delay at roundabout with unequal number of entry and circulating lanes.

5. Recommendation

Further studies could be conducted on smaller roundabouts and roundabouts with different number of entry, circulating or exit lanes to better understand the characteristics of drivers' lane choice in order to comprehend the impact of the roundabout size and number of lanes on the drivers' behaviour.

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