

CAPACITY OF A TURBO-ROUNDAABOUT DETERMINED BY MICRO-SIMULATION

Ir. Isaak Yperman and Prof. Ir. Ben Immers

Katholieke Universiteit Leuven
Department of Civil Engineering - Transportation Planning and Highway
Engineering
Kasteelpark Arenberg 40, 3001 Leuven (Belgium)
Phone: +32 16 32 96 14 / Fax: +32 16 32 19 76
E-mail : isaak.yperman@bwk.kuleuven.ac.be
E-mail: ben.immers@bwk.kuleuven.ac.be
<http://www.kuleuven.ac.be/traffic>

SUMMARY

On a turbo-roundabout, traffic streams are separated into separate lanes before they arrive at the roundabout and they stay in lane on the roundabout itself. This principle highly benefits roundabout capacity. To accurately assess the capacity of a turbo-roundabout, one can use a calibrated micro-simulation model. By adjusting the simulation parameters, the model is calibrated such that the capacity of a classical roundabout in the model corresponds to the capacity according to the Bovy formula, which is considered to represent reality.

INTRODUCTION

In 1997, turbo-roundabouts were presented for the first time by Fortuijn and Harte (1). Six years later, more than a dozen of these new roundabouts already have been constructed and are in use on the Netherlands roads network.

Turbo-roundabouts are thought to have a higher capacity, compared to the classical multi-lane roundabouts. This study examines this hypothesis, after setting up a method to determine the capacity of a turbo-roundabout. We start by explaining the principle of a turbo-roundabout.

Principle of a turbo-roundabout

On a turbo-roundabout, traffic streams are separated into separate lanes before they arrive at the roundabout and they stay in lane on the roundabout itself. The different lanes on the roundabout are physically separated, preventing traffic from weaving. This separation is interrupted there where the approaches give on to the roundabout. Vehicles on the approaches give way to vehicles on the roundabout.

Once a traveller finds himself on the turbo-roundabout, his further route is fixed. Therefore, travellers have to choose their lane on the approaches to the roundabout. They are informed in advance by arrow marking, signposts and lane selection signs. Turbo-roundabouts have a very specific shape to accomplish this splitting of traffic streams.

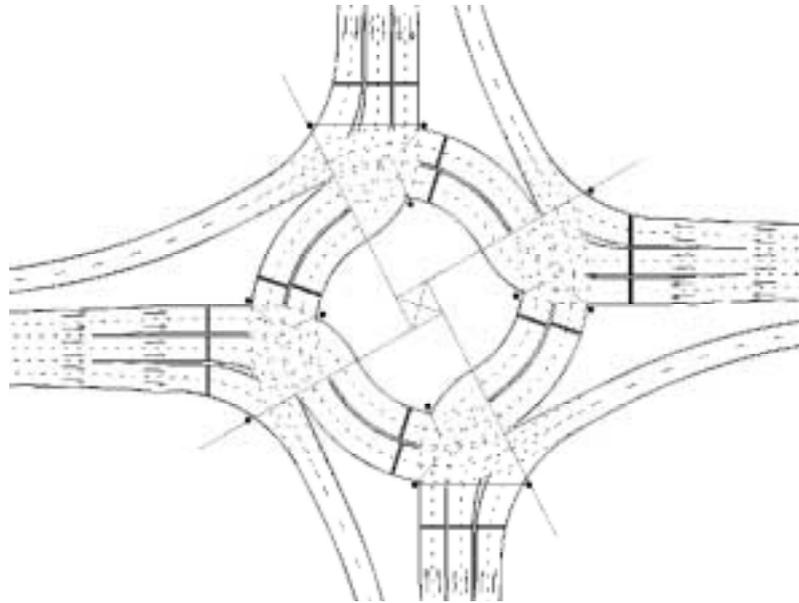


Figure 1: Turbo-roundabout

Four axes of translation meet each other in a central square (2). When a vehicle passes an axis, it has to ride an arc with a larger radius. For example, a vehicle that goes to the left, has to take the interior lane after passing a first axis of translation. One quarter of a roundabout further, it passes a second axis of translation and it now has to take the exterior lane. Another quarter of a roundabout further, it once again passes an axis and it now leaves the roundabout.

This way, the turbo roundabout forces the driver smoothly and comfortably towards the exit fork that he had to choose on the approach.

CAPACITY OF A ROUNDABOUT

Capacity determined by formulas

Empirical formulas are traditionally used to assess the capacity of a roundabout (3). The empirical method is based on measurements on existing roundabouts with one or more approaches saturated. A mathematical relation between the intensity of conflicting traffic before such an approach (Q_{co}) and the capacity of that approach (C_{en}) is derived out of these measurements. Thereby, a number of geometric characteristics are taken into account.

In 1980, Kimber found a linear relation between Q_{co} and C_{en} . In 1986, Cetur came up with a formula, also based on this linear relation. In 1991, the Cetur formula was slightly adjusted by Bovy (4) into:

$$C_{en} = \frac{1500 - \frac{8}{9} Q_{co}}{\gamma}$$

$$Q_{co} = \beta Q_{ci} + \alpha Q_{ex}$$

where

- C_{en} = capacity of the approach (pae/h)
- Q_{co} = intensity of the conflicting traffic before the approach (pae/h)
- Q_{ci} = intensity of the circulating traffic at the approach itself (pae/h)
- Q_{ex} = intensity of traffic leaving the roundabout at the approach (pae/h)
- α = factor that takes into account the influence of Q_{ex} on C_{en}
- β = factor that takes into account the number of lanes on the roundabout
- γ = factor that takes into account the number of lanes on the approach

The reduction factors α , β and γ are defined as follows:

Reduction factor α

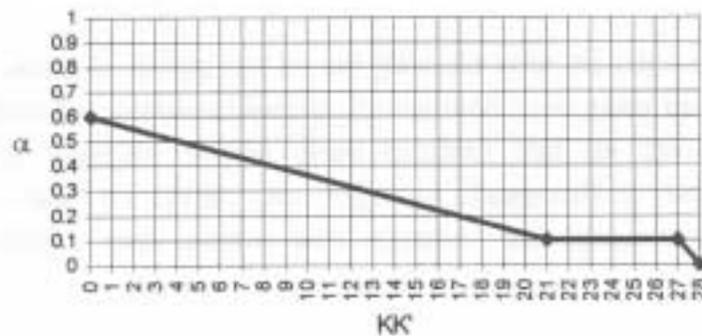


Figure 2: Definition of α

where KK' is the distance in meters, illustrated in the following figure:

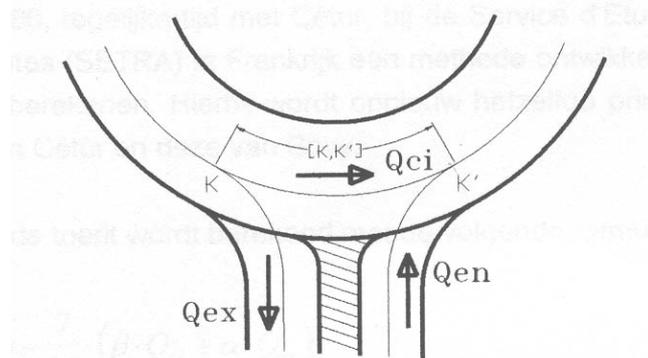


Figure 3: Method of Bovy

Reduction factor β

1-lane roundabout: $0,9 \leq \beta \leq 1$

2-lanes roundabout: $0,6 \leq \beta \leq 0,8$

3-lanes roundabout: $0,5 \leq \beta \leq 0,6$

Reduction factor γ

1-lane approach: $\gamma = 1$

2-lanes approach: $0,6 \leq \gamma \leq 0,7$

3-lanes approach: $\gamma = 0,5$

The Bovy formula defines the capacity of an approach to a roundabout.

The capacity of the roundabout itself can be defined as the total traffic using the roundabout ($= \sum_i Q_{en}(i)$), when only one approach is saturated.

The global capacity of a roundabout can be defined as the total traffic using the roundabout ($= \sum_i Q_{en}(i)$), when all approaches are saturated (3).

Capacity determined by micro-simulation

The microscopic traffic model Paramics

In the microscopic simulation model Paramics, the individual drivers and vehicles are dealt with separately (5). The driver- and vehicle characteristics at time $t + \Delta t$ are calculated according to their characteristics at time t . In this way the positions and speeds (among others) of all vehicles are computed. In contrast to macroscopic dynamic models, it is easier to specify different types of vehicles and drivers.

Besides the vehicles, dynamic characteristics pertaining to the infrastructure system, such as traffic lights, weather conditions and accidents, can also be modelled. The user-friendly nature and the numerous parameters of this microscopic model allow for a realistic representation of the traffic system (6).

Calibration

To guarantee a realistic representation of the traffic system, the microscopic model needs to be calibrated. Paramics contains a number of simulation parameters that determine the simulation progress (5). The model is calibrated by adjusting these parameters such that traffic streams in the model correspond to traffic streams in reality. There are many parameters that determine the simulation progress, but in this study, we only use two of them: the mean driver reaction time (MDRT) and the mean target headway (MTH). The smaller the values of these parameters, the smoother the circulation flow and the higher the capacity. Theoretically, even only one parameter would be enough to calibrate the simulation model. The two chosen parameters have a great influence on the simulation progress, making the calibration process easier.

For roundabouts, the objective is to equalize the capacity of the approaches in the model to their capacity in practice. The latter can be represented by the formula of Bovy, since this formula is in agreement with field measurements (3). The capacity of the approaches in the model should thus be brought in agreement with the capacity defined by the formula of Bovy.

Determining simulation parameters and global capacity

We construct a classical three-lane roundabout in Paramics.



Figure 4: Classical three-lane roundabout in Paramics

Priority rules are defined such that vehicles on the approaches give way to vehicles on the roundabout. At the end of an approach, traffic has to filter. Drivers turning to the left use the leftmost lane of the approach and so on. However, as happens in practice, not all drivers turning to the left, will use the interior roundabout lane. Some drivers will take the middle lane or even the exterior lane to reach their exit fork. These lanes are more attractive, because they don't require too much weaving, when leaving the roundabout. Likewise, some drivers going straight on will choose the exterior roundabout lane.

A traffic demand high enough to saturate each approach is released on to this roundabout. Traffic consists of vehicles that all have the same characteristics.

A first simulation is carried out with all simulation parameters set to their standard values within Paramics. The capacity of the approaches in the model can be measured and compared to the capacity according to the Bovy formula. The geometry of the constructed roundabout determines the reduction factors in the Bovy formula. In this case, the applied values are: $\alpha=0.2$, $\beta=0.55$ and $\gamma=0.5$.

A next simulation is then carried out with adjusted simulation parameters in order to closer approximate the Bovy capacity. This process continues, up to the point where the capacity of the approaches in the model has converged to the capacity according to Bovy. Table 1 shows an overview.

Table 1: Capacity of the approaches (pae/h) in the model and according to the Bovy formula

MDRT and MTH (s)		1	0.9	0.85	0.8	0.75	0.7
northern approach	Cen,model (pae/h)	1221	1282	1271	1325	1290	1357
	Cen,Bovy (pae/h)	1354	1362	1315	1292	1288	1262
	proportional dev (%)	-9.8	-5.9	-3.3	2.6	0.2	7.5
eastern approach	Cen,model (pae/h)	1299	1289	1408	1347	1406	1440
	Cen,Bovy (pae/h)	1392	1371	1407	1353	1364	1326
	deviation (%)	-6.7	-6.0	0.1	-0.4	3.1	8.6
southern approach	Cen,model (pae/h)	1280	1261	1244	1330	1299	1357
	Cen,Bovy (pae/h)	1417	1341	1335	1327	1312	1306
	deviation (%)	-9.7	-6.0	-6.8	0.2	-1.0	3.9
western approach	Cen,model (pae/h)	1304	1384	1390	1385	1425	1407
	Cen,Bovy (pae/h)	1423	1390	1373	1424	1357	1298
	deviation (%)	-8.4	-0.4	1.2	-2.7	5.0	8.4
mean square dev (%)		8.7	5.1	3.8	1.9	3.0	7.4

Table 1 shows that the capacities according to the Bovy formula can be approximated very closely by micro-simulation. When the parameters MDRT (mean driver reaction time) and MTH (mean target headway) both equal 0.8 s, the proportional deviations vary between 0.2% and 2.7%. The mean square deviation equals 1.9%.

We conclude that a calibrated micro-simulation model is able to accurately assess the capacity of a classical roundabout.

For these simulation parameters, the global capacity of a classical three-lane roundabout equals 5387 pae/h.

CAPACITY OF A TURBO-ROUNDAABOUT

Capacity determined by micro-simulation

As mentioned above, we constructed a classical three-lane roundabout in the micro-simulation model Paramics and then we calibrated this model in order to simulate realistic traffic flows.

Now, we construct a two-lane turbo-roundabout, where drivers cannot choose anymore which lane they take on the roundabout, but where they are forced to take the lanes that the turbo-roundabout imposes upon them. In the same simulation model, we use the same types of construction elements to build up this roundabout, the same priority rules, the same types of vehicles and driver characteristics and the same simulation parameters. Therefore, we assume that the same calibrated simulation model is also able to accurately assess the capacity of this kind of roundabout.



Figure 5: Turbo-roundabout in Paramics

Comparison of capacity

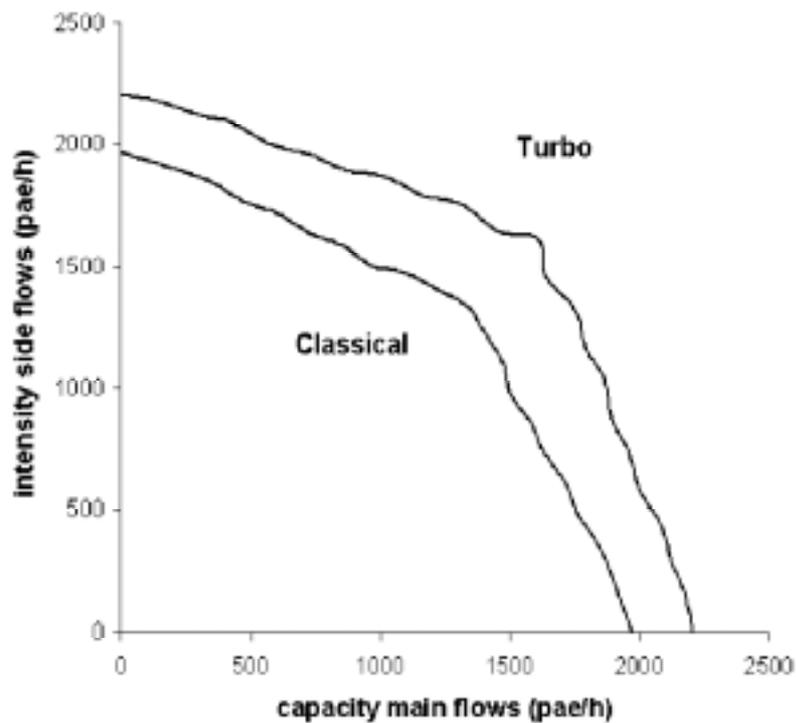


Figure 6: Comparison of capacity determined by micro-simulation

The side flows are the flows on the eastern and western approaches, the main flows those on the northern and southern approaches. The flow pattern is chosen as follows: for the two opposite approaches that have the lightest flows, these flows are imposed and the volumes are equal for all three turning directions. For the other two opposite approaches, the maximum flows are measured. They do not necessarily have the same volume for all three turning direction.

For the given flow pattern, figure 6 shows that the global capacity of a two-lane turbo-roundabout exceeds the global capacity of a classical three-lane roundabout by 12%, when the intensity of the side flows equals zero, up to 20 %, when the intensity of side and main flows are equal.

The forced use of the inside roundabout lanes has a huge impact on the global capacity of the turbo roundabout. On a classical multi-lane roundabout, the outside lane is much more attractive than the inside lanes, because from the outside lane, there is no need to weave, when leaving the roundabout. On a turbo roundabout, there are no weaving movements, and the inside lanes are used much more efficient.

Besides, on a turbo roundabout, the traffic driving on to the roundabout is no longer uncertain about possible lane changes of traffic on the roundabout, so the capacity from the approaches is higher (1).

Figure 6 also clarifies that the global capacity of both a roundabout and a turbo-roundabout rises, when the intensities of the four approaches are closer to each other. For a classical roundabout, when traffic is equally distributed among the four approaches, the capacity is 35% higher, compared to a distribution where the intensity of side flows equals zero. For a turbo-roundabout, this percentage rises up to 45%.

DISCUSSION

Usefulness of the suggested method

To determine the capacity of turbo-roundabouts more directly, one could also derive capacity formulas out of existing empirical formulas for classical roundabouts. However, some problems may rise, using that procedure. First of all, capacities are highly dependent on the geometry of the roundabout and turbo-roundabouts can occur in all kinds of weights and measures. Secondly, many field measurements would be necessary to determine the coefficients in the formulas. For the time being, there are too little turbo-roundabouts of the same kind in existence, to collect such field measurements.

For capacity assessments by micro-simulation, every new design has to be brought into the simulation model, and different simulations have to be carried out to determine the capacity. This process takes some time, but the advantage is that every aspect concerning geometry can be taken into account and that no formulas have to be derived.

We conclude that our method is suitable for a capacity assessment of roundabouts not having the typical shape of a classical roundabout.

Method assumptions

In our method, we assume the Bovy formula to give a good representation of reality. Observations on five Belgian roundabouts with different numbers of lanes, all showed good correspondence with the Bovy formula. In all cases, a proportional deviation of 2% was never exceeded (3). The method of Bovy gives good results in normal weather conditions.

It is necessary, however, to point out that the Bovy method only takes into account a few geometric characteristics and does not take into account weather conditions, nor the slope of the approach, nor possible blocking at the exit forks.

The results of a calculation are indicative and should be interpreted with care.

Also, the Bovy formula does not take into account the influence of cyclists and pedestrians. This influence is not easy to determine. A possible way would be to add these road-users to the motorised traffic, using a suitable equivalence coefficient.

We also assumed traffic to be homogeneous in our simulation model. Traffic consists of vehicles that all have the same characteristics. What if we would define another population of cars, where vehicles would have other characteristics? In that case, to accomplish the correspondence between model capacities and Bovy capacities, the simulation parameters would have to be adjusted. Once this is done, the re-calibrated simulation model will be able to accurately assess the capacity of the turbo-roundabout, if the composition of traffic is the same in the simulation model, both for the classical roundabout and the turbo-roundabout.

Cost benefit analysis

When (re)designing a crossroad, it's clear that a full cost benefit analysis should be carried out. This study mainly looks at capacities. Of course, in a full approach, traffic safety, livability, construction costs, use of space, ... should also be taken into account.

In this study, we compared a classical three-lane roundabout with a two-lane turbo-roundabout, because they are very comparable as far as use of space and construction costs are concerned. Not only in capacity, but also in terms of traffic safety and livability, we think the turbo-roundabout to have an advantage as compared to a classical multi-lane roundabout.

The absence of weaving traffic increases the predictability of traffic manoeuvres. Travellers are in no doubt about the intentions of other travellers. Therefore, motorised traffic as well as cyclists and pedestrians find themselves in a much safer situation, as compared to a classic multi-lane roundabout.

Turbo-roundabouts have the additional advantage that they contain lesser possible points of conflict. This also benefits traffic safety.

Extensions

This study only compares the calculated capacities for one specific case: the capacity of a classical three-lane roundabout is compared to that of a two-lane turbo-roundabout with the particular shape, defined in figure 5. Besides, while calculating capacities, we assumed a particular volume pattern of side flows and main flows.

This specific case should be seen as an example. The suggested method can easily be extended to cases with different flow patterns, different shapes of roundabouts, even to different types of crossings, like junctions with traffic lights, or even turbo-circuits with traffic lights (7). The method can be applied to whatever case a designer might want to consider.

Reliability

Designers of roundabouts should be aware that they have to take into account a certain reserve capacity. For a smooth traffic handling on the roundabout, the intensity of traffic should not exceed 90% of the capacity (3). If the roundabout is a part of a network that needs to be robust and reliable, an even higher reserve capacity is recommended.

CONCLUSIONS

By adjusting the simulation parameters, a micro-simulation model can be calibrated such that traffic streams in the model correspond to traffic streams in reality.

The capacity of a classical roundabout in the calibrated model shows good correspondence to the capacity according to the Bovy formula, which is considered to represent reality.

The calibrated model can then be used to accurately assess the capacity of a turbo-roundabout. For this type of roundabout, capacity assessment by micro-simulation is a suitable method.

For the given flow pattern, the global capacity of a two-lane turbo-roundabout exceeds the global capacity of a three-lane classical roundabout by 12 to 20%. Capacity is at its highest, when traffic is equally distributed among the four approaches.

REFERENCES

- (1) Fortuijn L.G.H. and Harte V.F., 'Multi-lane roundabouts: exploring new models', Traffic Engineering Working Days 1997, CROW, Ede.
- (2) de Leeuw A.M., Province of South Holland, Specification Turbo circuits (working paper in Dutch), Den Haag, 2001.
- (3) Flemish Ministry of Traffic, Vademecum Roundabouts (in Dutch), Brussels, 1997
- (4) Nissens H. and Welvaert G., Methods to assess the capacity of roundabouts (in Dutch), Gent, 1998
- (5) Quadstone, Paramics V4.0 System Overview, Quadstone Limited, Edinburgh, 2002
- (6) Logghe S. and Immers L.H., 'Representation of traffic shock waves in micro-simulation models', proceedings of the 7th World congress on ITS, Turin, 2000
- (7) Yperman I., Analysis and Optimisation of traffic handling on the Avenue King Boudewijn in Leuven (in Dutch), Leuven, 2002