Comparison of capacity between roundabout design and signalised junction design

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Abstract

In a junction design we often face with the choice between a roundabout design and a signalis junction design. To make the choice, one important question should be answered is which desi gives a higher capacity. Until now, there is few researches who clearly answer this questic Therefore a research about the detailed comparison of capacity of these two types of junct designs is needed. This paper try to compare the capacity of roundabout and signalised junct designs for junctions with four branches.

In order to compare the capacities of roundabouts and signal intersections, a concept of full pacity has been introduced both for the roundabouts and signalised junctions. The formulas calculating the full capacity of a roundabout and a signalised junctions have been developed has been found that for a given geometric design, the full capacity of roundabouts depends hea ily on the O-D traffic flow distribution at intersection, and the more vehicles turning left, lower the full capacity of roundabouts. The comparisons between the roundabout design and t signalised intersection design for a single lane (entry/exit) junction and multi-lanes junctions made and some interesting results are obtained. Further researches are also suggested .

Keywords

Roundabout design – capacity – signalised junction – Swiss Transport Research Conference – STRC 2001 – Monte Verità

1. Introduction

A junction has always a common space shared by several traffic streams. The conflicts between the traffic streams are the major sources of traffic accidents. To prevent traffic accidents, the conflicting traffic streams should be separated in time. Roundabout is a junction with a central island where the conflicting traffic streams are separated in time by the priority rules, i.e. the entry vehicles should give ways to circulating vehicles. Signalised junction is a junction with traffic lights where the conflicts are separated in time by the traffic lights.

In a junction design we often face with the choice between a roundabout design and a signalised junction design. To make the choice, one important question should be answered is which design gives a higher capacity. Until now, there is few research who clearly answer this question. Therefore a research about the detailed comparison of capacity of these two types of junction designs is needed. This paper tries to compare the capacity of roundabout and signalised junction designs for junctions with four branches and are symmetric about centre.

The difficulties about comparison of capacities is that, for roundabouts the concept of entry capacity is used, and for signal intersections the concept of lane group or approach capacity is used. These two concepts are not the same, so direct comparison can't be made. In order to compare the capacities of roundabouts and signal intersections, a concept of capacity which can be used both for the roundabouts and signal intersections must be used.

It should be noted that here the comparison will be done without considering the detailed information about geometry design and signal timing. It only requires the following basic data concerning

a. geometry :

roundabout: number of lanes in entries and number of lanes in the circulating carriageways;

signal intersection : number and use of lanes on approaches.

b. volumes :

given in total vph (vehicles per hour) for each movement.

2. The full capacity of roundabouts

In the early development of roundabout, the concept of weaving capacities was adopted, later this concept of capacity was abandoned in favour of the entry capacities. The entry capacity Qe is defined as the maximum inflow of an entry, evidently the entry capacity is depended on the conflicting flow Q_g. Investigations and researches in England, France and Switzerland have been shown that

$$Q_e = F - Q_g * f$$

where f and F are the coefficients. But the formula of TRRL (R.M. Kimber) takes

$$Q_g = Q_{cir}$$

and the formula of CETUR and the formula presented in Swiss guide on roundabout design consider

$$Q_g = \beta * Q_{cir} + \alpha * Q_s$$

where Qcir is the circulating flow crossing the entry and Qs is the flow leave the roundabout by the previous exit, α is a parameter reflecting the degree of vehicles in the entry disturbed by the vehicles exiting at the same branch. Investigations in Switzerland show that its value depends the distance between the conflict point of the entry and that of the previous exit. β is a parameter taking account of multi-lanes in the circulating carriageways.

Here the following formula presented in the Swiss guide on roundabout design is used for developing full capacity formula of roundabout.

$$Q_e = \kappa[1500 - (8/9)*Q_g] \qquad (2.1)$$

where $Q_g=(\beta *Q_{cir} + \alpha *Q_s)$, α is determined based on fig.1 (Lba is the distance between diverging point at exit and converging point at entry), κ and β are determined as follows :

1 lane in the entry: $\kappa = 1$;
2 lanes in the entry $\kappa = 1.4 - 1.6$;
3 lanes in the entry $\kappa = 2$;
1 lane in the circulating carriageway: $\beta = 0.9 - 1.0$;
2 lanes in the circulating carriageway: $\beta = 0.6 - 0.8$;
3 lanes in the circulating carriageway: $\beta = 0.5 - 0.6$.

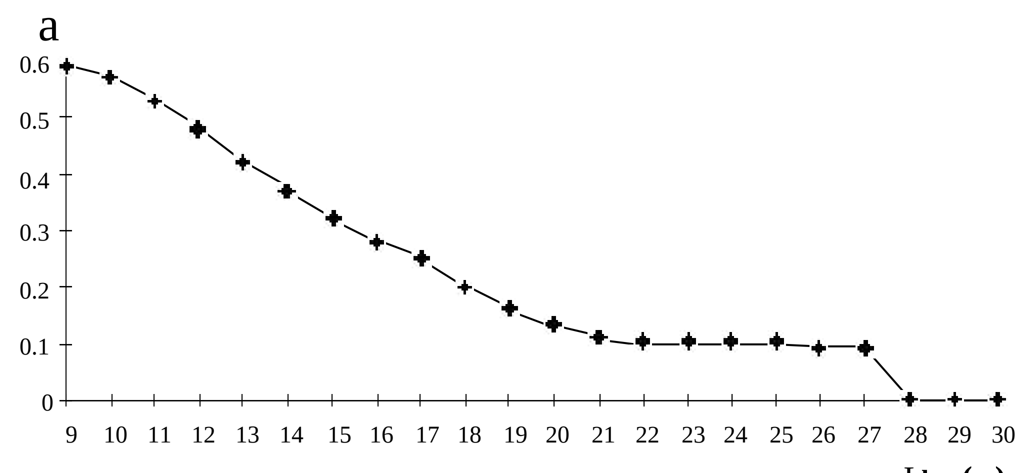

Fig.1 the relation of α and L_{ba}

Generally, the entry capacity is often used for analysis and evaluation of roundabouts. In order to compare the capacity between roundabouts and signal intersections, the full capacity will be used. The full capacity (named as Q_{fcr}) of roundabout is defined as the maximum inflow that a roundabout can accommodated under fully saturated conditions at all the entries for a given set of turning movements. In the following, the formula of full capacity for roundabout will be developed.

As shown in Fig.2, suppose that at each entries there are the long queues (fully saturated conditions), turning vehicles are uniformly distributed at all the entries and

Q_{ir}: the volumes of turning right in the entry i (v/h);
Q_{ih}: the volumes of going ahead in the entry i (v/h);
Q_{iL}: the volumes of turning left in the entry i (v/h);
Q_r: the total volume of turning right of roundabout (v/h);
Q_h: the total volume of going ahead of roundabout (v/h);
Q_L : the total volume of turning left of roundabout (v/h);
R_r: the ratios of tuning right of roundabout;
R_h: the ratios of going ahead of roundabout;
R_L: the ratios of turning left of roundabout;
Q_{ie}: the inflow of entry i (that is the entry capacity, v/h);
Q_{ig}: the conflicting flow of entry i (v/h);
Q_{icir}: the circulating flow for entry i (v/h);
Q_{is}: the leaving flow by the previous exit for entry i (v/h).

Because of the symmetrization of roundabout, then for all the entries, the entry capacity relations and the parameters κ, β and α can take the same values.

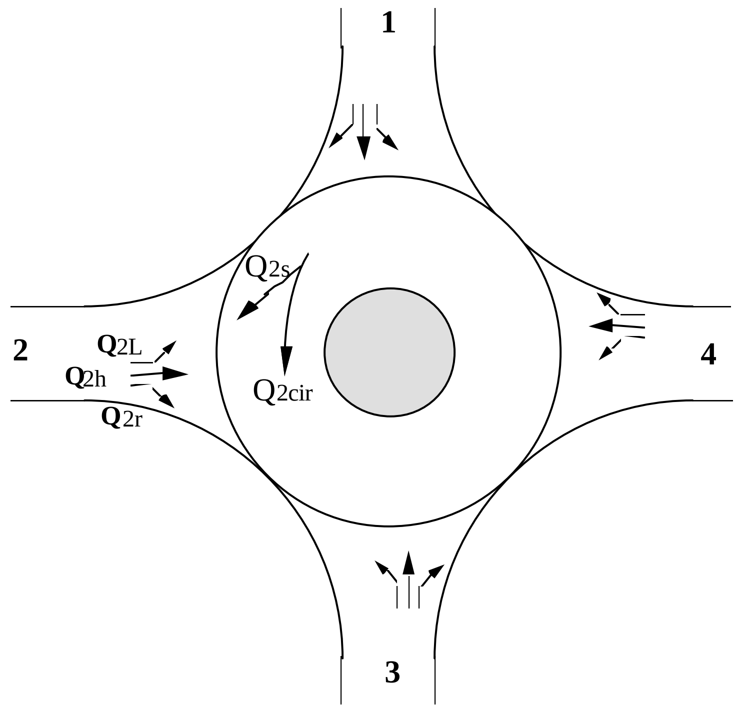

Fig.2 traffic flow at a roundabout

i.e.

$$Q_{ie}/\kappa + Q_{ig} * f = F$$

where

$$Q_{ig} = \beta * Q_{icir} + \alpha * Q_{is}$$

therefore, for entry 1, 2, 3 and 4

$$Q_{1e}/\kappa + [\beta *(Q_{3L} + Q_{4h} + Q_{4L}) + \alpha * (Q_{4r} + Q_{3h} + Q_{2L})] * f = F$$

$$Q_{2e}/\kappa + [\beta *(Q_{4L} + Q_{1h} + Q_{1L}) + \alpha * (Q_{1r} + Q_{4h} + Q_{3L})] * f = F$$

$$Q_{3e}/\kappa + [\beta *(Q_{1L} + Q_{2h} + Q_{2L}) + \alpha * (Q_{2r} + Q_{1h} + Q_{4L})] * f = F$$

$$Q_{4e}/\kappa + [\beta *(Q_{2L} + Q_{3h} + Q_{3L}) + \alpha * (Q_{3r} + Q_{2h} + Q_{1L})] * f = F .$$

Summing the above four equations , and noting that

$$Q_{fcr} = Q_{1e} + Q_{2e} + Q_{3e} + Q_{4e}$$

$$Q_L = Q_{1L} + Q_{2L} + Q_{3L} + Q_{4L}$$

$$Q_r = Q_{1r} + Q_{2r} + Q_{3r} + Q_{4r}$$

$$Q_h = Q_{1h} + Q_{2h} + Q_{3h} + Q_{4h}$$

then

$$Q_{fcr}/\kappa + [\ \beta *(Q_L + Q_h + Q_L) + \alpha * (Q_r + Q_h + Q_L)] * f = 4F\ .$$

Because

$$Q_L = R_L * Q_{fcr}$$

$$Q_h = R_h * Q_{fcr}$$

$$Q_r = R_r * Q_{fcr}$$

and

$$R_r + R_h + R_L = 1$$

then

$$Q_{fcr}/\kappa + Q_{fcr} * [\ \beta *(R_L + R_h + R_L) + \alpha * (R_r + R_h + R_L)] * f = 4F\ .$$

or

$$Q_{fcr} * \{\ 1/\kappa + [\beta *(R_h + 2R_L) + \alpha\ ] * f\} = 4F$$

Therefore

$$\mathbf{Q_{fcr} = 4F / \{ 1/k + [\ b *(R_h + 2R_L) + a\ ] * f\}} \qquad (2.2a)$$

It is clearly from this formula that the full capacity of a roundabout depends not only on the parameters α, β, κ but also on the O-D distribution of the traffic flow at the roundabout. And it is easily found out that the higher ratio of left turn movement, the lower the full capacity and one turning left vehicle is equivalent to two vehicles going ahead. Therefore decreasing the ratio of left turning at a roundabout by traffic network planning can increase the full capacity. It also show that under a certain traffic conditions the only method to increase the capacity (both entry and full capacity) is to modify the geometry design of roundabouts (so that to change the value of α, β and κ).

Similarly, the formulae for calculating the full capacity for a roundabout with three branches can be derived as

$$\mathbf{Q_{fcr} = 3F / \{ 1/k + [\ b * R_L + a\ ] * f\}} \qquad (2.2b)$$

3. The full capacity of signal intersections

Suppose that there are n_L entry lanes for a signal intersection, and the signal timing separating all the conflicts in time has been determined. Assuming for lane i, the saturation flow is S_i (v/h), the effective green time is G_i (s), the cycle time is C_L (s). Then the capacity of lane i may be stated as

$$C_i = S_i * G_i/C_L = S_i * G_{ri}$$

where $G_{ri} = G_i/C_L$ can be explained as the ratio of effective green time to the cycle length.

Full capacity Q_{fcs} of a signal intersection is defined as the maximum traffic flow (v/h) which can pass through the intersection under prevailing traffic, roadway and signalisation conditions. Clearly this definition is nearly the same as that of roundabout, so the concept of full capacity provide a measure to compare the capacity between the roundabouts and signal intersections. It is evident that

$$Q_{fcs} = \Sigma\, S_i * G_{ri} \qquad (3.1)$$

This formula shows that for a signal intersection, adjusting G_{ri} can change the capacity of that lane, so this provide a method to take account of different traffic demand (Q_i) for that lanes and ensure that capacity $C_i > Q_i$. On the other hand the full capacity of signal intersection heavily depend on the number of entry lanes. The more entry lanes, the higher capacity.

It should be noted that G_{ri} depends on the number of stages and the cycle length. If stages don't overlap, the above formula can be written as

$$Q_{fcs} = \Sigma\Sigma S_{ki} * G_{rki}$$

where S_{ki} is the saturation flow and G_{rki} is the ratio of effective green time to the cycle length of entry lane i in the stage k. Suppose that in each stage the ratios of effective green time on the cycle length for each lane are the same and equal G_{rk}, then

$$Q_{fcs} = \Sigma\, [G_{rk} \Sigma S_{ki}]$$

Because S_{ki} is in the range of (1600, 1800), for simplicity, suppose for all the lanes the saturation flow S_{ki} are the same, and equal to S, then

$$Q_{fcs} = S\, \Sigma\, G_{rk} * N_{Lk} \qquad (3.2)$$

where N_{Lk} is the number of lane facing the green in the stage k. If in each stage, N_{Lk} are the same and equals to n, then the formula can be simply written as

$$Q_{fcs} = S * n * \Sigma G_{rk} \qquad (3.3)$$

where ΣG_{rk} is the total effective green time to cycle length, it is in the range of [0.7 , 0.9] which depends on the number of stages and cycle length.

4. Comparison of full capacity

The comparison of full capacity of the roundabout and that of signalised intersection must be made at the same conditions. This means that they must take up the nearly same surface at intersections and they have the same O-D traffic distribution matrix.

Four types of junctions are taken into account here, i.e. mini-junctions, small junctions, moderate junctions and big junctions.

4.1 mini-junctions

In mini-junctions, usually there is only one lane at each approach. Supposing that the geometry designs in roundabout and signal intersection at a mini-junction are shown in fig.3.

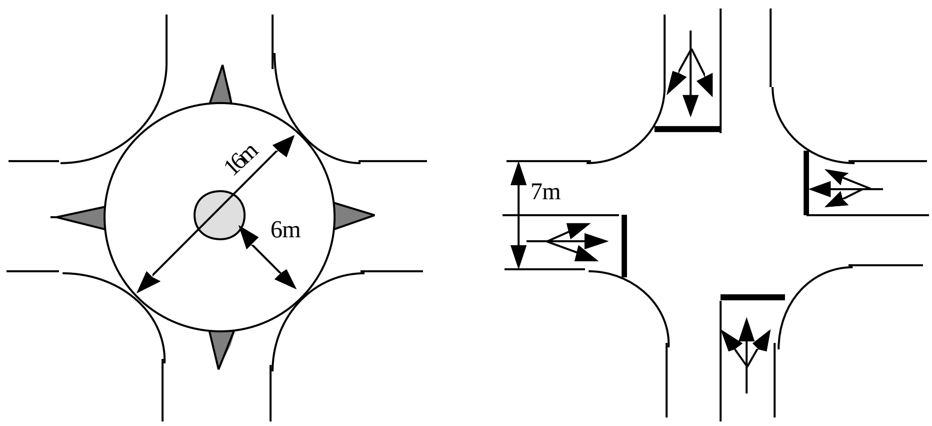

Fig.3 the roundabout design and the signalized intersection design at a mini- junction

For the roundabout design, F = 1500, f=8/9 and in this case κ =1, β =1, and α = 0.59 (L_{ba}= 9m) then according to different values of R_h and R_L, the full capacity for the roundabout can be calculated by applying the formula (2.2a) developed in 2.

$$Q_{fcr} = 6000/\{1 + [(R_h + 2R_L) + 0.59] * (8/9)\}$$

Now considering the full capacity of the signal intersection, as shown in fig.3, there are 4 lanes and at least 4 stages must be introduced to separate the conflicts by time. Suppose that the stages are determined as shown in fig.4 and it is clearly that in each phase there is only one lane facing the green. Suppose S = 1800, $\Sigma\, G_{ri} = 0.78$, then according to the formula (3.3).

$$Q_{fcs} = S * n * \Sigma\, G_{ri} = 1800 * 1 * 0.78 = 1404$$

stage No			
1	2	3	4

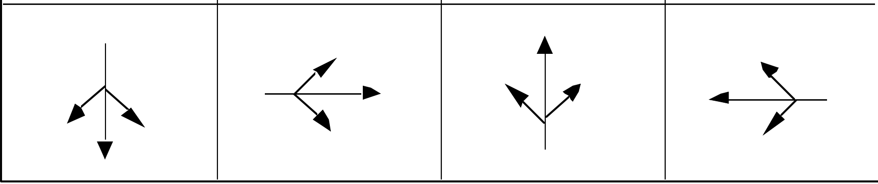

Fig.4 a stage designs for the mini-signalised junction

Now comparing the full capacity of the roundabout and that of the signalised intersection,

Suppose $Q_{fcr} > Q_{fcs}$

then

$$6000/\{1 + [R_h + 2R_L + 0.59] * (8/9)\} > 1404$$

By solving this inequality, we can obtain the full capacity of the roundabout is larger than that of the signalised intersection only if

$$R_h + 2R_L < 3.12$$

Because $R_r + R_h + R_L = 1$ and $R_L < 1$, the above inequality is always true. Therefore, **the full capacity of the roundabout design is always larger than that of the signalised intersection design for a mini-junction.**

4.2 small junctions

In this type of junctions, there are often 2 lanes at each approach. Suppose that the geometry designs in roundabout and in signal intersection for a small junction are shown in fig.5.

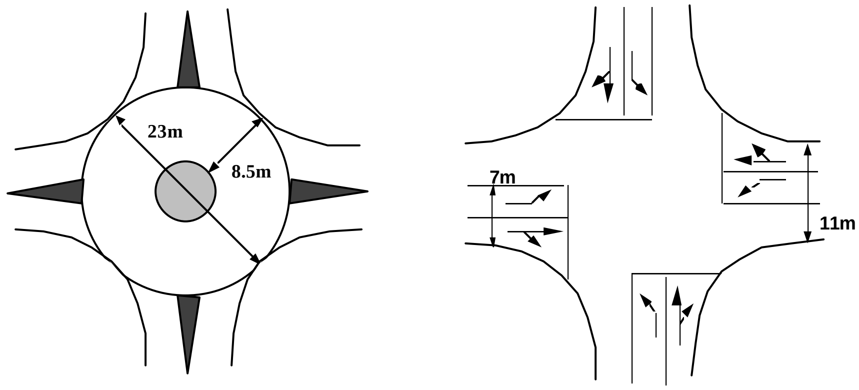

Fig.5 the roundabout design and the signalized intersection design at a small junction

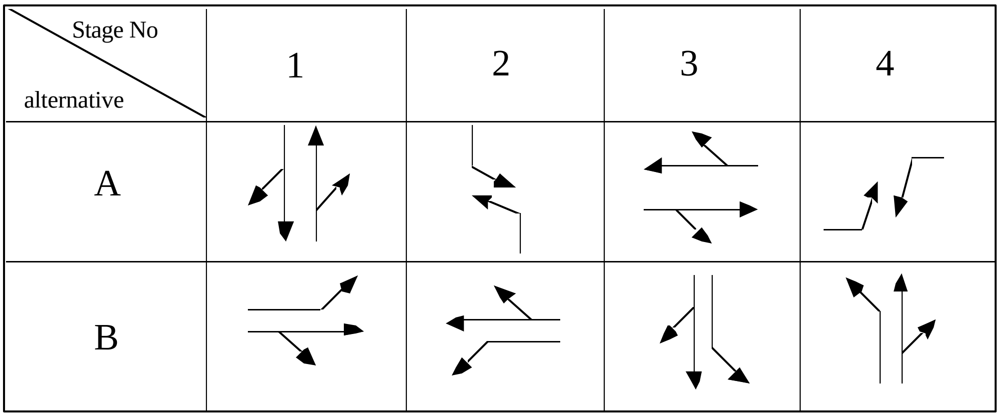

Fig.6 stage designs for the small signalised junction

Because F = 1500, f=8/9 and in this case κ =1, β =0.9, and α = 0.32 (L_{ba}= 15m) then according to different values of R_h and R_L, the full capacity for the roundabout can be calculated by applying the formula of capacity developed in 2.

$$Q_{fcr} = 6000/\{1 +[0.9*(R_h + 2R_L) + 0.32] * (8/9)\}$$

Now considering the full capacity of the signal intersection, as shown in fig.5, there are 8 lanes and at least 4 stages must be introduced to separate the conflicts by time. Suppose that the stages are determined as shown in fig.6, there are two types of stage design and in each stage there are two lanes facing the green. Suppose S = 1800, $\Sigma G_{ri} = 0.78$, then according to the formula (3.3).

$$Q_{fcs} = S * n * \Sigma G_{ri} = 1800 * 2 * 0.85 = 2808$$

Now comparing the full capacity of the roundabout and that of the signal intersection,

Suppose $Q_{fcr} > Q_{fcs}$

then

$$6000/\{1 + [0.9*(R_h + 2R_L) + 0.32] * (8/9)\} > 2808$$

By solving this inequality, we can obtain

$$R_h + 2R_L < 1.07$$

which is the condition of $Q_{fcr} > Q_{fcs}$.

Fig.7 is the graphic representation of this condition. By comparing the full capacity of the roundabout and that of the signal intersection, it is easily find out that in most ordinary cases the full capacity of the roundabout is larger than that of the signal intersection.

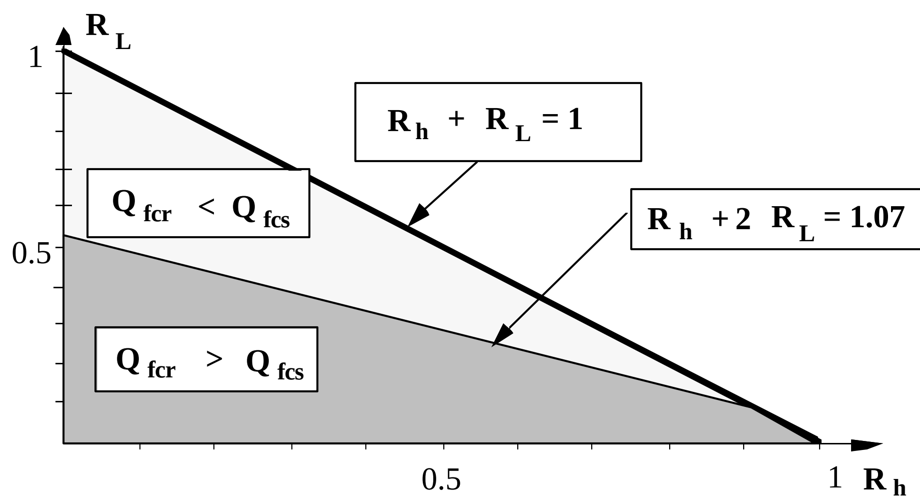

Fig.7 comparison of full capacity between the roundabout design and the signal intersection design for a small junction

4.3 moderate junctions

In this type of junctions, there are often 3 lanes at each approach for the signalised intersection design. Supposing that the geometry designs in roundabout and in signal intersection for such junction are shown in fig.8.

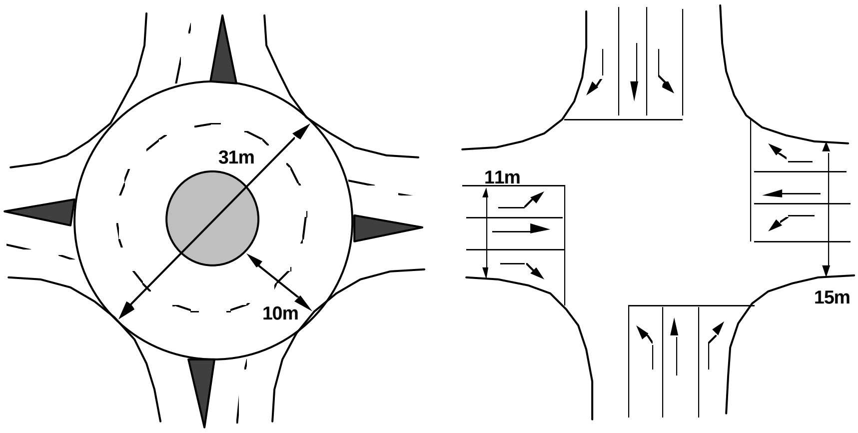

Fig.8 the roundabout design and the signalized intersection design at a moderate junction

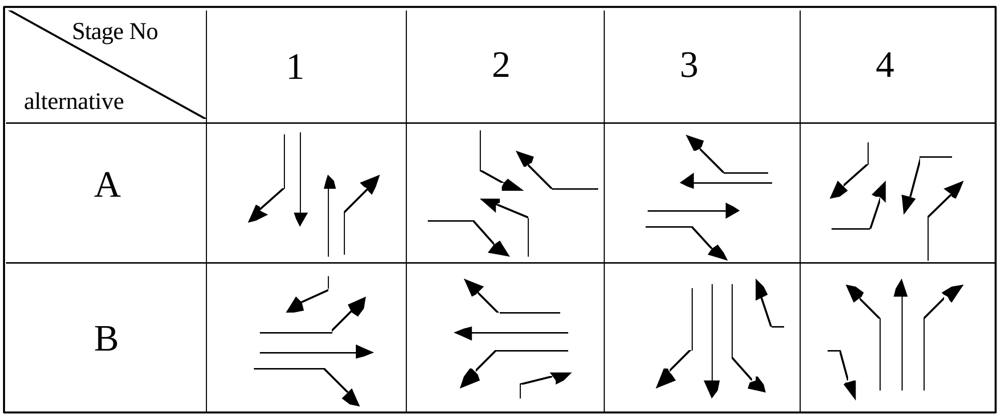

Fig.9 stage designs for the moderate signalised junction

Because F = 1500, f=8/9 and in this case κ =1.4, β =0.7, and α = 0.16 (L_{ba}= 19m) then according to different values of R_h and R_L, the full capacity for the roundabout can be calculated by applying the formula of capacity developed in 2.

$$Q_{fcr} = 4F / \{ 1/\kappa + [\beta * (R_h + 2R_L) + \alpha] * f \}$$

$$=6000/\{1/1.4 + [\,0.7*(R_h + 2R_L) + 0.16\,] * (8/9)\}$$

Now considering the full capacity of the signal intersection, as shown in fig.8, there are 12 lanes and at least 4 stages must be introduced to separate the conflicts by time. Suppose that the stages are determined as shown in fig.9, there are two types of stage design, and in each stage there are four lanes facing the green.

Suppose S = 1800, $\Sigma G_{ri} = 0.78$, then according to the formula (3.3).

$$Q_{fcs} = S * n * \Sigma G_{ri} = 1800 * 4 * 0.78 = 5616$$

Now comparing the full capacity of the roundabout design and that of the signal intersection design.

Suppose $Q_{fcr} > Q_{fcs}$

then

$$6000/\{1/1.4 + [\,0.7*(R_h + 2R_L) + 0.16] * (8/9)\} > 5616$$

By solving this inequality, we can obtain

$$R_h + 2R_L < 0.66$$

which is the condition of $Q_{fcr} > Q_{fcs}$.

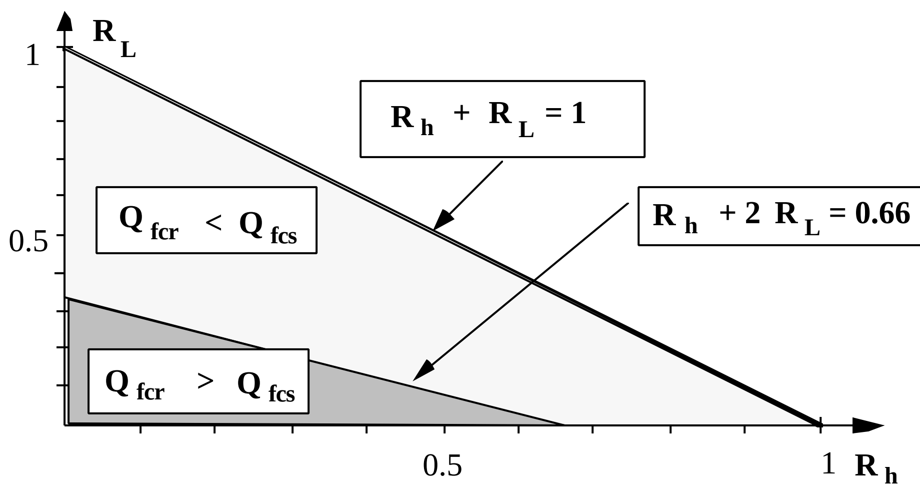

Fig.10 comparison of full capacity between the roundabout design and the signal intersection design for a moderate junction

Fig.10 is the graphic representation of this condition. From this figure, it is easily find usually the full capacity of signal intersection is larger than that of roundabout. The full capacity of signal intersection is less than that of roundabout only if there are few vehicles tuning to left.

4.4 big junctions

In this type of junctions, there are often 6 lanes at each branch for the signalised intersection design. Supposing that the geometry designs of a such junction in roundabout and in signal intersection are shown in Fig.11. The land area used by these two designs are nearly same.

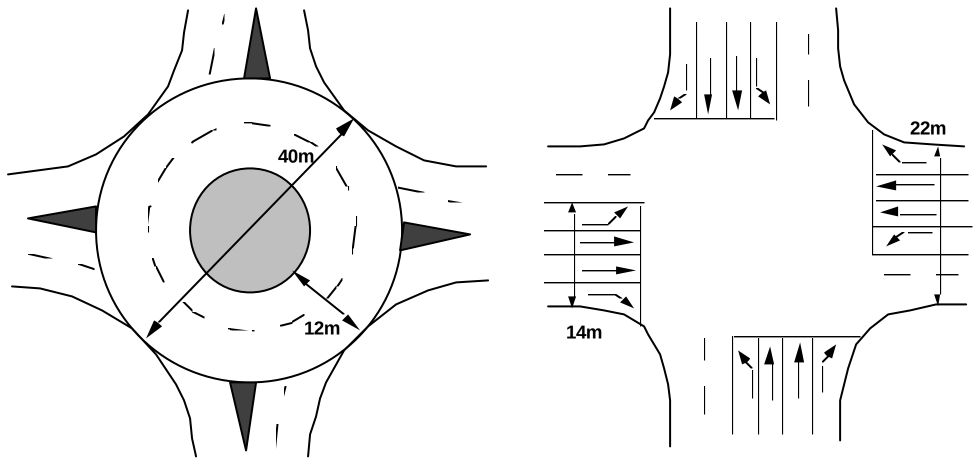

Fig.11 the roundabout design and the signalised intersection design at a big junction

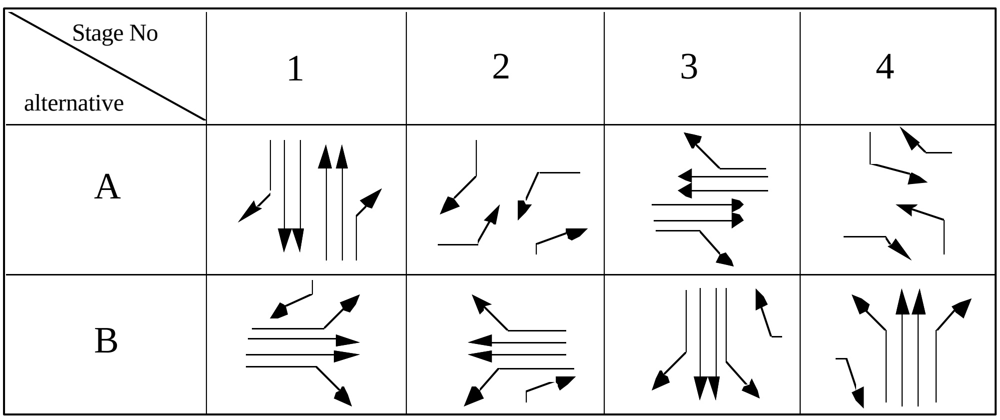

Fig.12 stage designs for the big signalised junction

Because $F = 1500$, $f=8/9$ and in this case $\kappa=1.6$, $\beta=0.6$, and $\alpha = 0.10$ ($L_{ba}= 23m$), then according to different values of R_h and R_L, the full capacity for the roundabout can be calculated by applying the formula of capacity developed in 2.

$$Q_{fcr} = 4F / \{ 1/\kappa +[\beta*(R_h + 2R_L)+ \alpha] *f\}$$

$$=6000/\{1/1.6 +[0.6*(R_h + 2R_L) + 0.10] * (8/9)\}$$

Now considering the full capacity of the signal intersection, as shown in Fig.11, there are 16 lanes at four entries and at least 4 phase must be introduced to separate the conflicts by time. Suppose the phases are designed as shown in Fig.12. There are two types of phase design and the full capacity for each cases are calculated as follows.

Case A:

In stage 1 and 3 there are six lanes facing the green and in phase 2 and 4 there are two lanes facing the green. Suppose $S = 1800$, $G_{ri} = 0.195$ ($i=1$ to 4, so $\Sigma G_{ri} = 0.78$) Therefore according to the formula (3.2).

$$Q_{fcs} = S \Sigma G_{rk}* N_{Lk} = 1800 * 0.195 *(6 + 4 + 6 +4) = 7020$$

Case B:

In each phase there are five lanes facing the green, suppose $S = 1800$, $\Sigma G_{ri} = 0.78$ then according to the formula (3.3).

$$Q_{fcs} = S * n * \Sigma G_{ri} = 1800* 5*0.78 = 7020$$

Now comparing the full capacity of the roundabout and that of the signal intersection

Suppose $Q_{fcr} > Q_{fcs}$

then

$$6000/\{1/1.6 +[0.6*(R_h + 2R_L) + 0.10] * (8/9)\} > 7020$$

By solving this inequality, we can obtain

$$R_h + 2R_L < 0.27$$

which is the condition of $Q_{fcr} > Q_{fcs}$.

It is quite clearly that in most cases the above conditions can't be satisfied. Fig.13 is the graphic representation of this condition. From this figure, it is easily find that in most cases, usually the full capacity of roundabout is less than that of signal intersection.

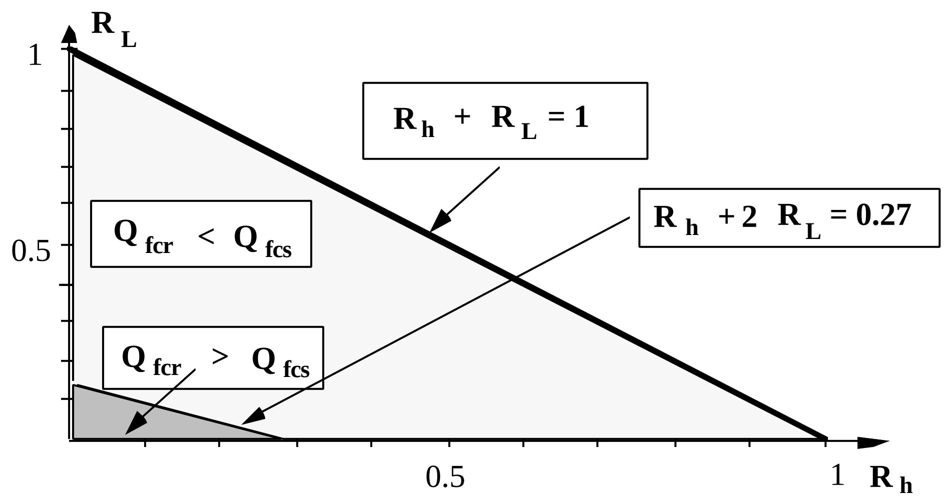

Fig.13 comparison of full capacity between the roundabout design and the signal intersection design for a big junction

5.Conclusions and further researches suggested

In order to compare the capacity of roundabouts and that of signal intersections, a concept of full capacity has been introduced and related formula for calculating full capacity have been developed both for roundabouts and signal intersections. It has been found that for a given geometric design, the full capacity of roundabouts depends heavily on the O-D traffic flow distribution at junctions, and the more vehicles turning left, the lower the capacity of roundabouts. By comparing full capacities of the roundabout design and the corresponding signalised intersection design at a mini-junction, a small junction, a moderate junction and a big junction, following interesting results have been obtained:

(1) at the mini-junction, the full capacity of roundabout design is always larger than that of signal intersection design;

(2) at the small junction, the full capacity of roundabout design is larger than that of signal intersection in most ordinary cases;

(3) at the moderate junction, the full capacity of roundabout is larger than that of signal intersection when the ratio of turning left and going ahead is relatively low, otherwise

the full capacity of signalised intersection design will be larger than that of roundabout design;

(4) at the big junction, the full capacity of roundabout is less than that of signal intersection in most ordinary cases;

It can be shown the same conclusions are also true for junctions with three branches. In this paper, the pedestrians and bicycles is not taken into account, further effort is needed to include especially the pedestrians crossing in the future researches. On the other side, in the formula of capacity of roundabout both for entry capacity and full capacity, the determination of coefficient 'β' and 'κ', which has great effect on the calculation of capacity of roundabout with the multi-lanes both at the circulating carriageways and at the entries, is needed to be further investigated.

References

Bovy Ph. (ed.) (1991) Guide Suisse des Giratoires. Lausanne, Suisse, 1991.

Center d'Etudes des Transports Urbains, (1988) Conception des carrefours a sens giratoire implantés en milieu urbain, Bagneux. Juillet 1988.

R. M. Kimber (1980) The traffic capacity of roundabouts, TRRL Report 942, Crowthorne 1980.

Tan Jian-an. (1997) Estimation of traffic queues and delays at roundabout entries, Third International Symposium on Intersections without traffic signals, Portland, Oregon USA. Jully 1997.

Tan Jian-an. (1993) Reserch on offside priority roundabout operations, Thesis no.1097. Swiss Federal Institute of Technology at Lausanne, 1993.

Tan Jian-an. (1991) A microscopic simulation model of roundabout entry operations, International workshop Intersections without traffic signals, Bochum, Germany. Jully 1991.

Tan Jian-an. (1991) Entry capacity formula in Switzerland, European Transport, Highways & Planning 19th Summer Annual Meeting, Sept.1991, Karlsruhe.

Transportation Research Board, National Research Council (1985) Highway capacity manual, special report 209, Washington, D.C. 1985.