Lecture with Computer Exercises:
Modelling and Simulating Social Systems with MATLAB

The impact of pedestrians on roundabouts entry ...

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Zurich
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Contents

1 Abstract

We are interested in measuring the pedestrians impact on the entry flow. Indeed, they influence the traffic on roundabout in a direct way, since the cars intending to merge into the circulation flow have to leave the priority to pedestrians on the crosswalk; and in an indirect manner since pedestrians crossing the streets at exits of the roundabout keep vehicles of the circulating flow from making their way out of the roundabout. We look at how the crosswalks location at the roundabout entrance play a role in the capacity entry taking into account different influencing factors and traffic's situations over a normal working day. We use a microscopic approach, where gap acceptance behavior is used to reproduce conflict with pedestrians. The estimated entry capacity results and limitations approach are interpreted.

2 Individual contributions

Several researches have been led lately in particular by japanese and germans researchers such that Wui, Kang Nan or Siegloch. Our project is inspired by their advanced works, where we've been trying to understand and summarize them. We derived a simplified theoretical model with simplified formulas and different parameters adapted to our framework and our objectives, which still lead to the coherent results found in the original papers. Indeed, while the storage space between the yield line and the crosswalk was considered as a fix constant we made it a variable and measure its impact on the entry capacity. We also made a MATLAB code reproducing a changing traffic and pedestrian flow over a typical working day.

3 Introduction and Motivations

In this project we consider fix small type roundabout 4 single lanes with crosswalks at each entrances which are closed to shopping center area or other attractive places. Those types are pretty common in Switzerland in small and middle towns. We noticed that the crosswalks are located most of the time right at the entrance, which in our opinions had a bad impact on the traffic flow and hence on the entry capacity of the roundabout. The reason for that is always claimed to be the pedestrian's safety. Indeed, vehicles willing to merge into the circulating flow on the roundabout have to slow down and then putting the crosswalk almost at the yield line make the pedestrians crossing the street where the vehicles are at theirs slowest speed and then optimizing safety by limiting fatal crash accident. It seems to us that putting the crosswalks further down the road would improve the traffic flow but decrease the pedestrian's safety since cars are still pretty fast and that, in practice, they tend to

cross randomly the road at the roundabout entrance instead of walking down the road to use the crosswalk. In consequence, there is clearly a trade off between the entry capacity of roundabouts and the pedestrian's safety and as a consequence we can't consider setting up the crosswalks too far from the roundabouts of Switzerland in the case described above to optimize the traffic. In other terms, the question we want to give an answer to is the following :
Is a reasonably small increase of the storage space between the yield line and the crosswalk has a significant positive impact on the entry capacity ?

4 Description of the Model

Gap acceptance theory(Kang, N., H. Nakamura, and M. Asano. An Empirical Analysis on Critical Gap and Follow-Up Time at Roundabout Considering Geometry Effect)

Our model is based on the gap acceptance theory, which is nothing but the expression of the priority rules applying to unsignalized intersections and in particular to roundabouts (which is a particular case of intersection). It is based on the concept of minor flows trying to merge into or cross the major flows. The minor flow is yielding the priority to minor flow. The considered roundabout is exactly of this type : the minor flow is represented by the cars willing to enter the roundabout, giving way first at pedestrians crossing the street who are hence a major flow. The minor flow intends afterwards to merge into the circulating flow which also have the priority and hence defined another major flow. Using gap acceptance theory we can simplify the model of our roundabout : we can consider that the minor flow is facing two intersections and want to cross the first one in order to merge into the second one. From this point of view, there is no difference between the pedestrian flow and the circulation flow.

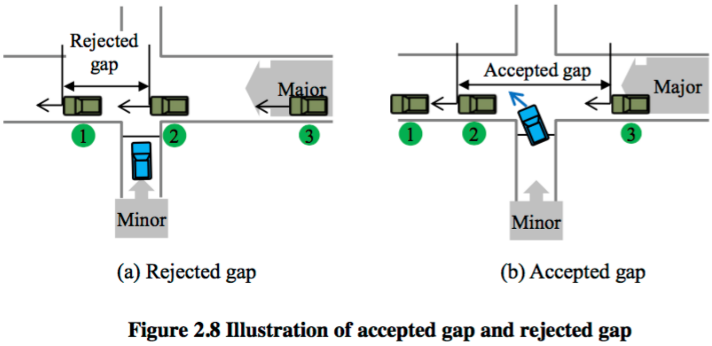

Figure 1: gap acceptance theory

As said before, gap is defined as the headway between two subjects. These gaps are measured in time. the minimum headways are τ_p for pedestrians and τ_c for the circulating flow, expressed in second. Subjects in minor flow judge the gaps in major flow to decide crossing or merging into major flow. Namely if the gap is bigger than t_{Cc} for circulating flow and t_{Cp} for pedestrians (those are called the critical time) then the minor flow takes the decision to merge into the traffic (respectively cross the crosswalk) while rejected gap is defined as the gap in major flows which smaller than these values. This gap judging behaviour is the gap acceptance behaviour. We define t_f to be the follow up time that is the time for a the second car queuing in the minor flow to follow the vehicle in front in merging into the traffic (resp crossing the crosswalk). For example, if the circulating flow provide a gap t with the length $t_{Cc} \leq t \leq t_{Cc} + t_f$ enables the departure of one vehicle, the gap t with the length $t_{Cc}+t_f \leq t \leq t_{Cc}+2*tf$ enables the departure of two vehicles, and so on. We define also $t_{0p} := t_{Cp} - \frac{t_f}{2}$ and $t_{0c} := t_{Cc} - \frac{t_f}{2}$ to be the intercept gap and determine the minimum physical distance between two given elements of the major flows to insert one car.

We recall that we aim to estimate the roundabout's entry capacity in terms of several factors, and in particular in terms of the storage space left between the yield line and the crosswalk. We state that the entry capacity of the roundabout (C_c) is determined by how many vehicles can enter in one accepted gap of circulating flow and how the accepted gaps are provided by circulating vehicles which is related to headway distribution of circulating vehicles. Namely, if $E(t)$ is defined as the maximum number of vehicles can enter in one available gap at gap size of t sec, $h(t)$

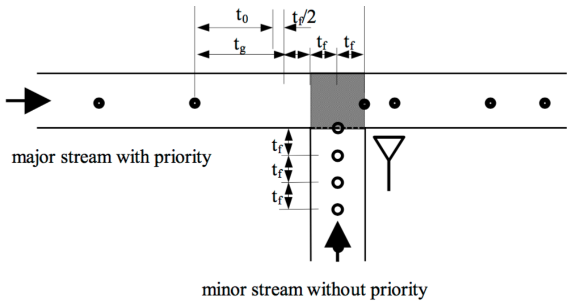

Figure 2: parameters in gap acceptance theory

is defined as the density function of headway distribution and q_c the circulating flow in front of entry S (vehicle/s) we have the following formula.

$$C_c = q_c \int_{-\infty}^{+\infty} E(t)h(t)dt$$

However, in our case, we are interested in standard single-lane roundabout with four legs (North, South, East, West), which includes crosswalks. Therefore, this formula has to be changed considering roundabout features such that the crossing pedestrians, behaviour of vehicles in the circulating road and so on.

Overview of the model(Kang, N., H. Nakamura, and M. Asano. An Empirical Analysis on Critical Gap and Follow-Up Time at Roundabout Considering Geometry Effect)

We here suggest a model to estimate the entry capacity C_s considering two cases of circulating flow in front of Entry S. Circulating flow is divided in two cases : either it is flowing or queuing due to congested traffic. We are explaining the two cases :

CASE (a)
Under the condition of flowing circulating vehicles, entry capacity C_a a is determined by pedestrians across Entry S, circulating flow passing in front of Entry S and the distance between crosswalk and yield line.

CASE (b)

On the other hand, the vehicles exiting to Exit N, E or W which are blocked by pedestrians across at these exits may lead to a queue in circulating roadway. When the queuing vehicles reaches up to front of Entry S, vehicles at Entry S are prevented from entering roundabout due to these queuing vehicles. Thus, entry capacity C_b is equal to zero under this condition since vehicles cannot enter roundabout at all.

P_f is defined as the probability of circulating vehicles flowing in front of Entry S in case (a), and P_q is defined as the probability of queuing vehicles reaching up to front of Entry S in case (b). Accordingly, entry capacity C_s considering cases (a) and (b) is estimated by :

$$C_s = P_f * C_a + P_q * C_b$$

Since the situations of circulating flow in case (a) and (b) are independent, $P_f + P_q = 1$. In addition, C_b is equal to zero as described in case (b). Thus, we have:

$$C_s = (1 - P_q) * C_a$$

It amounts now to estimate C_a and P_q.

Estimation of Ca

What follow next is due to the work of Nan Kang, N., H. Nakamura, and M. Asano. An Empirical Analysis on Critical Gap and Follow-Up Time at Roundabout Considering Geometry Effect.

We first estimate C_a. Entering procedure is divided into two separate parts due to the storage space, first crossing pedestrian flow and then merging into circulating flow. Thus, entry capacity C_a is determined by circulating flow passing in front Entry S and how many vehicles waiting at the yield line. Moreover, the number of vehicles that can wait at the yield line is determined by pedestrian flow and the maximum number of vehicles which can be stored between crosswalk and yield. Namely, n_a is defined as the maximum number of vehicles which can be stored between crosswalk and yield line and n is defined as the number of vehicles which are queuing in the storage space.P_n is defined as the probability of number of having n vehicles queuing in the storage space. Sum of the probabilities P_n for all of the possible number of queuing vehicles n must be equal to 1. Dependent on the value of n_a, the entering procedure can be classified into two states that we will sum up afterwards

State 1, $1 \leq n \leq n_a$
The illustration of this state is shown in Figure 4.2(a). Under this condition, n

vehicles queue in the space and the maximum number of vehicles which can enter roundabout is dependant on the circulating flow q_c. Hence, this maximum number of entering vehicles can be described by a function of $f(q_c)$ that we will define explicitly later on. Thus, entry capacity for $1 \leq n \leq n_a$ C_{a1} is given by the following equation :

$$C_{a1} = \sum_{n=1}^{n_a} P_n * f(q_c) = (1 - P_0) * f(q_c)$$

State 2, $n = 0$

n=0 represents the situation of no vehicle queuing in storage space. Under this situation, entry vehicle should cross pedestrian flow and circulating flow simultaneously without stopping in the storage space. Thus, entry capacity of state 2 C_{a2} is calculated by a function of circulating flow q_c and pedestrian flow q_p, $g(q_p, q_c)$ with the probability of P_0 as follow :

$$C_{a2} = P_0 * g(q_p, q_c)$$

Therefore, entry capacity C_a is given by :

$$C_a = (1 - P_0) * f(q_c) + P_0 * g(q_p, q_c)$$

We determine now P_0 : The follow-up times crossing pedestrian flow and merging into circulating flow are assumed to be identical. According to this, A continuous period, e.g. 1 hour, can be divided into m intervals of duration t_f, as 1h=3600sec=$m * t_f$. Therefore, the situation of the storage space will change at the end of each t_f. at each end time of t_f the situation of queuing vehicle in the storage space has $na + 1$ possibilities and are independents and have for probability $\frac{1}{n_a+1}$. Considering this subdivision of time in terms of t_f a simple calculations (which we choose to skip) leads to $P_0 = \frac{1}{n_a+1}$ and hence

$$C_a = \frac{n_a}{na + 1} * f(q_c) + \frac{1}{n_a + 1} * g(q_p, q_c)$$

It amounts now determine f and g which actually represent respectively the maximum entry flow considering only circulating flow and the maximum entry flow considering pedestrian and circulating flow simultaneously without stopping in storage space.

ESTIMATION OF f (Suzuki, K., and H. Nakamura. TrafcAnalyzerThe Integrated Video Image Processing System for Trafc Flow Analysis)

The above definition of f coincide avec C_c defined of acceptance gap theory. According to Nan Kang We can use $E(t) = \frac{t-t_{0c}}{t_f}$ if $t_{0c} \leq t$ and 0 otherwise and $h(t) = \exp(-q_c \frac{t-\tau_c}{1-\tau_c})$ in the equation to obtain :

$$f(q_c) = \frac{3600}{t_f}(1 - \tau_c \frac{q_c}{3600}) \exp(\frac{-q_c}{3600}(t_{0c} - \tau_c))$$

ESTIMATION OF g (Wu, N. A Universal Procedure for Capacity Determination at Unsignal-ized (Priority-Controlled) Intersections.)

for the calculation of g, one can divide the major flow in 4 distinguished periods which when one sums them up allow us to recover the traffic. More specifically, let us decompose the traffic in 3 different stages :

Stage I:
In this stage, the traffic flow in the major stream is divided into 2 states which excludes each other : queuing and queuing-free. In the state of queuing, the vehicles in the major stream stay at the stop line. Departure from the minor stream is not possible in the state of queuing (including discharge queuing for the real-life traffic conditions). In the state of queuing-free all vehicles in the major stream are in motion. Departure from the minor stream is possible in the state of Queuing-free possible but dependent on the traffic intensity and bunching situation within the major stream. Denoting the probability for the state of queuing by p_s the probability for the state of queuing-free is then $p_{0s} = 1 - p_s$.

Stage II:
In the stage II, the traffic flow in the queuing free state is also divided into 2 substates which excludes each other: bunching and bunching-free under the condition of queuing free. In the state of bunching, the vehicles in the major stream is in motion with the minimum gaps τ_c. Departure from the minor stream is not possible in the state of bunching. In the state of bunching-free the gaps between the vehicles are larger than τ_c and distributed by chance. Departure from the minor stream is in the state of Bunching-free possible but dependent on the traffic intensity within the major stream in this state. Denoting the probability for the state of Bunching under the condition of Queuing-free by $p_b = Pr(bunching|queuingfree)$, the probability for the state of bunching-free the condition of queuing-free is then $p_{0b} = Pr(bunchingfree|queuingfree) = 1 - p_b$.

Stage III:
In the stage III, the traffic flow in the bunchingfree state under the condition of

queuingfree is divided again into 2 sub-sub-states which excludes each other : single-vehicle and vehicle-free (Free-space) under the condition of (bunching-free — queuing-free). In the state of single-vehicle, vehicles in the major stream are moving independently from each other. In the front of a vehicle, a time period of the length t_0 is closed for the minor stream. The total closing time by the vehicles in the major stream is the sum of the set $\{t \leq t_{0c}\}$. Departure from the minor stream is not possible for the state of single-vehicle. In the state of free-space there is no vehicle in the major stream. Departure from the minor stream in the state of free-space is carried out with the saturation capacity $K = \frac{1}{t_f}$. Denoting the probability for the state of single-vehicle under the condition of (bunchingfree | queuingfree) by $p_f = Pr[singlevehicle|(bunchingfree|queuingfree)]$, the probability for the state of vehicle-free (free-space) under the condition of (bunchingfree | queuingfree) is then $p_{0f} = Pr[vehiclefree|(bunchingfree|queuingfree)] = 1 - p_f$.

Thus, the major stream can be divided into four regimes 1) that of state of Free-space (Vehicle- free), 2) that of state of Single-vehicle, 3) that of state of Bunching, and 4) that of state of Queuing. According to the definition of the conditioned probabilities, the probabilities p_s, p_b, p_f are completely independent of each other. They are to be determined according to the queuing theory. Let us omit the pedestrians for the moment and come back to that later.the formula for the determination of g reads:

$$g = Pr[Vehiclefree|(Bunchingfree|Queuingfree)]$$
$$= K * p_{0s} * p_{0b} * p_{0f}$$

with K to be the capacity in the free space state.
We use now queuing theory to calculate p_{0s}, p_{0b}, p_{0f} and K.

1)Determination of p_{0s}
The probability for the state of Queuing-free in the major stream p_s can in general (approximately according to the M/G/1 queuing system) be estimated with the degree of saturation, $x_c = \frac{\exp(t_{Cc} - t_f) * (\exp(t_f * q_c) - 1)}{q_c}$. The probability for the Queuing-free state in the major stream p_{0s} then reads $p_{0s} = 1 - p_s = 1 - x_c$.

2)Determination of p_{0b}
One can assume that bunching formation in the traffic in motion within the major stream is independent of the queuing saturation (Bunching during discharge queuing belongs to Queuing). Accordingly, it is true that $Pr(Bunchingfree|Queuingfree) = Pr(Bunchingfree)$ The probability of Bunching p_b in the major stream is simple the portion of the sum of the minimum gap τ_c for all vehicles. Namely, $p_b = q_c * \tau_c$ and then we have $p_{0b} = 1 - q_c * \tau_c$.

3)Determination of p_{0f}
It is identical to the probability that the gap in the major stream t is larger than zero-gap t_{0c} under the condition that the gap t is larger than the minimum gap τ_c. We choose to skip the calculation to assume that $p_{0f} = \exp(-q_f(t_{Cc} - \tau_c))$ with $q_f = \frac{(1-q_c*\tau_c)*q_c}{1-q_c*\tau_c}$.

4)Determination of K
Vehicle-free state the reciprocal of the mean service time of the queuing system. The mean service time in the vehicle free state is equal to the mean move-up time t_f $K = \frac{1}{t_f}$.

We recall that so far we've been ignoring the pedestrian's flow. In our model, we consider that the pedestrian's flow can be represented the same way before, i.e like the circulating flow. Hence, the theory above applies and then since the intersections are considered as parallel it amounts us to multiply by the equivalent of p_{0b}, p_{0s} and p_{0f} for the pedestrian's flow replacing the corresponding parameters.

Overall, we can estimate the formula for g.

and hence C_a is fully determined and depends explicitly on n_a. This allows us through a simulation to measure the impact of the gap between the yield line and the crosswalk on the entry capacity.

Estimation of Pq (Wu, N. A Universal Procedure for Capacity Determination at Unsignal-ized (Priority-Controlled) Intersections)

We recall that at downstream exits (referring to N, E or W), exit vehicles have conflict with pedestrians and cross pedestrian flow by available gaps of pedestrians. Thus, a queue of exit vehicles may be generated when there is no available gap in pedestrian flow. Exit vehicles and pedestrians form a queuing system. First, this of course depends highly on the roundabout's size, that in our case if fixed (we suppose that between two exits next to each other have the length to store two vehicle). For any exit X, P_X is defined as the probability of 2 vehicles queuing in circulating roadway. P_q is calculated as the maximum value of P_X over the entries. In our simulation we will make no difference between the different exits, taking higher values than we took for the subject entry S. According to queue theory, P_q can be calculated by

$$P_q = (1 - \frac{\lambda}{\mu_p}) * (\frac{\lambda}{\mu_p})^2$$

Here, we have that λ is related to the circulating flow passing in front of Entry S q_c and to α the proportion of demand of vehicles exiting from the downstream exits in circulating flow passing in front of Entry S; namely $\lambda = \frac{\alpha * q_c}{3600}$. For μ_p, since pedestrian flow plays a central role and exit vehicles cross pedestrian flow depending on available gaps of pedestrians, we can use the same decomposition we've been using for g above (computing p_{0s}, p_{0b} and p_{0f} with the parameters corresponding to the pedestrian's flow) leading to $\mu_p = 1 - (1 - x_p) * (1 - q_p * \tau_p)$.

Overall we have an explicit estimation for Cs. In the next chapter we are going to implement it and find out how big the impact of n_a on C_s is. Here is a summary scheme giving an overview of the model :

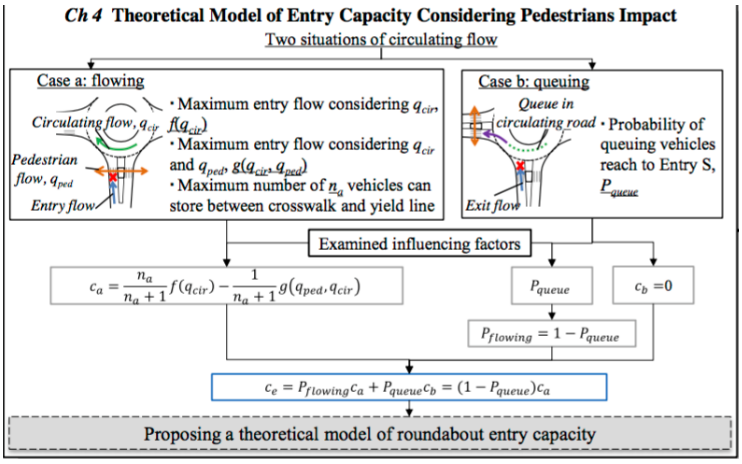

Figure 3: Summary

5 Implementation

We have done two implementation with Matlab, one called distance and one called daytime. Theyre both build similar, but are giving a different look at the mater.

The basic structure of daytime and distance:

As said before both are build similar. Both have a main script, in which the data storing and the plotting is done. To see the linking have a look at the flowchart shown in figure 4. In the parameters script, all constant parameters are implemented. It makes it easy to adjust some changes in the constant parameters. Both implementations consist of a bunch of functions, which are called from function or script one step higher and give back a value to the calling scrip or function. To see the purpose of every function have a look at the matlab code, where everything is documented. Because of the simplification of our model, some extra constants had to be added, just that our simulation gives results in the same hight as the simulations we used to abstract our model.

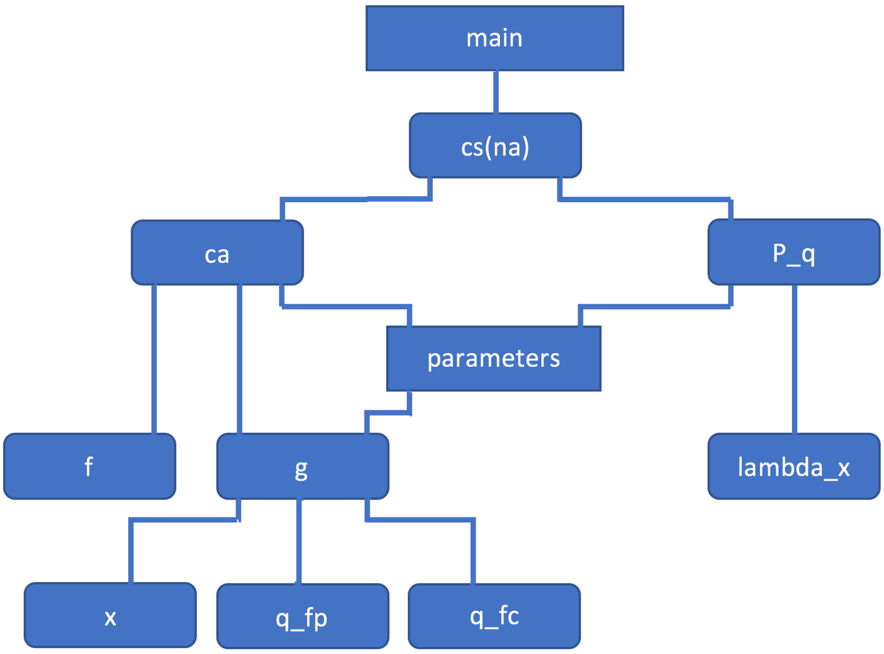

Figure 4: basic structure of the matlab code

THE IMPLEMENTATION "DISTANCE"

In this one, the whole calculation of the entry capacity $c_s$depends from the circulating flow q_c and the distance between the crosswalk and the yield line n_a. With that we produced two different plots. One in figure 2 which shows the affect of a growing n_a (from one to five cars) with a constant $q_c = 800$ [cars/hour]. This one shows clearly the affect of the distance n_a. And an other one in figure 1 where q_c and

n_a are variable. In both cases the produced date gets stored to the txt-file called $cs1$

parameter	value	unit
tau_p	2	sec
tau_c	2.2	sec
t_fp,t_fc	3.2	sec
t_Cc	4.5	sec
t_Cp	6.2	sec
t_0c	t_Cc-(0.5*t_fc)	sec
t_0p	t_Cp-(0.5*t_fp)	sec
q_p	(1/3600)*100	cars/sec
q_pprime	(1/3600)*50	cars/sec
q_m	(1/3600)*50	cars/sec
q_mprime	(1/3600)*50	cars/sec
q_c	800/not constant	cars
q_cprime=(1/3600)*400	(1/3600)*400	cars/sec
alpha_x	0.2	
n_b	2	cars
n_a	not constant	cars

Figure 5: parameters in "distance"

THE IMPLEMENTATION "DAYTIME"

In the implementation of daytime we simulated, with the same basic structure as in distance, the entry capacity c_s during 24 hours. The sampling rate was an half an hour. During this day we variated q_c, the circulating flow in front of the subject entrance, and q_cprime, the circulating flow in front of the main exit. We also variated q_p, the pedestrians crossing the crosswalk at the subject entrance, and q_pprime, the pedestrians crossing the crosswalk at the main entrance. The data for them was set for a usual roundabout in the city. This was done for $n_a = 1$ and $n_a = 2$. The percentage advantage of $n_a = 2$ compare to $n_a = 1$ over a day, was computed and displayed to the command window. Also we plotted the data to figure 3, which shows $c_s(n_a)$. All the produced data got stored in a txt-file called Daytimecs.

parameter	value	unit
tau_p	2	sec
tau_c	2.2	sec
t_fp,t_fc	3.2	sec
t_Cc	4.5	sec
t_Cp	6.2	sec
t_0c	t_Cc-(0.5*t_fc)	sec
t_0p	t_Cp-(0.5*t_fp)	sec
q_p	not constant	cars/sec
q_pprime	not constant	cars/sec
q_m	(1/3600)*50	cars/sec
q_mprime	(1/3600)*50	cars/sec
q_c	not constant	cars/sec
q_cprime	not constant	cars/sec
alpha_x	0.2	cars
n_b	2	cars
n_a	2	cars
t	not constant	hours

Figure 6: parameters in ”daytime”

6 Simulation Results and Discussion

Comparison of our work to Esimation of Roundabout Entry Capacity That Considers Conflict with Pedestrians written by Dr. Eng. Nan Kang and Dr. Eng. Hideki Nakamura
With the first implementation we wanted have a look at the impact on the entry capacity of a increasing space between the crosswalk and the yield line.

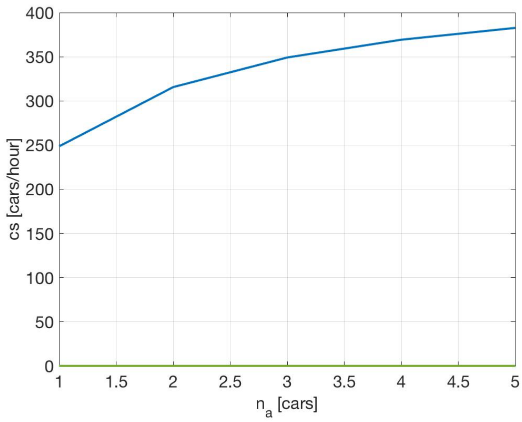

Figure 7: cs in terms of n_a

The first Graph plotted from distance shows, that there is clearly an effect of a growing n_a on the entry-capacity cs. We decided to only consider $1 \leq n_a \leq 5$. Because everything else isnt reasonable or in use in switzerland. It shows also, that the effect of a growing cs gets smaller with a bigger n_a. The biggest change is from $n_a = 1$ to 2. At a next point we wanted to see, if the effect also exist, with a growing q_c and we made a 3D plot.

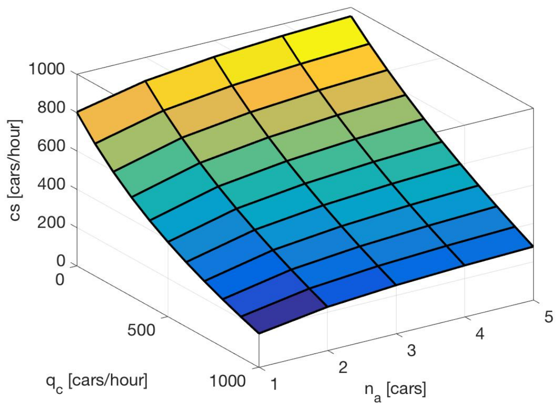

Figure 8: cs in terms of n_a and q_c

This Graph shows, that the effect of n_a on c_s is not really depending on q_c. Of course c_s gets smaller if q_c gets bigger. But it behaves the same for all the n_as. In other words, n_a has an homogeneous impact on c_s varying q_c.

Considering that q_cprime, q_p and q_pprime are taken as constant in the first implementation, the results of distance were only a hint in wich direction the research should go. Indeed, according to the previous results, the most significative difference is when n_a varies from 1 to 2. As a consequence, in the second implementation, we set n_a= 2 and compared it with $n_a = 1$, so we could see the advantage of having a slightly bigger gap, which isnt very usual in Switzerland. This gap is stll relatively small and it would still be reasonable for pedestrians to use it. Since we know that n_a = 3,4,5 dont provide a lot of change in terms of results, there wouldnt be necessary to negatively impact the convenience of pedestrians by putting the crosswalk further down the road.

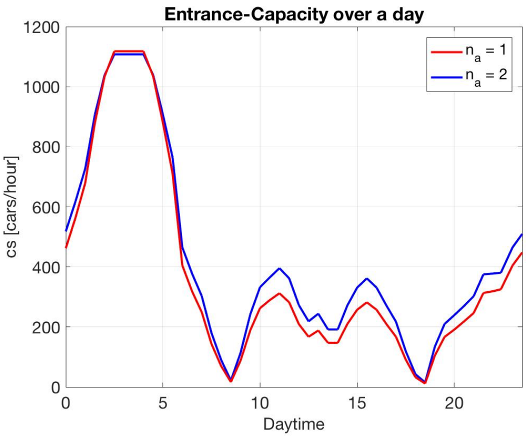

Figure 9: cs over a day for $n_a = 1$ and $n_a = 2$

As seen in the plot above collected from the implementation daytime, the smallest entry-capacity, is at 7.30 am, it is near to zero, and there is not even a difference between $n_a = 2$ and$n_a = 1$.The same applies at 6.30 pm. There also is not a big change between 0.00 am and 7.30 am, the reason in this case is that we are not having a lot of pedestrians, and that the amount of traffic is small. As seen in the main function of daytime(see appendix) the biggest density of pedestrians is between 7am in the morning and 8.30 pm. In this time the effect from the various n_as, is also the biggest. This matches with common sense, because if you have a high pedestrian rate the probability that a pedestrian blocks a car gets bigger, therefore cs gets smaller. Also if you have a bigger space between the crosswalk and the yield line, the before mentioned probability gets smaller and cs gets bigger. That explains the difference between the blue and the red line. Calculated over a day, we have with n_a equal to 2 a 11% higher entry-capacity than with $n_a = 1$. Although the data for this day was set by us, it clearly shows an advantage of a bigger n_a.

7 Summary and Outlook

In this project we have been presenting a theoretical model to estimate the entry capacity of the roundabout in terms of several factors and in particular the storage space between the yield line and the crosswalk. Although our model is highly simplified in comparison to the ones considered in the paper we red, it still gives satisfying results. Indeed, it allows us to give an answer to our question : A short increasing of n_a (from 1 to 2 for example) has a positive effect on the traffic and this effect is not so relevant for high n_a which allows us to save pedestrian's convenience. Our simulation shows clearly that it would be a progress to build a roundabouts with a space for to cars between the crosswalk and the yield line. Clearly you would have to do further researches. One next step would be to set the values of our simulation with collected data from a roundabout in Switzerland and compare the results. Which also points at the biggest problem of our research, we didnt consider actual data. Also one would have to do some research, in aspect of the safety of the pedestrians with $n_a = 2$ and compare it with the case $n_a = 1$. To Conclude one could say, that our model gives a hint that a little bigger n_a could make a non-neglected improvement on the roundabout capacity. In another hand, a couple of roundabouts features were not considered in this model, which could also provide different results and lead to different conclusions.

8 References

Wu, N. A Universal Procedure for Capacity Determination at Unsignal-ized (Priority-Controlled) Intersections

Kang, N., and H. Nakamura. An Estimation Method of Roundabout Entry Capacity Considering Pedestrian Impact.

Cowan, R. J. Useful Headway Models. Transportation Research, Vol. 9, No. 6, 1975, pp. 371375.

Siegloch, W. Die Leistungsermittlung an Knotenpunkten Ohne Lichtsig-nalsteuerung. Schriftenreihe Strassenbau und Strassenverkehrstechnik

9 Matlab code

See next page.

Implementation „distance“

```
%main skript
%Initialization
% x:= vector which contains values for n_a which is defined as the
%distance betwenn the crosswalk and the yieldline measured in cars
x = [1 2 3 4 5];
%Z := general entry-capacity of the roundabout stored in a vector matrix with the results of
c_s(x,q) [cars/hour]
Z = zeros(11,5);
%q := circulating flow infront of the subject entrance [cars/sec]
q = [0.1 100 200 300 400 500 600 700 800 900 1000];
%z := general entry-capacity of the roundabout stored in a vector with the results of c_s(x,800)
[cars/hour]
z2 = zeros(5);

%Determ cs(n_a) for q_c = 800
for i=1:(5)

    z12 = x(i);
    z22 = (1/3600)*800;
    z2(i)= cs(z12, z22);
end

%Plot of cs(n_a)
figure(2);
plot(x,z2,'LineWidth', 2);
box on;
grid on;
set(gca, 'FontSize', 16);
xlabel('n_a [cars]','FontSize', 16);
ylabel('cs [cars/hour]','FontSize', 16);

%Determ cs(n_a,q_cir)
for i=1:(5)
    for j=1:11
    z1 = x(i);
    z2 = (1/3600)*q(j);
    Z(j,i)= cs(z1, z2);
    end
end

%Plot of cs(n_a,q_cir)
figure(1);
surface(x,q,Z,'LineWidth', 2);
box on;
grid on;
set(gca, 'FontSize', 16);
xlabel('n_a [cars]','FontSize', 16);
ylabel('q_c [cars/hour]','FontSize', 16);
zlabel('cs [cars/hour]','FontSize', 16);

fid=fopen('cs1','w+')
fprintf(fid,'n_a:     ',x(i));
for i = 1:(5)
        fprintf(fid,'%e     ',x(i));
end

% Save cs(n_a,q_cir) to cs1
fprintf(fid,'\n');
fprintf(fid,'q_cir:     ',x(i));
for i = 1:(11)
        fprintf(fid,'%e     ',q(i));
end

fprintf(fid,'\n');
fprintf(fid,'\n');
fprintf(fid,'Cs(n_a,q_cir):     ');
fprintf(fid,'\n');

for i = 1:(11)
    for j = 1:(5)
        fprintf(fid,'%e     ',Z(i,j));
    end
    fprintf(fid,'\n');
end

fclose(fid);
%End main skript


%Calculation of ca (Entrycapacity when the circulatingflow is not blocked)
```

```matlab
function [y] = ca(n_a,q_c)
parameters;
temp =75000 * g(q_c);
y= (n_a/(n_a+1))*f(t_fc,q_c,tau_c,t_Cc)+(1/(n_a+1))*temp;


%Returns the general Entrycapacity of the roundabout
function[y]=cs(n_a,q_c)
p_Q = P_q();
Ca = ca(n_a,q_c);
y = (1-p_Q)*Ca;

%Calculation of ca (Entrycapacity when the circulatingflow is not blocked)
function [y] = ca(n_a,q_c)
parameters;
temp =75000 * g(q_c);
y= (n_a/(n_a+1))*f(t_fc,q_c,tau_c,t_Cc)+(1/(n_a+1))*temp;

%Probability of the queue in thecirculating roadqy reaching up to the front
%of the subject entry
function [y]= P_q()
parameters;
x_pprime = (q_mprime*exp(t_Cp-t_fp)*(exp(t_fp*q_pprime)-1))/q_pprime;
lambda = lambda_x(alpha_x, q_cprime);


%mue_p := service rate whoch is the reciprocal value of the aberage service time
mue_p = 1-(1-x_pprime)*(1-q_pprime*tau_p);

y = 150*(1-(lambda/mue_p))*(lambda/mue_p)^(n_b);

%Returns the maximum entry flow considering only the circulating flow q_c
function[y]= f(t_fc,q_cir,tau_c,t_Cc)
y = 3600*(1/t_fc)*(1-tau_c*(q_cir))*exp((-q_cir)*(t_Cc-(t_fc/2)-tau_c));

function [y] = g(q_c)
parameters;
%Maximum entryflow considering pedestrians and circulating flow without
%stopping and storage space
x_p = x(q_m,t_Cp,t_fp,q_p);
x_c = x(q_m,t_Cc,t_fc,q_c);
t_f = (t_fp + t_Cp)/2;

%traffic intenistiy with the portion of free traffic
q_fp1 = q_fp(tau_p, q_p);
q_fc1 = q_fc(tau_c,q_c);

y = ((q_fp1+q_fc1)/(1-exp(-(q_fp1+q_fc1)*t_f)))*(1-x_p) * (1- q_p * tau_p)*exp(-
q_fp1*(t_Cp*tau_p))*(1-x_c) * (1- q_c * tau_c)*exp(-q_fc1*(t_Cc*tau_c));

%Arrival rate of vehicles exiting from the main exit
function [y]= lambda_x(alpha_x, q_cprime)
y =  (alpha_x)* q_cprime;

%traffic intenistiy with the portion of free traffic
function [y] = q_fc(tau_c,q_cir)

phi = 1-q_cir*tau_c;
y = (phi*q_cir)/(1-q_cir*tau_c);

%traffic intenistiy with the portion of free traffic
function [y]= q_fp(tau_p, q_p)
phi = 1-q_p*tau_p;
y = (phi*q_p)/(1-q_p*tau_p);

%saturation degree of the queuing sytem
function y = x(q_m,t_c,t_f,q)
y = (q_m*exp(t_c-t_f)*(exp(t_f*q)-1))/q;

%Start parameters skript

% Min.  Headway for pedestrians: The time interval [sec]  between of two successive
% pedestrians
tau_p = 2;

% Min.  Headway for cars: The time interval between the arrivals of two successive
% the vehicles in the Majorflow(from front to front);
tau_c = 2.2;

%For pedestrians
%Follow-up time: Time between the departure of one vehicle from the minor s
%treet and the departure of the next vehicle using the same gap under a
%condition of continuous queuing.
t_fp = 3.2;
```

```
%For cars
%Follow-up time: Time between the departure of one vehicle from the minor s
%treet and the departure of the next vehicle using the same gap under a
%condition of continuous queuing.
t_fc = 3.2;

%Critical gap: The minimum major-stream headway during which a minor-street
%vehicle can make a maneuver.
%%t_Cc=Critical gap for cars
t_Cc= 4.5;

%t_Cp: Critical gap for pedestrians
t_Cp= 6.2;

%Intercept gap for cars: Mimimum physical gap  when one car from the
%minorflow can merge into the majorflow
t_0c= t_Cc-(0.5*t_fc);

%Intercept gap for pedestrians: Mimimum physical gap when one car
%from the minorflow can cross the majorflow(pedestrians)
t_0p= t_Cp-(0.5*t_fp);


%q_p := pedestrians crossing the crosswalk at the subject entrance [pedestrians/sec]
q_p=(1/3600)*100;

%q_m: Constant representing the minorflow at the entrance
q_m= (1/3600)*50;

%q_cprime := circulating flow infront of the main exit [cars/sec]
q_cprime= (1/3600)*400;

%q_pprime := pedestrians crossing the crosswalk at the main entrance [pedestrians/sec]
q_pprime=(1/3600)*50;

%q_m: Constant representing the minorflow at the main exit
q_mprime= (1/3600)*50;

%alpha_x: Propoation of demand of vehicles exiting the main exit X in
%circulating flow q_c
alpha_x = 0.2;

%Number of cars which can be stored between the entrance and the following
%exit. It defines the size of the roundabout
n_b= 2;


%End parameters skript
```

Implementation „daytime "

```
%Start main skript
%Initialisation

%q_c := circulating flow in front of the subject entrance [cars/sec]
q_c =       (1/3600) * 0.8 * [550 450 350 200 100 50 50 50 50 100 200 300 600 700 800 1000 1200 1400
1150 900 750 700 650 700 850 950 900 1000 1000 850 750 700 750 850 950 1150 1350 1450 1100 950 900
850 800 700 700 700 600 550];
%q_cprime := circulating flow in front of the main exit [cars/sec]
q_cprime =  (1/3600) * [550 450 350 200 100 50 50 50 50 100 200 300 600 700 800 1000 1200 1400 1150
900 750 700 650 700 850 950 900 1000 1000 850 750 700 750 850 950 1150 1350 1450 1100 950 900 850
800 700 700 700 600 550];
%q_p := pedestrians crossing the crosswalk at the subject entrance [pedestrians/sec]
q_p =       (1/3600) * 0.6 * [25 25 25 25 25 25 25 25 25 25 25 50 50 75 100 125 175 175 200 225 225
225 250 275 300 300 275 275 275 275 275 275 275 275 275 250 225 225 175 150 150 125 125 100 75 50 50
50];
%q_pprime := pedestrians crossing the crosswalk at the main entrance [pedestrians/sec]
q_pprime =  (1/3600) * [25 25 25 25 25 25 25 25 25 25 25 50 50 75 100 125 175 175 200 225 225 225
250 275 300 300 275 275 275 275 275 275 275 275 275 250 225 225 175 150 150 125 125 100 75 50 50
50];
%t := time of the day;
t = [0.0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5
14 14.5 15 15.5 16 16.5 17 17.5 18 18.5 19 19.5 20 20.5 21 21.5 22 22.4 23 23.5];
%c_s := general entry-capacity of the roundabout for n_a= 1 [cars/hour]
cs_n1 = zeros(length(t));
%c_s := general entry-capacity of the roundabout for n_a= 2 [cars/hour]
cs_n2 = zeros(length(t));

%Settings for the plot
figure(3);
```

```
hold on
box on;
grid on;
title('Entrance-Capacity over a day')
set(gca, 'FontSize', 16);
xlabel('Daytime','FontSize', 16);
ylabel('cs [cars/hour]','FontSize', 16);
axis([0.0,23.5,0,1200])

%Calculation and plotting of cs(for n_a = 2)
for i = 1: (length(t)-1)
c1_temp = cs(2,q_c(i),q_cprime(i),q_p(i),q_pprime(i));
c2_temp = cs(2,q_c(i+1),q_cprime(i+1),q_p(i+1),q_pprime(i+1));
t1_temp = t(i);
t2_temp = t(i+1);
v_t = [t1_temp t2_temp];
v_cs = [c1_temp c2_temp];
cs_n2(i)=c1_temp;
if i == 36
    cs_n2(i+1) = c2_temp;
end

figure(3);
color = 'r';
p2 = plot(v_t,v_cs,'b','LineWidth', 2);

end

%Calculation and plotting of cs(for n_a = 1)
for i = 1: (length(t)-1)
c1_temp = cs(1,q_c(i),q_cprime(i),q_p(i),q_pprime(i));
c2_temp = cs(1,q_c(i+1),q_cprime(i+1),q_p(i+1),q_pprime(i+1));
t1_temp = t(i);
t2_temp = t(i+1);
v_t = [t1_temp t2_temp];
v_cs = [c1_temp c2_temp];
cs_n1(i)=c1_temp;
if i == 36
    cs_n1(i+1) = c2_temp;
end

figure(3);
color = 'b';
p1 = plot(v_t,v_cs,'r','LineWidth', 2);

end
hold off
legend([p1,p2],'n_a = 1','n_a = 2');

%Calculation of the average adventage a_p of n_a = 1 to n_a= 2
 temp_c1 = 0;
 temp_c2 = 0;
for i=1:length(t)
    temp_c1 = temp_c1 + cs_n1(i);
    temp_c2 = temp_c2 + cs_n2(i);
end
a_p = (100/temp_c1)*temp_c2-100;
disp(a_p);

%Storing data to of cs to "Daytime_cs" and a_p
fid=fopen('Daytime_cs','w+')
fprintf(fid,'Daytime:          ');
fprintf(fid,'cs(n_a=1):        ');
fprintf(fid,'cs(n_a=2):      ');
fprintf(fid,'\n');

for i = 1:length(t)
        fprintf(fid,'%e     ',t(i));
        fprintf(fid,'%e     ',cs_n1(i));
        fprintf(fid,'%e     ',cs_n2(i));
        fprintf(fid,'\n');
end
fprintf(fid,'\n');
fprintf(fid,'\n');
fprintf(fid,'a_p= ');
fprintf(fid,'%e     ',a_p);

fclose(fid);


%End main skript

%Returns the general Entrycapacity of the roundabout
function[y]=cs(n_a,q_c,q_cprime,q_p,q_pprime)
p_Q = P_q(q_cprime,q_pprime);
Ca = ca(n_a,q_c,q_p);
```

```
y = (1-p_Q)*Ca;

%Calculation of ca (Entrycapacity when the circulatingflow is not blocked)
function [y] = ca(n_a,q_c,q_p)
parameters;
temp =75000 * g(q_c,q_p);
y= (n_a/(n_a+1))*f(t_fc,q_c,tau_c,t_Cc)+(1/(n_a+1))*temp;

%Maximum entryflow considering pedestrians and circulating flow without
%stopping and storage space
function [y] = g(q_c,q_p)
parameters;
x_p = x(q_m,t_Cp,t_fp,q_p);
x_c = x(q_m,t_Cc,t_fc,q_c);
t_f = (t_fp + t_Cp)/2;

%traffic intenistiy with the portion of free traffic
q_fp1 = q_fp(tau_p, q_p);
q_fc1 = q_fc(tau_c,q_c);

y = ((q_fp1+q_fc1)/(1-exp(-(q_fp1+q_fc1)*t_f)))*(1-x_p) * (1- q_p * tau_p)
*exp(-q_fp1*(t_Cp*tau_p))*(1-x_c) * (1- q_c * tau_c)*exp(-q_fc1*(t_Cc*tau_c));



%Arrival rate of vehicles exiting from the main exit
function [y]= lambda_x(alpha_x, q_cprime)
y =  (alpha_x)* q_cprime;

%Probability of the queue in thecirculating roadqy reaching up to the front
%of the subject entry
function [y]=  P_q(q_cprime,q_pprime)
parameters;
x_pprime = (q_mprime*exp(t_Cp-t_fp)*(exp(t_fp*q_pprime)-1))/q_pprime;
lambda = lambda_x(alpha_x, q_cprime);


%mue_p := service rate whoch is the reciprocal value of the aberage service time
mue_p = 1-(1-x_pprime)*(1-q_pprime*tau_p);

y = 150*(1-(lambda/mue_p))*(lambda/mue_p)^(n_b);

%traffic intenistiy with the portion of free traffic
function [y] = q_fc(tau_c,q_c)
%phi := portion of free traffic in the mahor stream
phi = 1-q_c*tau_c;
y = (phi*q_c)/(1-q_c*tau_c);

%traffic intenistiy with the portion of free traffic
function [y]= q_fp(tau_p, q_p)
%phi := portion of free traffic in the mahor stream
phi = 1-q_p*tau_p;
y = (phi*q_p)/(1-q_p*tau_p);

%saturation degree of the queuing sytem
function y = x(q_m,t_c,t_f,q)
y = (q_m*exp(t_c-t_f)*(exp(t_f*q)-1))/q;

%Returns the maximum entry flow considering only the circulating flow q_c
function[y]= f(t_fc,q_c,tau_c,t_Cc)
y = 3600*(1/t_fc)*(1-tau_c*(q_c))*exp((-q_c)*(t_Cc-(t_fc/2)-tau_c));

%Start parameters skript
% Min.  Headway for pedestrians: The time interval between of two successive
% pedestrians
tau_p = 2;

% Min.  Headway for cars: The time interval between the arrivals of two successive
% the vehicles in the Majorflow(from front to front);
tau_c = 2.2;

%For pedestrians
%Follow-up time: Time between the departure of one vehicle from the minor s
%treet and the departure of the next vehicle using the same gap under a
%condition of continuous queuing.
t_fp = 3.2;

%For cars
%Follow-up time: Time between the departure of one vehicle from the minor s
%treet and the departure of the next vehicle using the same gap under a
%condition of continuous queuing.
t_fc = 3.2;

%Critical gap: The minimum major-stream headway during which a minor-street
```

```
%vehicle can make a maneuver.
%%t_Cc=Critical gap for cars
t_Cc= 4.5;

%t_Cp: Critical gap for pedestrians
t_Cp= 6.2;

%Intercept gap for cars: Mimimum physical gap  when one car from the
%minorflow can merge into the majorflow
t_0c= t_Cc-(0.5*t_fc);

%Intercept gap for pedestrians: Mimimum physical gap when one car
%from the minorflow can cross the majorflow(pedestrians)
t_0p= t_Cp-(0.5*t_fp);


%q_m: Constant representing the minorflow at the entrance
q_m= (1/3600)*50;


%q_m: Constant representing the minorflow at the main exit
q_mprime= (1/3600)*50;

%alpha_x: Propoation of demand of vehicles exiting the main exit X in
%circulating flow q_c
alpha_x = 0.2;

%Number of cars which can be stored between the entrance and the following
%exit. It defines the size of the roundabout
n_b= 2;


%End parameters skript
```

txt-Files

Daytime_cs

```
Daytime:          cs(n_a=1):        cs(n_a=2):
0.000000e+00      4.620623e+02      5.180568e+02
5.000000e-01      5.637577e+02      6.181445e+02
1.000000e+00      6.789727e+02      7.270239e+02
1.500000e+00      8.799614e+02      9.072704e+02
2.000000e+00      1.034383e+03      1.038773e+03
2.500000e+00      1.118018e+03      1.107832e+03
3.000000e+00      1.118018e+03      1.107832e+03
3.500000e+00      1.118018e+03      1.107832e+03
4.000000e+00      1.118018e+03      1.107832e+03
4.500000e+00      1.034383e+03      1.038773e+03
5.000000e+00      8.799614e+02      9.072704e+02
5.500000e+00      7.103802e+02      7.640819e+02
6.000000e+00      4.049145e+02      4.650511e+02
6.500000e+00      3.191786e+02      3.779749e+02
7.000000e+00      2.493616e+02      3.030777e+02
7.500000e+00      1.436944e+02      1.803000e+02
8.000000e+00      7.004107e+01      9.030283e+01
8.500000e+00      1.670396e+01      2.174793e+01
9.000000e+00      8.857285e+01      1.144371e+02
9.500000e+00      1.893605e+02      2.424414e+02
1.000000e+01      2.627142e+02      3.326648e+02
1.050000e+01      2.894267e+02      3.649480e+02
1.100000e+01      3.123836e+02      3.958648e+02
1.150000e+01      2.821973e+02      3.620065e+02
1.200000e+01      2.095237e+02      2.727370e+02
1.250000e+01      1.674821e+02      2.188229e+02
1.300000e+01      1.884245e+02      2.443341e+02
1.350000e+01      1.473042e+02      1.918359e+02
1.400000e+01      1.473042e+02      1.918359e+02
1.450000e+01      2.104645e+02      2.722580e+02
1.500000e+01      2.573763e+02      3.311568e+02
1.550000e+01      2.821973e+02      3.620065e+02
1.600000e+01      2.573763e+02      3.311568e+02
1.650000e+01      2.104645e+02      2.722580e+02
1.700000e+01      1.673624e+02      2.175075e+02
1.750000e+01      9.188347e+01      1.198062e+02
1.800000e+01      3.283443e+01      4.295881e+01
1.850000e+01      1.175581e+01      1.542800e+01
1.900000e+01      1.048432e+02      1.343473e+02
1.950000e+01      1.670720e+02      2.102033e+02
2.000000e+01      1.912184e+02      2.394405e+02
2.050000e+01      2.184382e+02      2.697454e+02
```

2.100000e+01	2.465544e+02	3.026368e+02
2.150000e+01	3.133062e+02	3.753319e+02
2.200000e+01	3.191786e+02	3.779749e+02
2.240000e+01	3.254414e+02	3.808163e+02
2.300000e+01	4.049145e+02	4.650511e+02
2.350000e+01	0.000000e+00	0.000000e+00

a_p= 1.123363e+01

cs1

n_a: 1.000000e+00 2.000000e+00 3.000000e+00 4.000000e+00 5.000000e+00
q_cir: 1.000000e-01 1.000000e+02 2.000000e+02 3.000000e+02 4.000000e+02 5.000000e+02 6.000000e+02 7.000000e+02 8.000000e+02 9.000000e+02 1.000000e+03

Cs(n_a,q_cir):

8.032027e+02	8.780855e+02	9.155269e+02	9.379917e+02	9.529683e+02
6.911126e+02	7.762520e+02	8.188217e+02	8.443636e+02	8.613915e+02
5.969198e+02	6.872404e+02	7.324007e+02	7.594969e+02	7.775611e+02
5.170390e+02	6.086629e+02	6.544748e+02	6.819620e+02	7.002868e+02
4.485330e+02	5.385366e+02	5.835383e+02	6.105394e+02	6.285401e+02
3.890808e+02	4.752901e+02	5.183947e+02	5.442575e+02	5.614993e+02
3.368539e+02	4.176810e+02	4.580945e+02	4.823426e+02	4.985080e+02
2.904155e+02	3.647286e+02	4.018851e+02	4.241791e+02	4.390417e+02
2.486397e+02	3.156600e+02	3.491702e+02	3.692763e+02	3.826804e+02
2.106464e+02	2.698669e+02	2.994772e+02	3.172433e+02	3.290874e+02
1.757497e+02	2.268707e+02	2.524312e+02	2.677675e+02	2.779917e+02