TOMAŽ TOLLAZZI, D.Sc.
Fakulteta za gradbeništvo
Univerza v Mariboru
Institut prometnih ved
Maribor, Smetanova 17
Republika Slovenija

Science in Traffic
Preliminary Communication
U.D.C. 625.717.44:656.142+656.183
Accepted: Dec. 14, 1998
Approved: Feb. 18, 1999

REDUCTION OF THE ROUNDABOUT CAPACITY DUE TO A STRONG STREAM OF PEDESTRIANS AND/OR CYCLISTS

ABSTRACT

Single-lane roundabouts may face the problems of getting crowded and empty in their circulatory roadway due to a strong stream of pedestrians and/or cyclists.

Vehicles at the roundabout entries or exits have to provide the right of way over pedestrians and/or cyclists. Therefore, it comes to disturbances and traffic jams.

If there are jams at the entry carriageway, vehicles are unable to get into roundabouts. If there are jams at the exit carriageway, vehicles are not able to leave the roundabout. When the length of vehicle platoon at the exit is so long that it reaches the preceding entry, the roundabouts suffer from getting fully overcrowded.

The paper presents the methodology of calculating the reduction of the roundabout capacity due to the pedestrian or cyclist stream.

The method of calculating the reduction of the roundabout capacity with the disturbed streams may be used for roundabouts in urban environments, where the strength of the cyclist or pedestrian streams is not negligible.

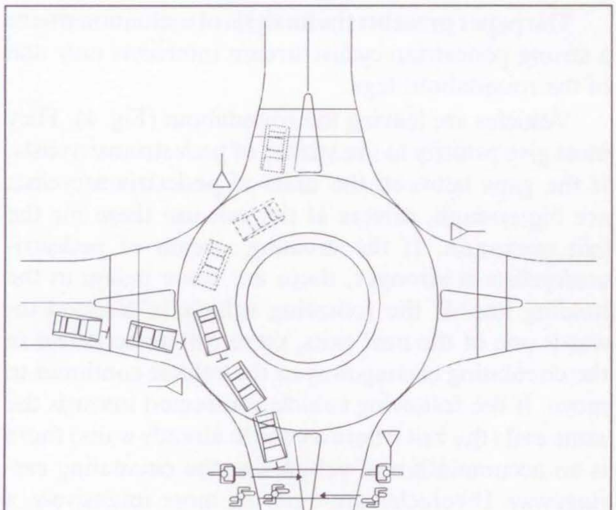

Figure 1 - Disturbed streams in roundabouts

KEY WORDS

roundabout, pedestrians and cyclists, roundabout capacity

1. INTRODUCTION

Single-lane roundabouts may face the problems of getting crowded and empty in their circulatory roadway due to a strong stream of pedestrians and/or cyclists. If the stream of vehicles is directed to the entry, it will be uncertain of reaching the minimum capacity. If the stream of vehicles is directed to the exit, the maximum capacity is exceeded (Fig.1)

To what extent does the strength of the pedestrian/cyclist stream influence the roundabout capacity or to what extent do the crossing streams of pedestrians and cyclists disturb the stream of vehicles?

Although there are mainly two problems (the problem of filling and the problem of emptying roundabouts), in reality they occur at the same time. The paper treats them separately in order to get a better explanation.

2. EMPTYING THE ROUNDABOUT

The stream of motor vehicles is directed to the roundabout exit and it is crossed by a strong pedestrian/cyclists stream (Fig. 2). When a strong pedestrian/cyclist stream crosses one of the roundabout legs, disturbances in vehicular flow at the first adjacent entry occur (opposite the traffic movement in the roundabout). It leads to vehicle delays.

If the strength of the pedestrian/cyclists stream increases, the flow disturbances are carried over to the next entry and entering or leaving the carriageway is possible only on remaining two quadrants. Accumulation of vehicles on one of the two remaining quadrants results in delays on all entries. Thus, the whole roundabout is totally blockaded.

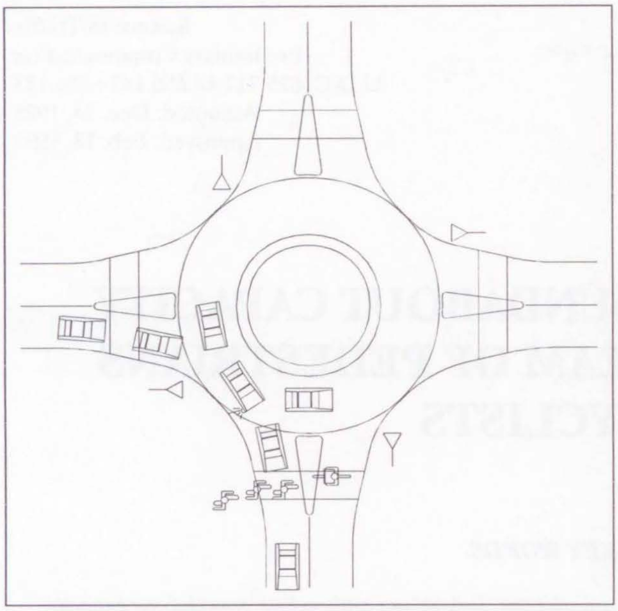

Figure 2 - Disturbances in vehicular flow at the first adjacent entry (opposite the traffic movement in the roundabout)

The blockade of a roundabout, which may or may not occur, depends on the strength of the traffic flow and on the way (distribution) how pedestrians or cyclists enter the roundabout.

3. FILLING THE ROUNDABOUT

Similar situation occurs when vehicles enter a roundabout. However, in this case vehicles are hindered twice (Fig. 3). Vehicles enter the roundabout leg which is intersected by a flow of pedestrians/cyclists.

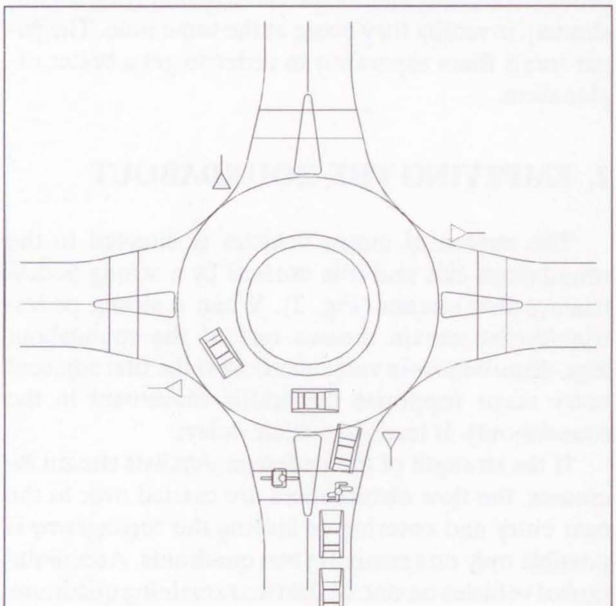

Figure 3 - Filling up the roundabout

Gaps between two successive pedestrians/cyclists are so long that vehicles at the entry use them and drive into the roundabout undisturbed. If there is no circulation carriageway in the roundabout or the gaps between vehicles in the circulation carriageway are big enough, vehicles drive into the carriageway undisturbed.

By increasing the flow of pedestrians/cyclists, gaps between traffic flow units decrease. There are situations when particular gaps are shorter than it is acceptable. In this case the vehicle is queued before pedestrian crossing. If the flow of pedestrians/cyclists is strong, a platoon of vehicles appear at the entry of the roundabout. A platoon also takes place at the entry if there is a strong circulation carriageway. In this case one vehicle delays between inscribed kerb of the circulation carriageway and the kerb of the pedestrian crossing, while other vehicles queue up at the entry of the intersection.

A delay at the roundabout entry occurs also in the case of the vehicles delay on a circulation segment which results from disturbed flows at the next roundabout exit.

4. EMPTYING AND FILLING THE ROUNDABOUT AT THE SAME TIME

In practice, there is usually a combination of both examples at the same time, that means the roundabout gets filled or emptied at the same time.

It is also usual that the intensive flow of pedestrians/cyclists intersects only one of the roundabout legs. However, there are occasions when a stream of pedestrians/cyclists intersects all the legs, the consequence of which is that the blockade occurs earlier.

The paper presents the analysis of a situation where a strong pedestrian/cyclist stream intersects only one of the roundabout legs.

Vehicles are leaving the roundabout (Fig. 4). They must give priority to the stream of pedestrians/cyclists. If the gaps between the units of pedestrians/cyclists are big enough, drivers at the exit use them for the exit operation. If the crossing stream of pedestrians/cyclists is stronger, there are some delays in the holding line. If the following vehicle is directed towards one of the next exits, there will be no delays in the circulating carriageway as the vehicle continues to move. If the following vehicle is directed towards the same exit (the exit where a vehicle already waits) there is an accumulation of vehicles in the circulating carriageway. If vehicles are entering more intensively, a platoon occurs. If the platoon of waiting vehicles stretches to the preceding entry, there are problems of filling the roundabout with vehicles at the preceding entry.

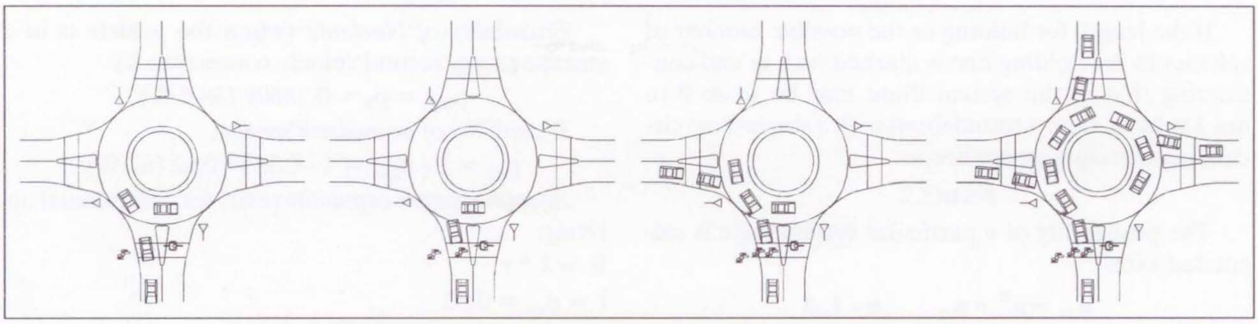

Figure 4 - Emptying and filling the roundabout at the same time

In a single-circulating roundabout with a storage place for one waiting vehicle three situations occur:

- Gaps between particular units of crossing stream satisfy the moving of the vehicles and there are no vehicles in the storage place
- Gaps between particular units of crossing stream still satisfy the moving of the vehicles although there are some delays with one vehicle.
- Gaps between particular units of crossing stream are too small, the storage place is occupied all the time and every entering vehicle queues in the circulating carriageway.

Theoretically seen, a rough estimation of the effects of the pedestrian and cyclist crossing traffic may be defined from the basic elements of the pedestrian movement and under condition that they enter the roundabout separately. Considering the average length of stride, the speed of walking and the width of the roundabout exit/entry, we can define the biggest number of pedestrians in a certain time interval.

5. CALCULATION OF THE REDUCED ROUNDABOUT CAPACITY DUE TO DISTURBED STREAMS

The problem of disturbed streams in roundabouts can be solved by using the theory of mass service, as a single channel open system.

The entering/leaving units (vehicles) into the system (roundabouts) are coincidental. The system is single-channelled, as at a certain moment only one unit (vehicle) may be serviced (crossing). The system is open as the units (vehicles) enter the system (the roundabout) from the surroundings (Fig. 5).

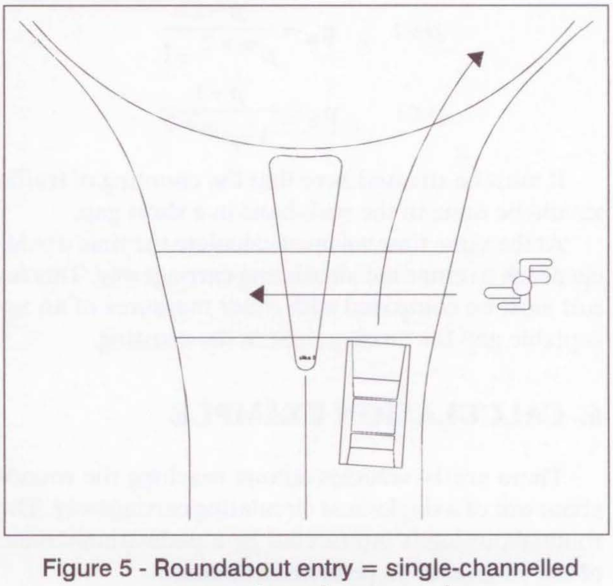

Figure 5 - Roundabout entry = single-channelled open system of mass service

The entering/leaving of the vehicles follows the Poisson's law of distribution, as the following is accomplished:

- the probability of entering/leaving of a vehicle $\mathbf{p_n(t)}$ depends on the length of gaps and the number of entering/leaving vehicles, and not from the beginning of its measuring,
- the probability of entering/leaving of a vehicle $\mathbf{p_n(t)}$ does not depend on the number of entering vehicles before gap measuring - flow without consequences,
- in a sufficiently long gap two or more vehicles cannot enter.

Stream disturbing may be defined with the factor of operation:

$$\rho = \frac{\lambda}{\mu}$$

where

λ is the intensity of entering vehicles at the entry/exit

μ is the operating intensity at the roundabout entry/exit

The value of the operating factor can be

$\rho < 1$ the stream of the vehicles is undisturbed

$\rho \geq 1$ the stream of the vehicles is disturbed

We define the criterion for the blockade of the roundabout exit with single-lane circulating carriageway:

The roundabout exit is blockaded in the case when a vehicle reaches the exit, but the vehicle that had reached it before has not left the holding line yet.

In this case we deal with a single-channelled system of mass operation with a limited holding line.

If the length for holding or the possible number of vehicles in the holding line is marked with **m** and considering that in the system there may be from 0 to m+1 vehicle, then a roundabout with a single-lane circulating carriageway applies as:

$$\mathbf{0 \le m \le 2}$$

The probability of a particular system state is calculated with:

$$\mathbf{p_n} = \rho^{\mathbf{n}} * \mathbf{p_o} \qquad \mathbf{n = 1, 2}$$

while $\mathbf{p_o}$ depends on the value of the operation factor.

$$\rho > 1 \qquad \mathbf{p_o} = \frac{\rho - 1}{\rho^{m+2} - 1}$$

$$\rho \le 1 \qquad \mathbf{p_o} = \frac{\rho - 1}{1 - \rho^{m+2}}$$

It must be stressed here that the counting of traffic should be done in the rush hour in a short gap.

At the same time we must calculate the time a vehicle needs to enter the circulating carriageway. This result must be compared with other measures of an acceptable gap for turning right in the crossing.

6. CALCULATION EXAMPLE

There are 14 vehicles/minute reaching the roundabout exit of a single-lane circulating carriageway. The roundabout leg is intersected by a pedestrian stream of the volume of 12 pedestrians/minute.

Permeability of the roundabout exit or the disturbance stage of vehicle stream should be determined.

Operation factor:

λ = 14 vehicles/minute - the intensity of entering vehicles

μ = 12 pedestrians/minute = 5 seconds/pedestrian

A vehicle needs 5 seconds to leave the roundabout, it means that drivers use gaps between pedestrians for leaving the roundabout.

$$\rho = \frac{\lambda}{\mu} = 14/12 = 1.167$$

$\rho > 1$ delays - disturbed streams

In the storage place there is a space for one vehicle to wait (m=1):

$$\rho > 1 \qquad \mathbf{p_o} = \frac{\rho - 1}{\rho^{m+2} - 1}$$

$$\mathbf{p_o} = \frac{\rho - 1}{\rho^{m+2} - 1} = \frac{1.167 - 1}{1.167^3 - 1} = \frac{0.167}{0.589} = 0.2835$$

$$\mathbf{p_1} = \rho^1 * \mathbf{p_o} = 1.167 * 0.2835 = 0.3308$$

$$\mathbf{p_2} = \rho^2 * \mathbf{p_o} = 0.38609$$

The control:

$\sum p = 1$;

$p_o + p_1 + p_2 = 0.2835 + 0.3308 + 0.38609 \cong 1$

Probability of blockade (when the vehicle is in a storage place, second vehicle comes into it):

$$p_{bloc} = p_2 = 0.38609 \ (38.6\ \%)$$

Probability of immediate service:

$$p_{ser} = 1 - p_{bloc} = 1 - 0.38 = 0.62 \ (62\ \%)$$

Absolute system capability (exit) for coincidental arriving:

$R = \lambda * r$

$r = p_{ser} = 0.62$

R = 14 vehicles/minute * 0.62 = 8.68 vehicles/minute

Because of the gaps, caused by in store placewaiting vehicle (giving preference to pedestrians) at the moment, when second vehicle is coming to the roundabout exit, the actual capacity of the system (exit from roundabout) will be 62%.

When the intensity of pedestrian flow is such that drivers could not make use of the time between two subsequent pedestrians, the absolute capacity of the exit will be 0 and the exit completely blocked.

7. CONCLUSION

In calculating the actual capacity of a roundabout with a single-lane entry, a single-lane circulating carriageway and with a strong cross stream of pedestrians and cyclists, it is necessary to take into consideration the decrease of the roundabout capacity due to disturbed flows at the roundabout entries and exits.

Disturbed flows appear when the pedestrian/cyclist stream is strong and the gaps are too small to enable the vehicles to pass. Vehicles at the roundabout entries and exits have to give way to pedestrians/cyclists. Therefore, there are disturbances in flows and delays.

The stage of disturbance depends on mutual relation and volume of vehicle flows and pedestrians and/or cyclists.

POVZETEK

V krožnih križiščih z enim voznim pasom v krožnem toku lahko, zaradi močnega toka pešcev in/ali kolesarjev, nastopajo problemi polnjenja in praznjenja krožnega križišča.

Vozila na vhodih/izhodih v krožno križišče morajo pešcem/kolesarjem odstopiti prednost. Vsled tega prihaja do oviranosti tokov in zastojev.

V primeru, da do zastojev prihaja na vhodu, vozila ne morejo uvažati v krožno križišče. V primeru, da do zastojev prihaja na izhodu, vozila ne morejo zapuščati krožnega križišča. V primeru, ko je dolžina vozil v koloni na izhodu iz krožnega križišča tako dolga, da doseže predhodni vhod, prihaja do problemov s polnjenjem krožnega križišča.

V prispevku je prikazana metodologija izračuna zmanšjanja kapacitete krožnega križišča zaradi tokov kolesarjev in pešcev.

Metodologija izračuna zmanjšanja kapacitete krožnega križišča s pomčojo oviranih tokov je uporabna pri krožnih križiščih v urbanih sredinah, kjer so jakosti prometnih tokov kolesarjev in pešcev nezanemarljive.