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Analysis of Traffic Operation Performances at Roundabouts

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Abstract

The traffic operation performances at roundabouts are complicated under the influence of confluence operations. On the basis of the Mengxi square in Zhenjiang city roundabouts survey using video cameras, some parameter performances of different vehicle types on weaving sections and circulating lanes are analyzed, which included the velocity distribution, the gap distribution, as well as the distance distribution of lane changing. Based on the analysis, some of the conclusions are as follows: 1) The vehicle velocity of inner circulating lane is larger than the outer circulating lane 2) The entry vehicle velocity is smallest 3) The distribution of entry gaps is different from circulating gaps 4) the characteristics of vehicle teams are mostly same in different lanes 5) When the type is bigger, the lane changing distance is smaller 6) For the same type, the distance of lane changing shows ladder-like distribution.
The research result will be a base for improving the capacity of roundabouts.

Keyword: Roundabouts; Confluence Section; Velocity; Gap; Lane Changing

1. Introduction

1.1. Backgrounds

In order to avoid the conflict between entry vehicles and circulating vehicles, there are a mass of confluence operations at roundabout weaving sections. The performance parameters are difficult to be determined due to the great complexity of traffic performances at roundabout weaving areas. In this paper, according to the analysis of various kinds of data obtained by using video cameras, several performance parameters were calculated, including the velocities of circulating lanes and confluence sections, the gaps of circulating vehicles and confluence vehicles and the position of lane changing. The statistical regularities were analyzed, and the general performances were summarized for operation performances at roundabout confluence sections.

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1.2. Research Review

Traffic operation performances at roundabout weaving sections include the regulation of the velocity distribution, the headway distribution of confluence vehicles and circulating vehicle, and the distance distribution of lane changing. Turner calculated the flow rate, average travel time, and the delay of roundabouts under a certain traffic condition. They also analyzed the advantages of roundabouts differentiating from other intersections. By simulation software, Sisiopiku et al. compared the differences among stop control, priority control, signal control, and roundabout control under different traffic conditions, including flow rate, proportion of turning orientation, and number of entry lanes. Troutbeck et al. proposed a method for calculating critical gap of roundabouts and compared various methods. Several scholars intensively explored the capacity and operation performances of the on-ramp and off-ramp of expressways.

2. Date Collection

Mengxi square roundabout in Zhenjiang, China, is chosen as a measure object, which is located in the unsignalized intersection of Mengxi road (north entry and south entry), Xuefu road (east entry) and Zhengdong road (west entry). The diameter of the roundabout is 60 meters. The measure area is the circulating and confluence section between Mengxi road (N) and Zhengdong road. The waving section comprises three lanes which is numbered 1, 2, 3. The traffic flow was surveyed using video cameras from 7:50 to 8:20 on April 17, 2012. Some parameter values can be obtained by replaying the video. The flow rate of west entry of Zhengdong road is 1299 pcu/h and the weaving area is 2077 pcu/h.
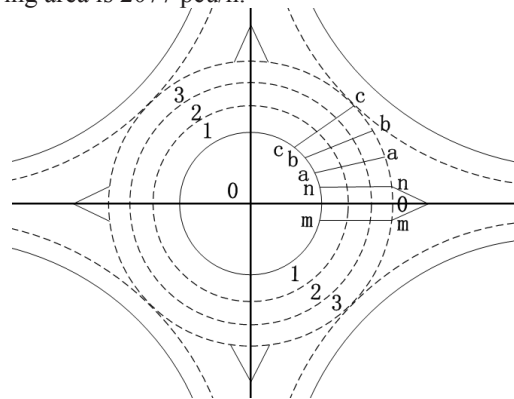

Fig. 1. Position and distance of date collection

In order to collect traffic flow data, some auxiliary lines are drawn on the roundabout in Figure 1. Survey data on m-n section and a-b-c section are chosen to analyze some characters of circulating vehicles and confluence vehicles. According to the different lane changing form, the entry flow are divided into three categories: Type 1(To Lane 3), Type 2(To Lane 3-2), Type 3(To Lane 3-2-1).The start point for lane-changing analysis is spot 0. 594 circulating vehicles on m-n section, 565 circulating vehicles on a-b-c section and 509 vehicles of entry-flow are surveyed separately. There are 324 vehicles, 208 vehicles and 62 vehicles distributed in lane 1, lane 2 and lane 3 during the section m-n. At the same time, 197 type 1 entry vehicles, 185 type 2 entry vehicles, and 127 type 3 entry vehicles are observed.

3. Distribution of velocity

3.1. Average Velocity of Circulating Vehicles and Confluence Vehicles

The average velocity of three lane vehicles on section m-n, b-c and entry flow are showed in Table 1 and Figure 2. The order of average velocity are showed as followed: (1) Lane: lane 1>lane 2>lane 3; (2) Vehicle: car > bus; (3) Car: $V_{bc} > V_{mn} > V_{entry}$; (4) Bus: $V_{entry} > V_{bc} > V_{mn}$.

Table 1. Average velocity of vehicles (km/h)

	Lane 1			Lane 2			Lane 3		
	m-n	b-c	entry	m-n	b-c	entry	m-n	b-c	entry
Average velocity of car	25.84	27.38	26.05	24.25	24.13	23.49	22.73	24.68	19.89
Standard deviation of car	6.20	8.34	11.19	5.34	7.41	8.02	7.73	7.35	7.67
Average velocity of bus	22.35	23.83	32.43	22.12	22.11	27.16	18.22	24.07	22.61
Standard deviation of bus	3.67	5.73	5.84	4.89	6.40	6.58	5.26	7.87	5.83
Average velocity	25.54	27.00	26.37	23.95	23.83	23.79	21.64	24.53	20.16
Standard deviation	6.09	8.17	11.06	5.32	7.29	7.96	7.43	7.38	7.55

The difference of the velocity values between three lanes is caused by the different diameters of circulating lanes and confluence action. These values indicate that confluence vehicles rarely influence the velocity of lane 1 vehicles. Confluence vehicles have lower velocity because they usually decelerate before entering a roundabout. The circulating cars are accelerated to a higher speed before the weaving section, and slowed down as they encounter the entry flow. On the impact of turning radius, the bus speed is lower than the car speed and has a higher speed of entry flow.
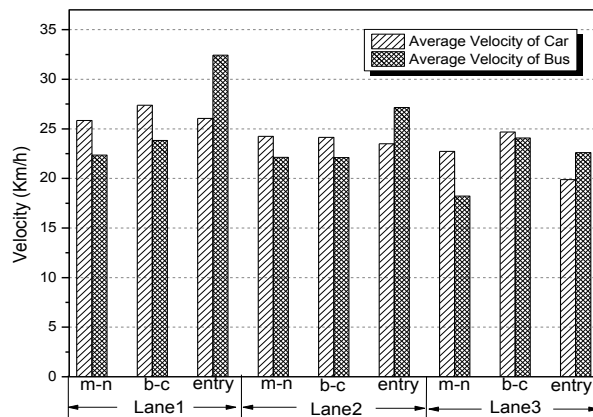

Fig. 2. Contrast of Average Velocity

3.2. Distribution of Circulating Velocity

As the distribution of velocity showed in Table 2 and Figure 3, 4, the circulating section velocity values of lane 1 vehicles, lane 2 vehicles, and lane 3 vehicles are located in the intervals of 15-35 km/h (93.62%), 15-35 km/h (93.75%), and 10-35 km/h (91.93%). The three velocity graphics conform to the normal distribution and have obvious peak respectively. The velocity converges to 20-27 km/h. On the contrast, the distribution of

velocity on section b-c is dispersing with a little smoother peak. These values indicate that the velocity of weaving section is impacted by entry flow.

Table 2 Distribution of Velocity(km/h)

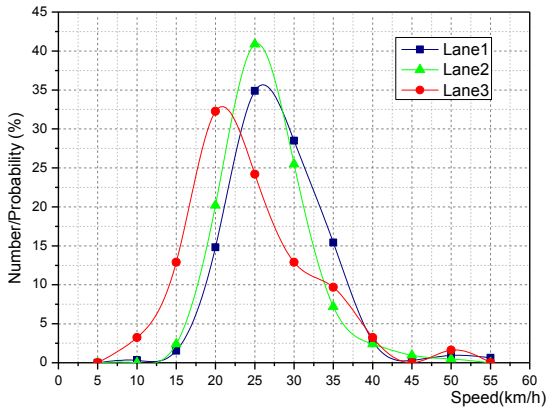|	Lane 1	Lane 2	Lane 3
Circulating section(m-n)	15-35 (93.62%) ;	15-35 (93.75%)	10-35 (91.93%)
Confluence section(b-c)	15-45 (91.04%)	10-35 (91.37%)	10-35 (92.85%)

Figure. 3. Distribution of Velocity on Circulating Lanes(m-n)
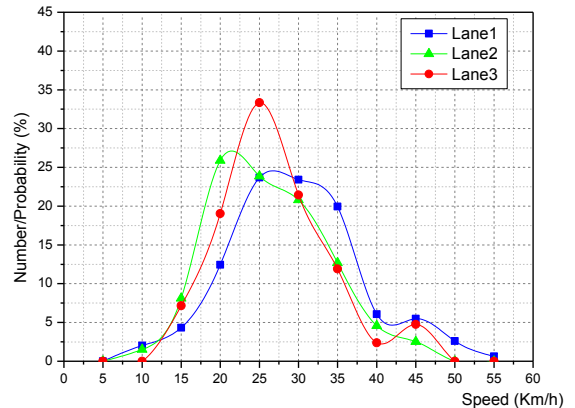

Figure. 4. Distribution of Velocity on Circulating Lanes (b-c)

3.3. Distribution of Entry Velocity

Three type of entry vehicles are analyzed respectively. As showed in Figure 5(a), 5(b), Most of the velocity values of type 1 vehicles, type 2 vehicles are located in the intervals of 10-30 km/h in lane 3 and the velocity distribution is mostly consistent with the circulating velocity. In the while, the velocity of type 3 in lane 3 is lower than the average with the reason that the type 3 vehicles have to slow down for waiting accepted gaps.
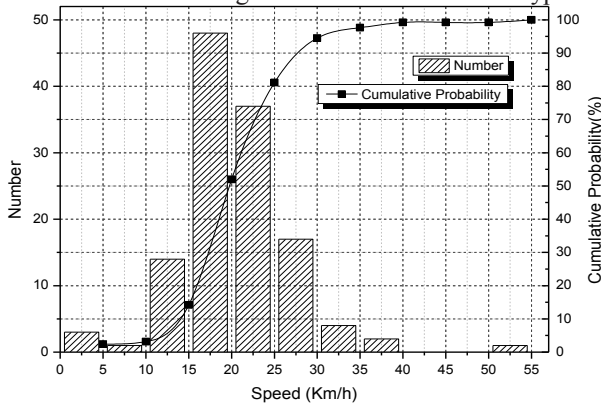

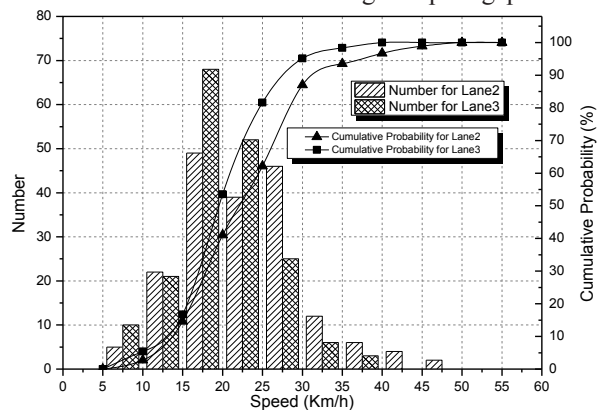Figure. 5. (a) Distribution of Velocity of Entry Flow for Type 1(3)

Figure. 5.(b) Distribution of Velocity of Entry Flow for Type 2(3-2)

After Lane 3, the type 2 vehicles speed up observably to consist with the circulating velocity. It is noticed in particular that there are some vehicles of low speed in lane 2 and lane 3. It is because that the vehicles must slow down to wait for entering into inner lanes where has a flow queue.
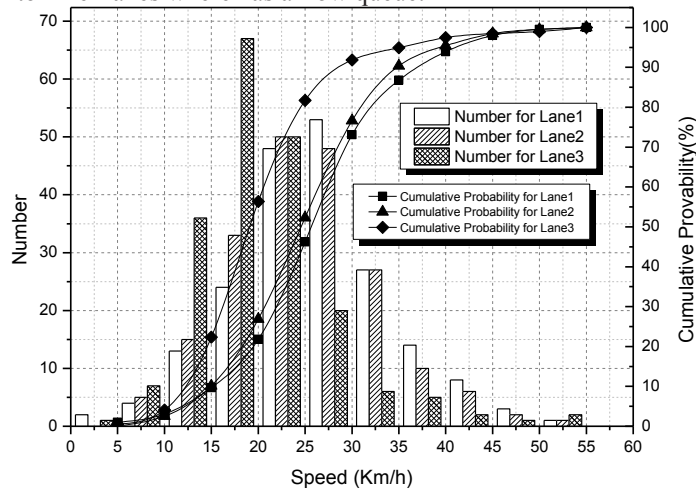

Fig. 5. (c) Distribution of Velocity of Entry Flow for Type 3(3-2-1)

4. Distribution of gap

Entry vehicles enter roundabouts using the chance of accepted gap, thus the research of confluence performance is emphasized at weaving areas. On the one hand, the headways between confluence vehicles and circulating vehicles provide a basis to study critical gaps and the capacity of an entry. On the other hand, the headways between influence vehicles and circulating vehicles are the basis to analyze traffic performances of exit flow and exit capacity. Entry is the bottleneck of a roundabout to raise full capacity. On the basis of the survey of gaps, some conclusions are given as followed.

4.1. Average Gap of Confluence Vehicles and Circulating Vehicles

Though the survey time is morning rush hour, there are no vehicle teams at some time. The maximum accepted gap is 5.8 s, so the gaps which are bigger than 6 s are removed in Table 3. Both data are discussed in Figure 6(a) ,6(b). Some conclusion are given: (1) All gap data: Lane 1 < Lane 2<Lane 3. There is a distinctly difference among three lanes gap data .It is because that most vehicles choose to drive in lane 1 or lane 2 and it is difficult to make a vehicle team. (2) gap data <6s: The difference between three lanes' gap are significantly reduced. It is indicates that the character of vehicle team are mostly same in different lane. (3) gap data <6s: Lane 1 < Lane 2 < Lane 3. This feature is mostly significant on section m-n but less so on section a-c. (4) Gaps in lane 1: m<n<a<b<c, standard deviation: m<c. It can be explained that the traffic operation is complexity on weaving section, so the gaps are bigger than non-weaving section.

Table 3 Average gap of vehicles (s) (gap data <6s)

Lane 1		Lane 2		Lane 3	
Gap（s）	Standard	Gap（s）	Standard	Gap（s）	Standard

	deviation			deviation			deviation
m	2.76	1.27	2.98	1.37	3.28	1.60
n	2.84	1.33	2.96	1.41	3.46	1.37
a	2.92	1.28	2.91	1.30	2.94	1.61
b	2.96	1.33	2.94	1.37	2.81	1.81
c	2.99	1.47	2.97	1.53	3.44	2.12
Average	2.90	1.34	2.95	1.39	3.27	1.59
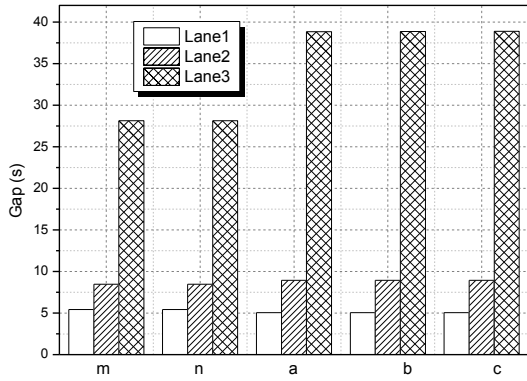
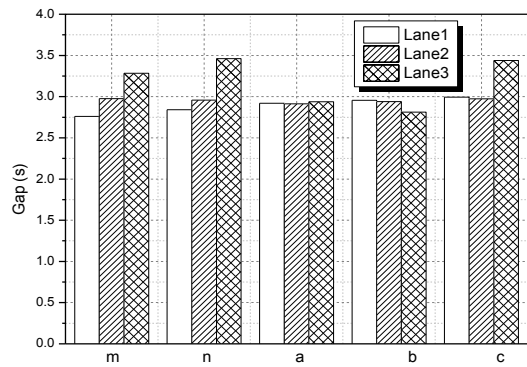Fig. 6. (a) Contrast of Average gap (all gap data)

Fig. 6. (b) Contrast of Average gap (gap data <6s)

4.2. Distribution of Circulating Gap

As the distribution of gaps showed in Figure 7 and Figure 8, the lane 1 graphics conform to the normal distribution and have obvious peaks between 1.2 s and 4.4 s (81.7%). The lane 2 graphics have disperse with little smoother peaks. On the contrast, the data of lane 3 are scanty and irregular. It can be found that the gaps of weaving section are dispersion under the influence of confluence actions.
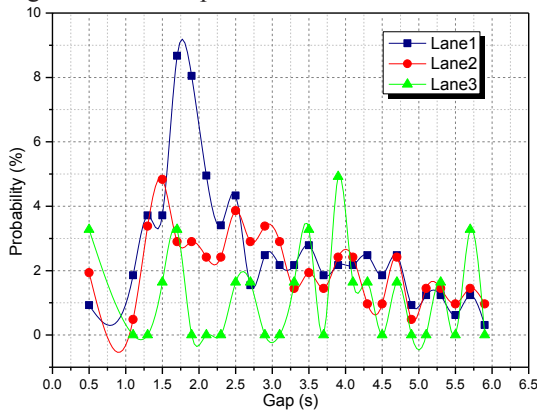

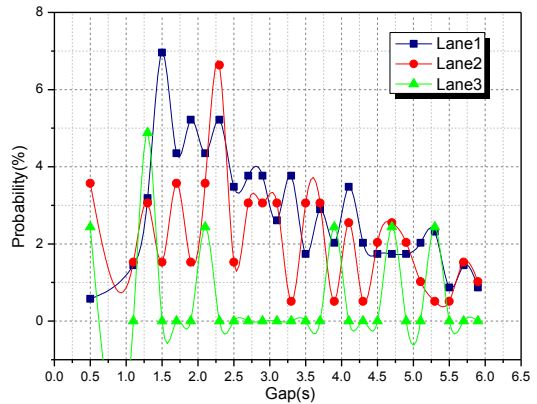Fig. 7. Distribution of Gaps on Circulating Lanes(Spot m)

Fig. 8. Distribution of Gaps on Circulating Lanes(Spot b)

4.3. Distribution of Entry Gap

As showed in Table 4 and Figure 9, the distribution of entry gaps is different from circulating gaps. There are many gaps less than 1 s because of that the entry vehicles can choose a long distance to change lanes, while two or three vehicles can reach to the three lanes in the same time. The result can be used to revise the entry gap data. On the contrast, the average gap and of entry flow is bigger than the average gap of circulating flow. The entry flow gap values of 'to lane 1', 'to lane 2', 'to lane 3' vehicles are located in the intervals of 0-3.6 s(80.89%), 0-3.6 s(81.49%) and 0-3.6 s(82.49%).

Table 4 Average Gap of Entry Flow

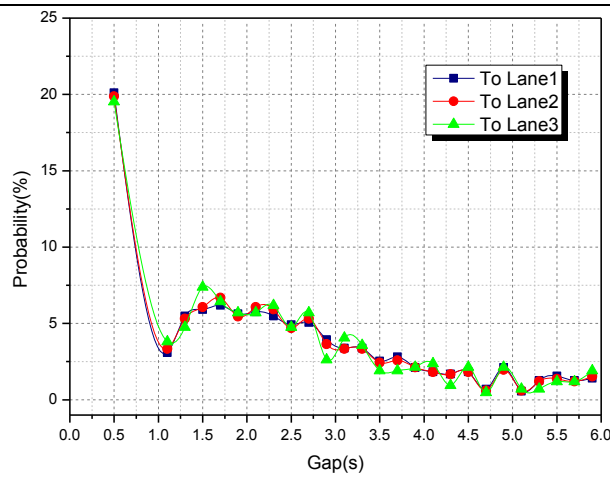|	To Lane 3	To Lane 2	To Lane 1
Gap(s)	3.54	3.52	3.52
Standard deviation	3.58	3.62	3.57

Fig. 9. Distribution of Gap for Entry Flow

5. Rule of lane changing

5.1. Average Distance of Entry Flow

The average lane changing distance of three type vehicles are showed in Table 5 and Figure 10. The order of average distance is showed as followed: To lane 1 > To lane 2 > To lane 3. It keeps the consistent of the fact that the distance is elongated when the vehicle is moving into the inner lane.

Table 5 Average Distance of Entry Flow for Lane Changing

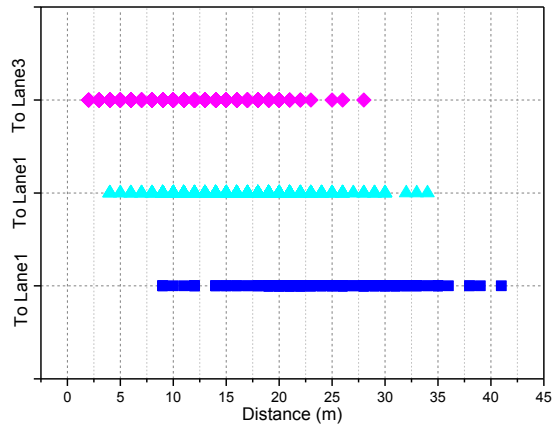|	To Lane 3	To Lane 2	To Lane 1
Average distance of lane changing（m）	11.64	16.59	24.04
Standard deviation	4.48	5.73	6.15

Fig. 10. Average Distance of Entry Flow for Lane Changing

5.2. Distribution of Lane Changing Distance

Three type of entry vehicles are analyzed respectively in Figure 11(a), 11(b), 11(c). The distance distribution to lane 1 of type 1, type 2, and type 3, are located in the intervals of 5-20 m (92.06%), 5-20 m (96.22%), and 0-15 m,(98.99%). The distance distribution to lane 2 of type 2 and type 3, are located in the intervals of 10-30 m (95.13%) and 5-20 m (93.90%).On the contrast, the distance distribution to lane 1 of type 3 are located in the intervals of 10-35 m (95.43%).
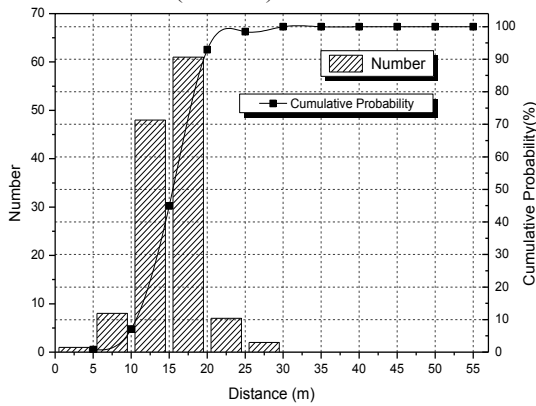

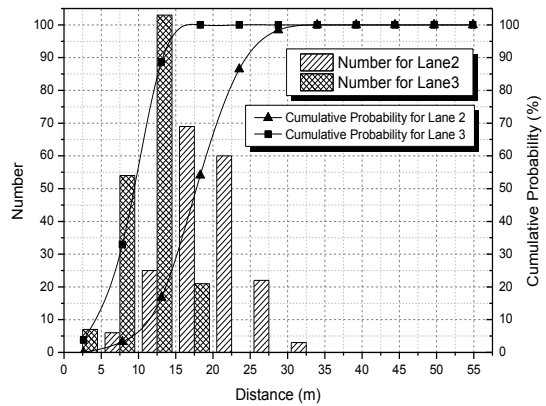Fig. 11. (a) Distribution of Lane-Changing Distance for Type 1

Fig. 11. (b) Distribution of Lane-Changing Distance for Type 2

Some conclusion can be given: (1) when the type is bigger, the lane changing distance is smaller. (2) For the same type, the distance of lanes showed ladder-like distribution. (3) Every graphs of distance distribution has a peak.
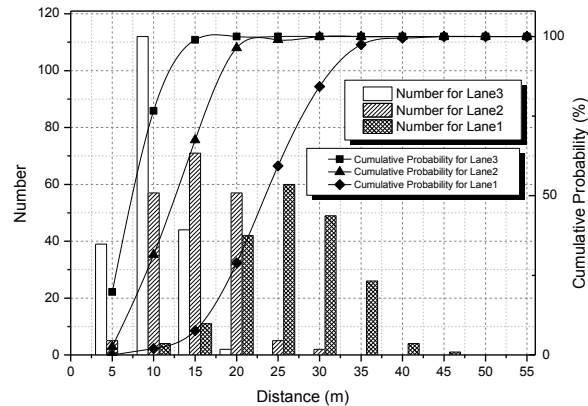

Fig. 11. (c) Distribution of Lane-Changing Distance for Type 3

6. Conclusion

On the basis of the traffic operation parameters survey of Mengxi square roundabout in Zhenjiang, China, the operation performances were analyzed, which included vehicle velocity distribution, gap distribution, and lane changing distribution.

Some conclusions can be drawn as follows: (1) The order of average velocity are showed as followed: ① lane 1>lane 2>lane 3; ② car > bus; ③ Car: $V_{bc} > V_{mn} > V_{entry}$; ④ Bus: $V_{entry} > V_{bc} > V_{mn}$. These values indicate that confluence vehicles rarely influence the velocity of lane 1 vehicles. (2) The three circulating velocity distribution conform to the normal distribution and have obvious peaks respectively on section m-n. On the contrast, the distribution of velocity on section b-c is disperse with a little smoother peak. (3) The velocity distribution of type 1 vehicles, type 2 vehicles are mostly consistent with the circulating velocity in lane 3, while the velocity of type 3 in lane 3 is lower than the average with the reason that the type 3 vehicles have to slow down for waiting accepted gaps. (4) Gap analysis: ① There is a distinctly difference among three lanes gap data. ② The character of vehicle team are mostly same in different lane. ③ gap data <6s: Lane 1 < Lane 2 < Lane 3. This feature is mostly significant on section m-n but less so on section a-c. ④ The traffic operation is complexity on weaving section, so the gaps are bigger than non-weaving section. (5) The distribution of entry gaps is different from circulating gaps. (6) When the type is bigger, the lane changing distance is smaller; For the same type, the distance of lanes showed ladder-like distribution; Every graphs of distance distribution has a peak.

Being the theoretical basis of traffic flow, the regularity of vehicle operation in roundabout weaving area is helpful to study traffic parameters, model and simulate traffic flow, and calculate capacity and delay. Thus, the study on vehicle operation performance at weaving area provides the basis for designing and improving roundabouts. Further researches are needed to analyze more performance parameters including density, flow rate, and headway, and so on. A large number of samples in different cities and roundabouts are needed to capture general regularity.

Acknowledgements

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