THE ANALYSIS OF PEDESTRIANS STREAM ON THE ROUNDABOUT CAPACITY USING MICRO-SIMULATION MODEL

Tomaž Tollazzi[1], Tone Lerher[2] and *Matjaž Šraml[1]

[1]University of Maribor, Faculty of Civil Engineering,
2000 Maribor, Smetanova 17, Slovenia
[2]University of Maribor, Faculty of Mechanical Engineering
2000 Maribor, Smetanova 17, Slovenia

**sraml.matjaz@uni-mb.si (Matjaz Šraml)*

Abstract

The use of modern roundabouts as a viable traffic control measure instead of traffic light or priority intersections is increasing over the past decades. Their strength lies in their ability to reduce the number of vehicular conflicts at intersections and thereby enhance the intersection capacity and safety. In the past, many authors have used different ways of determining the capacity of roundabouts and different approaches of determining the influence of the stream of non-motorised traffic flow on the capacity of a roundabout. The main purpose of this paper is to analyse the influence of the strong pedestrian stream and circulated stream of motorised vehicles on the capacity of the one-lane roundabout. The observed area of traffic flow is a representative part of roundabouts where the strongest traffic flows occur. An approach is suggested for dimensioning roundabouts with modelling traffic flows, using the discreet simulation method and considering the statistically evaluated entry data for motorised vehicle and pedestrian stream. The presented model derives from the expected time void in the vehicular traffic flow, used by the pedestrians, presuming their priority when joining the traffic. The simulation analysis has been performed on a roundabout in Maribor, where measurements of motorized vehicle traffic flow and pedestrian traffic flow had taken place.

Keywords: Roundabouts, Traffic analysis, Micro-simulation modelling, Performance analysis.

Presenting Author's biography

Matjaž Šraml is a docent, holding Ph.D degree of mechanical engineering (2001), working on the Faculty of Civil Eng. and Faculty of Mechanical Eng., University of Maribor. His habilitation refers to pedagogical topic of "Traffic technique" and "Devices, systems and constructions for transport". He has been included in applicable and fundamental projects. He is a principal researcher of international bi-lateral projects and also participates in some other international projects. He is also a member of several professional associations and he is author and co-author of original scientific, scientific and technical articles in the field of his habilitation, refers to simulation of material flow, logistics and transport analysis, analysis of technical systems.

1 Introduction

In one-lane roundabouts, problems with entering and exiting the roundabout can occur due to large pedestrian flows. Vehicles on entries and exits should give priority to pedestrians. For this reason, disturbances occur in the main vehicle flow, considered as a priority when dimensioning a roundabout intersection and its capacity for the resulting congestions [1]. When a flow of vehicles, traversed by pedestrians, is oriented towards an entry, achieving the minimum capacity of the roundabout becomes questionable. When a flow of vehicles, traversed by pedestrians, is oriented towards an exit, the maximum capacity gets exceeded [2, 3]. The possibility of a roundabout blockage can occur in several ways. In the past, many authors [4, 5] have used different ways of calculating the capacity of roundabouts and different approaches for determining the influence of the non-motorized traffic flow on the capacity of a roundabout. The common feature of all approaches is an abundance of mathematical calculations [6] and simplifications to make the calculation possible in the first place. This is why this kind of calculation has been used in exceptional cases only. Among the simpler methods, where only a diagram or one equation are used, are the German method for determining the influence of pedestrians [7] and the Dutch method for determining the influence of cyclists [8] on the capacity of a one-lane roundabout.

Several analytical and micro-simulation models offer variants of roundabout analysis based on either the gap acceptance or empirical approaches. Yet further calibration work under various operating conditions is still required in order to confirm their reliability [9]. Examples of such codes are SIDRA, RODEL, VISSIM, SYNCHRO, PARAMICS etc. RODEL is an empirical model based on empirical studies [9]. SIDRA [10, 11, 12] was developed primarily for Australian operating conditions but has been expanded to include the United Kingdom (UK) regression equations as well as various gap acceptance models. One of the main advantages is also that it incorporates all Highway Capacity Manuel (HCM) [10, 11, 12] standards/defaults and could be adopted for almost all traffic problems around the world. Roundabout analyses in the VISSIM and SYNCHRO follow the HCM approach and are insensitive to the geometric features [9]. The analysis in PARAMICS is based on the gap acceptance approach and it takes into account some roundabout geometric features. The Paramics model is an advanced micro-simulation tool with the ability of modelling both roundabouts and traffic signals at an acceptable level of detail. The motion of an individual vehicle is simulated in small intervals and each vehicle is being followed from the time it enters the network to the point of its exit. A drawback is that it is one-lane based model, whereby it is not possible to influence the entry width.

In contrast to the abovementioned computer codes, for the present analysis, the discreet simulation code AUTOMOD [13] has been used. Although the chosen code is not specialised for traffic simulation, the discrete simulation algorithm is very efficient for analysing different situation events. The proposed model derives from the expected time void in the pedestrian traffic flow, used by vehicles for entering and exiting the roundabout, presuming their right of way when joining the traffic. The geometry of the roundabout is carefully modelled, whereby all the necessary data are taken into account. Furthermore, the measured data relating to the pedestrian and vehicle flow have been determined by counting subjects in an authentic roundabout. Afterwards the simulation model has been verified for the measured values and the discreet model.

The main purpose of this study is to analyse the influence of the strong pedestrian stream on the capacity of the one-lane three-armed roundabout, using the discreet numeric simulation modelling. The presented model derives from the expected time void in the pedestrian traffic flow, used by the vehicles for entering and exiting the roundabout, assuming their right of way when joining the traffic. In the proposed model a separate approach to the roundabout is considered, with the influence of the circulating flow of vehicles on the circulatory carriageway (see Fig. 1). The restrictions of the model are: the constant average velocity of all pedestrians; the constant average velocity of personal car units (PCU), without any respect to the driver behaviour. The arrivals of PCU from the main arm line flow are generated by using an exponent distribution of the counted traffic flow, assuming a normal PCU flow. Also the circular flow of PCU in the roundabout is considered, which presents an additional disturbance for the main flow of PCU. The origin of pedestrians and their arrivals are defined with a multi-channel flow instead of the flow in a column.

The simulation analysis was verified on a real example of a roundabout in Maribor, where all the necessary traffic-flow measurements were made. The procedure, shown in the article, along with the scientific approach to mathematical modelling, presents an instrument that is helpful when deciding how reasonable it is to implement a roundabout in the case of strong pedestrian flows.

2 Problem description

When defining the reduction of the roundabout capacity because of the pedestrian flow crossing the arm of the roundabout, two different samples can be distinguished. In the first case, the traversing pedestrian flow influences the capacity of the roundabout, but it still works. In the second case, the influence of the pedestrian flow is so large that bottlenecks on roundabout entry and exit are possible, which could also be extended to the adjacent roundabout arms.

The abovementioned problems of entering and exiting a roundabout normally appear simultaneously in a real situation. Under real circumstances it is also usual for the intensive pedestrian flow to traverse only one arm of the roundabout, although in some cases the pedestrian flow traverses all arms at once. In these cases the blockage of the roundabout is easier to occur.

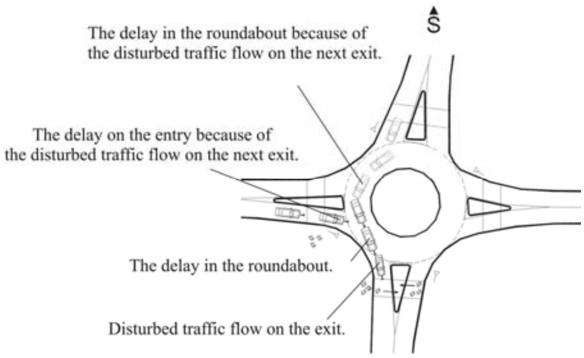

Fig. 1 Queue formation in a roundabout [3]

In the following section, an example of roundabout where the strong pedestrian flow traverses only one arm is described in order to make it easier to explain. The priority pedestrian flow traverses the (southern) arm of the roundabout (Fig. 1). Time interspaces between two consecutive pedestrians are long enough; therefore the vehicles exiting the roundabout make use of them and exit the roundabout without disruption. The vehicle flow on the exit is stable in this case.

With an increase in pedestrian flow, time interspaces between traffic flow units are reduced. Occasionally situations occur where individual time interspaces between pedestrian flow units are shorter than is acceptable. In these cases the vehicle waits in the waiting place between the outside edge of the circulatory roadway and the inside edge of the pedestrian crossing. The flow is still stable, but occasionally disrupted.

The blockage is transferred from the exit towards the preceding entry to the roundabout (inversely to the direction of driving) and from here towards the preceding exit. The entire procedure can occur again and again in the inverse direction of driving until the roundabout is completely blocked.

In the one-lane roundabout with waiting space for one vehicle only the following three situations can generally occur in the waiting place between pedestrian crossing and the outer edge of the circulatory carriageway:

- time interspaces between individual units of the traversing pedestrian flow are sufficient for the vehicle flow, therefore there are no waiting vehicles in the waiting place;
- time interspaces between individual units of the traversing pedestrian flow are still sufficient for the vehicle flow, although vehicles do wait in the waiting place;
- time interspaces between individual units of the traversing pedestrian flow are not large enough, the waiting place is occupied all the time and every next vehicle waits in the circulatory roadway.

How many times these situations occur, what are the conditions for the occurrence of these situations, what conditions have to be fulfilled for a blockage of one roundabout arm and at what traffic load of pedestrians or motorised traffic flow the disturbance is transferred from one to another arm are the questions, the answers to which determine the influence of the pedestrian flow on the capacity of the one-lane roundabout.

It is obvious that so complex influences and mutual actions of different variables cannot be solved without appropriate mathematical models or discreet simulations of motorised and non-motorised traffic flow. In the following chapters the methodology and simulation of traffic flow in a given roundabout is presented.

3 Methodology

According to discreet models [10, 11, 12, 14, 15 and 16] and the traffic movement, simulation methods can be generally divided into two groups, (*i*) macroscopic and (*ii*) microscopic models. Macroscopic models combine vehicles and travelling among groups, the traffic flow is presented as a statistical model; the results are presented as the average value after certain time. With macroscopic models the emphasis is laid on the links, intersections are simplified in the model. Unlike microscopic models, macroscopic models focus on a long-term planning period. With microscopic models every vehicle, pedestrian, cyclist, etc. can be described with real characteristics (dimension, velocities, accelerations, decelerations, etc.). Microscopic models are used for traffic flow analyses in a short-term planning period.

Considering the complexity of the analytical model of the roundabout and the application of the discreet simulation technique, a discreet event simulation was used for the analysis of the flow capacity of the observed area of the roundabout. In this article, a special program tool AutoMod [13] has been used for the flow capacity analysis of the roundabout. AutoMod [13] is mostly used to implement discreet numeric simulations of internal logistic systems and all other logistic discreet systems. To the user it offers a reliable tool for planning or reconstructing complex and inter-dependent systems and it has already been put to use in works of our research team [1, 17]. The programming tool consists of individual programming modules that construct the AutoMod [13] as integrity. When modelling a general system, the already built-in elements (connection transporters, automated transport vehicles, etc.) that present certain complexes in the chosen process can be used. In the source file, the characteristics which suit the real situation are determined. With the help of command lines in the source file the implementation of the simulation is determined. On the basis of the acquired results of simulation analysis and its statistical processing in AutoStat [13], the success and the efficiency of the system are analysed.

In the following section the steps of the simulation and the analysis of the PCU traffic flow in the three-armed, one-lane roundabout with a strong pedestrian flow on Koroska Street West in Maribor (Fig. 2) are shown. Actual geometrical and kinematics data are acquired from a sample of pedestrian and PCU traffic flow from the observed area of roundabout, gathered by counting traffic participants and statistically evaluating the acquired data (see Tab. 2).

3.1 A simulation model – an analysis of the pedestrian and vehicle traffic flows

The simulation model for an area of one-lane three-armed roundabout (Fig. 2) consists of the actual geometry of the roundabout and the velocity characteristics of PCU and pedestrians (Tab. 1). The measured data was used for the calibration of the simulation model. The measured places are defined with MP_i (see Fig. 2) and are presented in Tab. 2. The average velocity of PCU before entering the roundabout equals 40 *km* per hour, in the area of the roundabout it equals 20 *kmph*; the average velocity of pedestrians equals 5 *kmph*. The arrivals of pedestrians are supposed to be in three parallel ranks from both sides with probability density functions $f_{P1}(t)$ and $f_{P2}(t)$ (see Figs. 2 and 3). The influence of cyclists is neglected in this study. However, the influence of the roundabout circulation is taken into account (MP_3), with the presumed average velocity 20 *kmph.* For all motorised vehicles (the main traffic flow MP_4, roundabout circulating MP_3 and traffic flow from roundabout in the direction of Koroska Street East MP_5), the personal car unit model (PCU) is applied. A three-hour (6.30 – 9.30) counting has been performed on the observed area for the requirements of the analysis, separately for the PCU and pedestrian traffic. Based on the traffic count of the PCU and pedestrians of the roundabout on the Koroska Street, the acquired data have been statistically evaluated. The results of the evaluation of the PCU and pedestrian traffic counting that are used in this work are presented in Tab. 2.

Experimentally acquired input data present the input data for the traffic flow of PCU and pedestrians in the simulation model. Since the measurements were taken by counting on an individual arm of the roundabout, the presumption has been made that the traffic flow of PCU_i and pedestrians j (j = 1, 2) matches with *Poisson's statistical distribution*. In this case the time between the arrivals of two PCU and pedestrians is distributed according to the *exponent statistical distribution*.

Legend (refers to the Fig. 2):

MP_1 – Arrival of pedestrians 1 with probability density function $f_{p1}(t)$ in the direction to north

MP_2 – Arrival of pedestrians 2 with probability density function $f_{p2}(t)$ in the direction to south

MP_3 – Circulating roundabout PCU_3 flow

MP_4 – Main PCU_4 flow in arm A

MP_5 – PCU_5 flow from the roundabout in the direction to Koroska Street east

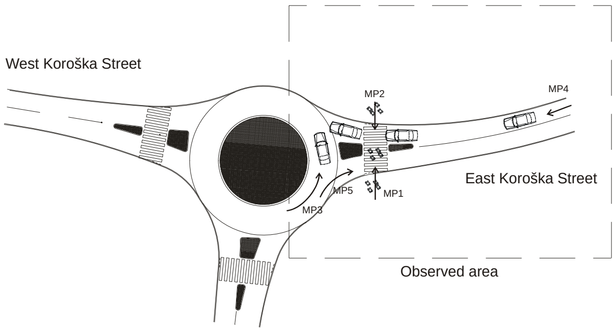

Fig. 2 Geometry of the roundabout (distances are measured in meters)

Tab. 1 Geometrical and kinematics input data

Geometrical input data	
Outside diameter of the roundabout	31 m
Inside diameter of the roundabout	19 m
Width of the road	3.7 m
Width of the pedestrian crossing	4.5 m
Length of entrance road of observed area	A – 115 m
Length of pedestrian crossing	10 m
Kinematics input data	
Velocity $v_{1,2}$ of a pedestrian	5 km/h
Velocity v_3 of a PCU in the roundabout circulation	20 km/h
Velocity v_5 of a PCU near the pedestrian crossing	20 km/h
Velocity v_4 of a PCU on the arm	40 km/h

Tab. 2 Measurements at MP_i of PCU and Pedestrians *i* for the time interval of 3 h

Time interval (min.)	Observed area of roundabout				
	MP_1 Ped. 1 (Q_1)	MP_2 Ped. 2 (Q_2)	MP_3 PCU's $_3$ (Q_3)	MP_4 PCU's $_4$ (Q_4)	MP_5 PCU's $_5$ (Q_5)
6.30 – 6.35	27	2	27	48	43
6.35 – 6.40	18	8	29	60	49
6.40 – 6.45	21	6	27	50	48
6.45 – 6.50	30	10	28	63	53
6.50 – 6.55	64	4	33	70	52
6.55 – 7.00	26	5	44	61	48
7.00 – 7.05	22	4	38	64	50
7.05 – 7.10	24	4	38	57	60
7.10 – 7.15	43	6	37	64	38
7.15 – 7.20	20	5	28	52	41
7.20 – 7.25	39	8	31	55	41
7.25 – 7.30	42	7	34	48	45
7.30 – 7.35	39	10	30	60	53
7.35 – 7.40	61	5	26	67	48
7.40 – 7.45	38	7	45	58	46
7.45 – 7.50	45	9	40	59	53
7.50 – 7.55	36	5	39	64	51
7.55 – 8.00	41	7	34	63	53
8.00 – 8.05	21	7	38	56	50
8.05 – 8.10	35	8	32	58	44
8.10 – 8.15	26	7	32	55	48
8.15 – 8.20	37	5	26	57	43
8.20 – 8.25	22	8	33	61	43
8.25 – 8.30	27	3	23	50	42
8.30 – 8.35	23	6	29	53	49
8.35 – 8.40	25	9	24	52	41
8.40 – 8.45	44	5	27	54	51
8.45 – 8.50	24	8	26	58	47
8.50 – 8.55	29	13	18	53	48
8.55 – 9.00	25	7	23	53	50
9.00 – 9.05	20	9	25	60	56
9.05 – 9.10	22	11	20	48	42
9.10 – 9.15	25	9	22	53	41
9.15 – 9.20	29	9	20	63	47
9.20 – 9.25	24	6	29	58	43
SUM	1120	254	1073	2053	1697
Frequency λ_i [Q_i/sec.]	λ_1 = 0,1037	λ_2 = 0,02352	λ_3 = 0,09935	λ_4 = 0,19	λ_5 = 0,1571
Mean time between two arrivals *exp*. ($1/\lambda_i$) [sec./Q_i]	*exp.* (9,65)	*exp.* (42,58)	*exp.* (10,06)	*exp.* (5,26)	*exp.* (6,37)

The time between two arrivals of pedestrians or PCU is defined according to the relation presented in the next case. *Case:* the number of PCU_3 arrivals within the time interval from 6.30 to 6.35 is 27, which is presumed to be distributed as the *Poisson statistical distribution*, with an average degree of arrivals per time unit $\lambda = 27/5 = 5{,}4$ [PCU_3/min]; the time between two consecutive arrivals of PCU_3 can then be determined using the *exponential statistical distribution* with the mean value of $t = 1/\lambda = 0{,}185$ [min/ PCU_3].

3.2 The theoretical background of the simulation model

When planning a roundabout, its capacity in relation to the traffic flow (*i*) of PCU and (*ii*) pedestrians is predominantly the main point of interest. The general rule in every roundabout (roundabouts with traffic lighting system are an exception) is that pedestrians are always given priority over the PCU traffic flow. When determining the capacity of a roundabout, the rates of PCU (λ_3, λ_4, λ_5) and pedestrian flow (λ_1, λ_1), crossing each other on an individual arm of the roundabout, are used. The total capacity of PCU and pedestrian flow in an individual arm of the roundabout can be presented with the following simplified relation dependence.

The arrivals of PCU and pedestrian flow in the individual arm of the roundabout can be treated as a system of a waiting line with one serving place. When determining the appropriate system of the waiting line the basic condition that the arrivals of PCU are distributed according to the *Poisson's statistical distribution* is taken into account. The condition that the time between two arrivals of pedestrians is distributed according to the *Poisson's statistical distribution* is also considered. Due to the connection between the *Poisson's* and *exponential statistical distribution*, the following relation has to be defined. If the number of PCU and pedestrian arrivals in a given time interval t is distributed according to the *Poisson's statistical distribution* with an average degree of arrivals in a time unit λ and a medium value $\lambda \cdot t$, then the time intervals between the arrivals of two consecutive PCU and pedestrians are distributed according to the *exponent statistical distribution* with a medium value of $1/\lambda$. The relations in the roundabout can be represented with the following expressions:

- *M* – refers to the *Poisson's distribution* of PCU and pedestrian arrivals in a given time unit,
- *D* – refers to the constant or deterministic distribution of time, required for the driving of PCU by the pedestrians crossing and the crossing of pedestrians to the other side of the roadway,
- 1 – only one serving station exists in the system, which is connected to the pedestrian crossing,
- ∞ – arrival to the roundabout is determined by an infinite flow of PCU and pedestrians,
- *FIFO* – when coming into the system, PCU and pedestrians are first served according to the first-in-first-out (FIFO) selection rule

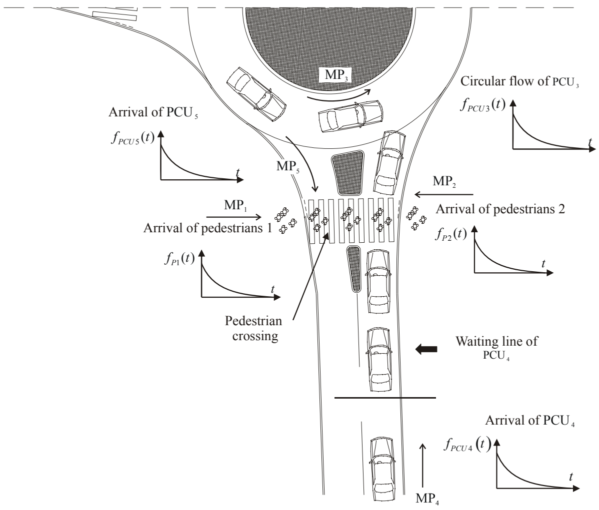

Fig. 3. An individual roundabout arm (observed area see Fig.2)

Due to three independent traffic flows PCU_i (i = 1, 2, 3) and pedestrian P_j (j = 1, 2) flow, an individual arm in a roundabout presents a combination of two independent systems, that is:

- The combination of $M/D/1/\infty/FIFO$ for the PCU_4 main traffic flow and pedestrian j (j = 1, 2) flow $M/D/1/\infty/FIFO$.
- The combination of $M/D/1/\infty/FIFO$ for the PCU_3 circulating flow and the PCU_4 main flow $M/D/1/\infty/FIFO$.

While the PCU flow presents a typical $M/D/1/\infty/FIFO$ system, the pedestrian flow system $M/D/1/\infty/FIFO$ is modified, since in the abovementioned system waiting time periods and waiting line never occur. This assertion can be explained by the fact that in a roundabout pedestrians and cyclists are always given priority over the motorised vehicles. Because of the complexity and non-determination of the system, the capacity of the traffic flow of an individual arm of a roundabout and the entire roundabout is difficult to be analytically treated. Therefore, a possible solution to the problem is the use of discreet numeric simulations method, presented in the following section.

3 Simulation model

On the basis of the experimental roundabout in Koroska Street in Maribor a simulation model has been created (Figs. 4 and 5 present two detailed drafts of the simulation model). The simulation model in the programming tool AutoMod [13] is illustrated with paths, where the motorised vehicle (PCU) and pedestrian flow are entwined. The simulation model has been created on the basis of actual presented geometrical data in the CAD drawing and kinematics values, which are presented in Tab. 1, as well as from a sample of PCU and pedestrian flow (see Tab. 2).

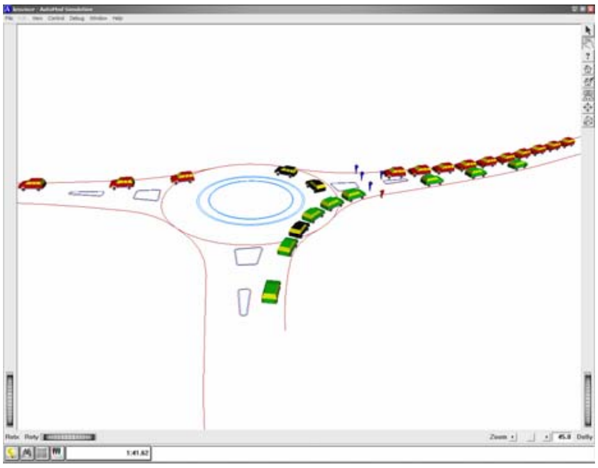

Fig. 4 Microsimulation model of roundabout–detail I

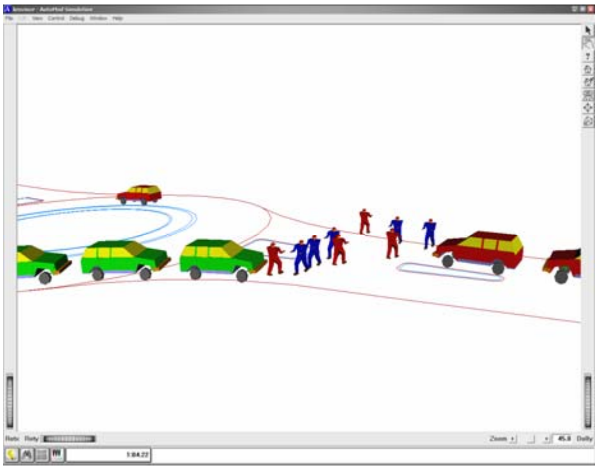

Fig. 5 Microsimulation model of roundabout–detail II

The simulation begins with a process based on user determined functions in the source file of the program. The functions start the operation of the roundabout. When the function »*Begin model initialization function*« equals »true«, the process »*P_roundabout_start*« begins. The process consists of project variables, pedestrians and PCU attributes of type integer and real, subroutines and individual program loops. The model is built according to defined geometrics construction of the roundabout from the CAD file and kinematics characteristics for pedestrians and PCU. The mean time between two consecutive arrivals of PCU and pedestrians are programmed according to the experimentally acquired values, presented in Tab. 2. It is presumed that the arrivals of PCU and pedestrians are uneven; therefore the *exponential statistical distribution* has been used for generating the traffic flow. When creating the main program logic of the roundabout, the general condition that pedestrians are always given priority over the PCU traffic flow has been applied.

- **The gap acceptance model**

The gap acceptance model in our simulation model of the roundabout has been modelled using the *Block claim and Block release functions* and the *Order list*. The *Block claim function* for the arrival of PCU_4 on the considered pedestrian crossing verifies whether there is already a pedestrian on the pedestrian crossing or not. In case there is a pedestrian on the pedestrian crossing (the function "*B_block_1 current claims <> 0*"), the PCU_4 immediately stops and waits until the pedestrian leaves the pedestrian crossing (see Fig. 6). During the waiting period, the PCU_4 is inscribed into the *Order list wait for path* ("*wait to be ordered on Ol_waithForPath_1*") – see Fig. 6, where part of a program code for the implementation of the gap acceptance model is presented. When the pedestrian flow is extremely heavy, waiting lines of PCU_4 occur.

```
begin p_roundabout_starts arriving procedure
        if B_block_1 current claims <> 0 then begin
                wait to be ordered on Ol_WaitForPath_1
        end
end
begin block claim function
        if theBlock is B_block_1 then begin
        print " PCU4 entering B_block1. Total PCU4 " theBlock current
        claims to message
        end
end
begin block release function
        if theBlock is B_block_1 then begin
                if theBlock current claims = 0 then begin
                        order 1 PCU4 from Ol_WaitForPath_1 to continue
                end
        print " PCU4 leaving B_block. Total PCU4: " theBlock current
        claims to message
end
```

Fig. 6 Part of a program code for the implementation of the gap acceptance model

The moment the pedestrian crossing is free the "*B_block_1 current claims = 0*", PCU_4 continues with driving in the first-in-first-out (FIFO) consequence according to their waiting line. The driving of PCU_4 takes place until the next pedestrian appears in the pedestrian crossing, which again halts the driving of PCU_4. In the case of roundabout circulating flow PCU_3 according to the main traffic flow PCU_4, the same approach with the *Block claim and Block release functions* and the *Order list* has been used. For every passing of PCU_4 and pedestrians the program registers the basic information variables "*V_waiting_time*" for PCU_4, "*V_no._of_ PCU₄*" and "*V_no._of_pedestrians*" as follows: the number of passing PCU_4 and the number of pedestrian crossings in the roundabout, the length of an individual PCU_4 has been in the observed arm of the roundabout (the waiting time period) and the number of successfully passed PCU_4 and pedestrians in the defined-analysed time.

The main goal of the simulation analysis is to establish the PCU_4 capacity on the observed arm when the waiting line in front of a pedestrian crossing and consequently the waiting time for crossing the observed arm is still acceptable.

5 Analysis of the results

The results of the performed analysis for determining the average waiting time and capacity of the PCU_4 main traffic flow depending on the pedestrian flows give basic conclusions, presented in Tabs 3 and 4.

On the basis of the performed counting of the PCU and pedestrian traffic flow (see Fig. 2, Tab. 2) it can be stated that the frequency of pedestrians (λ_1) presents the biggest influence on the capacity of the PCU main traffic flow (Fig. 3). Assuming that the pedestrian capacity will only get bigger in the future (closure of the old bridge, increase in the public transportation), it would be interesting to find out what level of increase in the number of pedestrians in both directions with regard to the main traffic flow of PCU would still be admissible. When analysing the capacity of the treated arm of the roundabout, we deal with a number of independent variables, i.e. different frequencies of the PCU (λ_3, λ_4, λ_5) and pedestrian traffic flow (λ_1, λ_2). To determine the influence of a variable on the system's response (waiting time and roundabout capacity) it is therefore necessary to fix individual variables and change the value of only one variable or both at the same time. Since we are mainly interested in the influence of pedestrians on the capacity of the roundabout's arm, the frequency of pedestrians 1 (λ_1) and the frequency of pedestrians (λ_2) in the roundabout's arm present the main variables. Due to a different frequency of pedestrians in both directions (λ_1 = 0,1037 ped/sec. and λ_2 = 0,02352 ped/sec.) the influence on the waiting time and capacity of the roundabout has been analysed in the following way:

a) beside the fixed variables (λ_3, λ_4, λ_5) the frequency of pedestrians 2 (λ_2) has also been fixed. In the analysis, values λ_1 have been changed or increased to the level that the average waiting time and capacity of the main traffic flow of PCU_4 are still admissible (Tab. 3);
b) beside the fixed variables (λ_3, λ_4, λ_5) the frequency of pedestrians 1 (λ_1) has also been fixed. In the analysis, values λ_2 have been changed or increased to the same level as the frequency of pedestrians 1 (Tab. 4);

Analysis results for every average waiting time and the roundabout capacity shown in Tabs. 3 and 4 have been carried out on the basis of 100 consecutively performed simulations in the AutoStat programming tool [13]. Consequently, a good enough representative average is obtained, which would not be the case with probability functions with a small number of performed simulations.

6 Conclusion

In this paper the analysis of the strong pedestrian traffic flow on the capacity of the one-lane three-armed roundabout using the discreet numeric simulations modelling is presented. Before the existing roundabout was constructed, there was a classical crossroads with traffic lights, which was then reconstructed to montage the roundabout (analysed in work [1]). However, the analysis presented in this paper provides a new confirmation of the traffic flow and the influence of the strong pedestrian flow on the capacity of the roundabout.

First, the main theoretical background for the analysis of the motorised vehicle flow – personal car unit (PCU) and pedestrians in the roundabout are presented. Since in roundabouts the pedestrian traffic flow is given priority, the vehicles on entries/exits must yield the right of way to pedestrians. Consequently, disturbances at entering/exiting of motorised vehicles occur and the motorised vehicle flow is disrupted. The more disrupted the motorized vehicle flow is, the lower is the capacity of the roundabout. In case the flows towards the entry of the roundabout are disturbed, the minimum capacity is not reached. In case the flows towards the exit of the roundabout are disturbed, the maximum capacity can get exceeded. Under real conditions, the entering and exiting of the motorised traffic flow are simultaneously disturbed and congestions are transferred from arm to arm, in clock-wise direction. For this purpose, the mathematical modelling of traffic flows with the use of discreet simulations has been used for the analysis of the influence of the pedestrian flow on the capacity of the roundabout, considering the statistically evaluated input data of the PCU and pedestrian traffic flows.

The main part of this article consists of the discreet numeric simulation of the roundabout. The simulation model of the roundabout is general, i.e. it can be

Tab. 3 The influence of increasing arrivals of pedestrians 1 on the mean waiting time and mean capacity of the main traffic flow of PCU_4

PCU arrivals ($1/\lambda_3$ = 10,06) ($1/\lambda_4$ = 5,26) ($1/\lambda_5$ = 6,36)	Arrivals of pedestrians 1 (sec./pedestrian)				
	Pedestrians 1 ($1/\lambda_1$ = 9,65) λ_1 = 100 %	Pedestrians 1 ($1/\lambda_1$ = 7,72) λ_1 = 120 %	Pedestrians 1 ($1/\lambda_1$ = 5,79) λ_1 = 140 %	Pedestrians 1 ($1/\lambda_1$ = 3,86) λ_1 = 160 %	Pedestrians 1 ($1/\lambda_1$ = 2,895) λ_1 = 170 %
	Pedestrians 2 ($1/\lambda_2$ = 42,58) λ_2 = 100 %	Pedestrians 2 ($1/\lambda_2$ = 42,58) λ_2 = 100 %	Pedestrians 2 ($1/\lambda_2$ = 42,58) λ_2 = 100 %	Pedestrians 2 ($1/\lambda_2$ = 42,58) λ_2 = 100 %	Pedestrians 2 ($1/\lambda_2$ = 42,58) λ_2 = 100 %
Mean wait. time T (s)	**3,62**	**4,49**	**6,81**	**18,58**	**266,67**
SD	0,25	0,34	0,74	3,06	117,92
95 % conf. interval	(3,58 – 3,67)	(4,27 – 4,56)	(6,67 – 6,96)	(17,97 – 19,18)	(243,27 – 290,06)
Mean capacity Q_4 (PCU_4)	**2048**	**2048**	**2048**	**2046**	**1956**
SD	48	48	48	47	35
95 % conf. interval	(2039 – 2058)	(2039 – 2058)	(2039 - 2058)	(2037 – 2056)	(1949 – 1963)

Tab. 4 The influence of increasing arrivals of pedestrians 2 on the mean waiting time and mean capacity of the main traffic flow of PCU_4

PCU arrivals ($1/\lambda_3$ = 10,06) ($1/\lambda_4$ = 5,26) ($1/\lambda_5$ = 6,36)	Arrivals of pedestrians 2 (sec./pedestrian)				
	Pedestrians 2 ($1/\lambda_2$ = 42,58) λ_2 = 100 %	Pedestrians 2 ($1/\lambda_2$ = 34,064) λ_2 = 120 %	Pedestrians 2 ($1/\lambda_2$ = 25,548) λ_2 = 140 %	Pedestrians 2 ($1/\lambda_2$ = 17,032) λ_2 = 160 %	Pedestrians 2 ($1/\lambda_2$ = 12,774) λ_2 = 170 %
	Pedestrians 1 ($1/\lambda_1$ = 9,65) λ_1 = 100 %	Pedestrians 1 ($1/\lambda_1$ = 9,65) λ_1 = 100 %	Pedestrians 1 ($1/\lambda_1$ = 9,65) λ_1 = 100 %	Pedestrians 1 ($1/\lambda_1$ = 9,65) λ_1 = 100 %	Pedestrians 1 ($1/\lambda_1$ = 9,65) λ_1 = 100 %
Mean wait. time T (s)	**3,62**	**3,8**	**4,15**	**4,94**	**5,87**
SD	0,25	0,28	0,33	0,46	0,6
95 % conf. interval	(3,58 – 3,67)	(3,75 – 3,86)	(4,09 – 4,21)	(4,85 – 5,03)	(5,76 – 5,99)
Mean capacity Q_4 (PCU_4)	**2048**	**2048**	**2048**	**2048**	**2048**
SD	48	48	48	48	48
95 % conf. interval	(2039 – 2058)	(2039 – 2058)	(2039 – 2058)	(2039 – 2058)	(2039 – 2058)

extended for every individual implementation according to the chosen geometrical and kinematics sizes. The mathematical model derives from legalities of acceptable time voids in the pedestrian traffic flow, used by the vehicles for entering/exiting a roundabout, using the exponent and Poisson statistical distribution. For determination of the traffic flow of motorised vehicles and pedestrians the real input data acquired by the traffic counting on Koroska Street in Maribor have been used. The results of measurements and simulation analyses match well, which means that simulation analysis results give a good prediction for the evaluation of the waiting period and waiting lines of motorized vehicles in an individual arm of a roundabout. According to the waiting period the distribution and consequentially waiting lines are dependent on the number of motorised vehicles. It can be established that waiting periods and queues of motorized vehicles are proportionally low. It has been determined that the current situation of the traffic flow is acceptable for the roundabout capacity. With an increase of the pedestrian flow (in both directions) a major influence on the roundabout capacity is not expected. On the basis of analysis results it can be established that there is a relatively great reserve available in relation to the capacity of pedestrians 1 and 2 (up till 60 % of current frequencies λ_1 in λ_2). Since the traffic flow of PCU is going to increase in the future, we assume that the capacity reserve will get lower, but still great enough to allow an undisturbed traffic flow of PCU. It should be mentioned that the analysis results refer to the counting of traffic flow carried out at morning peak hour, only at the treated part of the roundabout. In the continuation of this research it would be reasonable to analyse the influence of the average waiting time and PCU capacity on the whole roundabout and in the afternoon peak hour.

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