# Remastering the Traffic Circle Control: Cumulative Waiting Time (CWT) Approach

Team Control Number: 5577

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**Abstract**

**PROBLEM A:** Designing a Traffic Circle

Team Control Number: 5577

The design of roads and especially road junctions tries to follow the necessities of people for mobility and safety to be achieved in a minimum time. A traffic circle is a particular road junction in which traffic enters a one-way stream around a central island. In conventional traffic circles there are no traffic lights and the cars already in the circle have priority with respect to the ones that are incoming from side roads. However this priority rule is not always the most efficient solution, especially at peak time. This paper presents a computational approach of the set of priority rules and traffic lights configurations that increases the efficiency of the traffic circle for different given geometries and traffic intensity.

The model, implemented in MATLAB, uses a discrete representation of the traffic circle, each unit corresponding to possible positions of cars. The program takes as input data the geometry, i.e. the number of lanes in the circle and the maximum number of cars that fit into one lane, the number of incoming and outgoing lanes as well as their position, the directional traffic intensity depending on the hour, and the traffic code. The program uses Monte Carlo method to calculate Cumulative Waiting Time (CWT) which represents the averaged time spent by all cars waiting while crossing the traffic circle during a given period. CWT is a direct measure of the efficiency. The main idea is to simulate the effect of different configurations of priority signs and traffic lights on CWT for given input data, and choose the one that provides a minimum CWT. For the traffic circles that undergo large variations of traffic intensities, a model for Self-Organizing Traffic Lights (SOTL) was implemented that takes into account the number of cars waiting in the queue. In order to process large sets of rules, multi-threading was implemented and simulations were executed on the university's computer laboratory cluster consisting of 40 dual-core servers.

The output of the program consists of the set of rules (priority signs and traffic lights including all the parameters describing their operation) that provides the minimum CWT, and thus the most efficient configuration for the flow control of the traffic circle.

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# 1 Analysis of the Problem

## 1.1 Performance Analysis

The following performance measures are typically used to estimate the performance of a given roundabout design: *degree of saturation, delay (level of service) and queue length.* Each measure provides a unique perspective on the quality of service at which a roundabout will perform under a given set of traffic and geometric conditions. Whenever possible, the analyst should estimate as many of these parameters as possible to obtain the broadest possible evaluation of the performance of a given roundabout design. In all cases, a capacity estimate must be obtained for an entry to the roundabout before a specific performance measure can be computed.

### 1.1.1 Degree of Saturation

Degree of saturation is the ratio of the demand at the roundabout entry to the capacity of the entry. It provides a direct assessment of the sufficiency of a given design. The degree of saturation is mainly determined by the geometry of the traffic circle and the vehicle flow.

### 1.1.2 Delay

Delay is a standard parameter used to measure the performance of an intersection. The Highway Capacity Manual [1] identifies delay as the primary measure of effectiveness for both signalized and unsignalized intersections, with level of service determined from the delay estimate. Currently, however, the Highway Capacity Manual only includes control delay, the delay attributable to the control device. Control delay is the time that a driver spends queuing and then waiting for an acceptable gap in the circulating flow while at the front of the queue. This concept was implemented in our algorithm as Cumulative Waiting Time which is automatically calculated based on a given model.

# 2 Mathematical Model

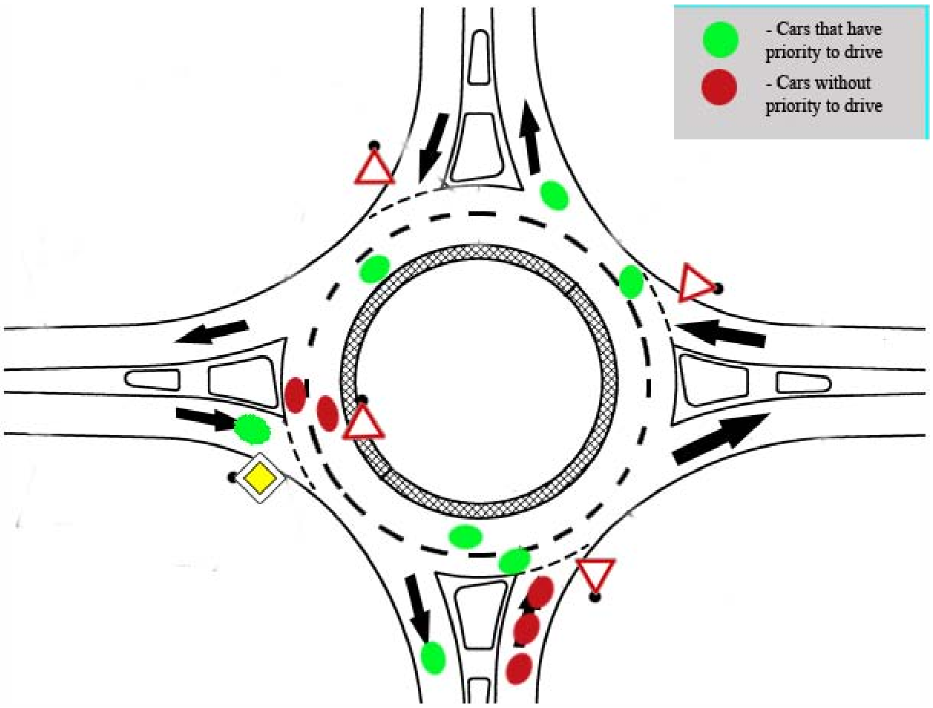


Figure 1: Traffic Circle Scheme

## 2.1 Assumptions

The traffic circle model implemented was based on the following assumptions:

- Traffic circle geometry/roads are initially given and street markings are uniquely determined by the number of lanes in the incoming and outgoing roads. Consequently, none of these parameters will be considered for optimization.
- Simulated car drivers respect the traffic code. Cars do leave the roundabout towards their preferred destination as soon as it is possible for them, without making infinite loops around the roundabout.
- Statistical traffic data is given to the simulation model for realistic optimization.
- Car crashes are not being modeled.
- Cars are moving at standardized optimal speeds on the roads and the roundabout.

## 2.2 Self-Organizing Traffic Lights

In general, traffic circles are designed to avoid the use of traffic lights. However, when 2 or more lanes with large traffic flows intersect, traffic light control is more efficient than the default priority control. In our model we have adapted a modified version of the Self-Organizing Traffic lights (SOTL) (the original version is named SOTL-*platoon* [2]). The objects representing traffic lights have several properties:

(1) Presence - controls the existence of the traffic light at the intersection (boolean variable)

(2) Queue size - minimum queue size to trigger green signal.

(3) 'On' time - total time traffic light is operating (green/red signal).

(4) 'Off' time - minimum time traffic light is forced to be in *'inactive'* mode (blinking yellow signal: priority signs determine the rules).

**How does it work?** At every junction between a traffic circle and an incoming lane, one of the two roads has priority. As long as the number of cars waiting on the non-priority lane is smaller then the Queue size, every installed traffic light is working in *'inactive'* mode and counts the cars waiting for entry into the circle. After the number has reached a certain threshold (queue size), the light turns red for the priority street and green for the non-priority street for a given amount of 'On' time. Afterwards the traffic light returns to *'inactive'* mode and is forced to stay there for at least 'Off' time until it can turn green again.

## 2.3 Implementation details

### 2.3.1 Representation

The traffic system considered in this report is European, i.e. cars drive on the right side. All objects and time in the traffic system are discretized and simplified for simulation purposes: time discretized to iterations, roads to car slots. Every lane of the traffic circle has a fixed number of cars slots it can hold. Every car occupies only 1 slot, independently of it's type.

Artificial intelligence (AI) is implemented for circle-lane switching:

- a car can switch to the other lane only if it is free;
- a car switches to the left if its destination is far away;

- a car switches to the right if it will need to leave the circle soon;
- a car tries to switch to the required lane without stopping; if it fails, it must drive around the circle once more.

Lane-switching in incoming lanes is avoided, because:

- number of switching cars after they have already chosen the lane is small and statistically not significant;
- the lane choice (approaching traffic circle) is determined by AI as well. AI takes into account final destination (outgoing-lane): a car enters lane which it needs to enter for optimal passing time;
- choice of lane is distorted by noise function which simulates natural distortions (humans irrationality, mad drivers, novice drivers) in the real life.

Traffic speeds are discretized and in case of free traffic (no queues) are considered equal and constant for all cars. Thus, the car is either moving at speed $v$ slots per iteration or has completely stopped and is waiting.

### 2.3.2 Model execution

Model is initiated with the geometry of the traffic circle and hourly segmented statistical data for traffic flows. Then, for every set of rules (priority signs and traffic lights that include discretized, limited timings and queue sizes) it runs a predefined number $N$ of simulations with noise-distorted traffic flows from all directions. More than one simulation is required since traffic flow involves noise and is not deterministic. To obtain mean values, the average of the results from all simulations is calculated (implementation of Monte-Carlo method). In this way, every simulation returns CWT (Cumulative Waiting Time) and the set of rules with the least CWT is determined. This set is printed out as the optimal configuration of priorities and traffic lights.

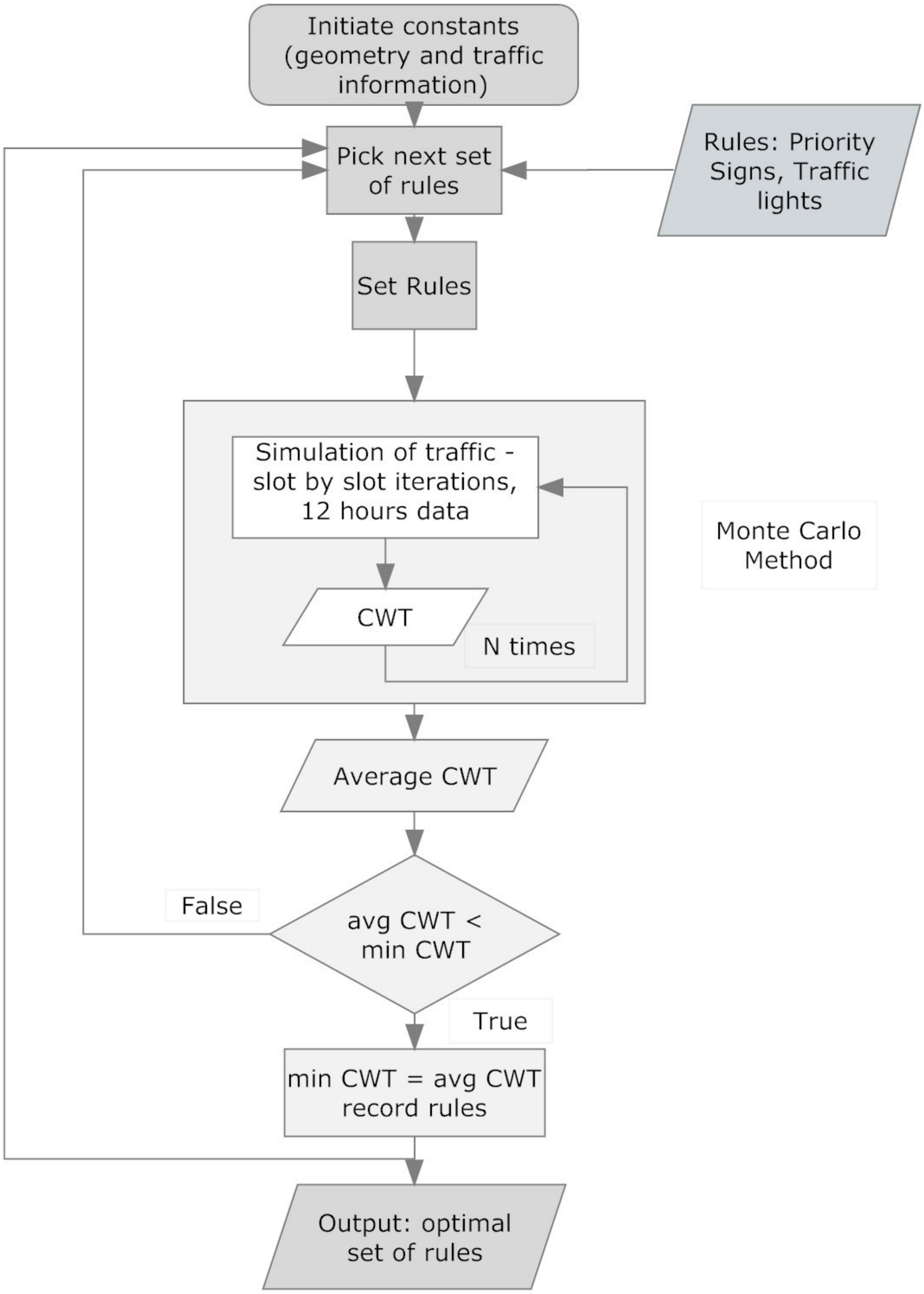


Figure 2: Algorithm Flowchart

# 3 Simulation and Results

## 3.1 Case Study: Clearwater City Roundabout, Florida

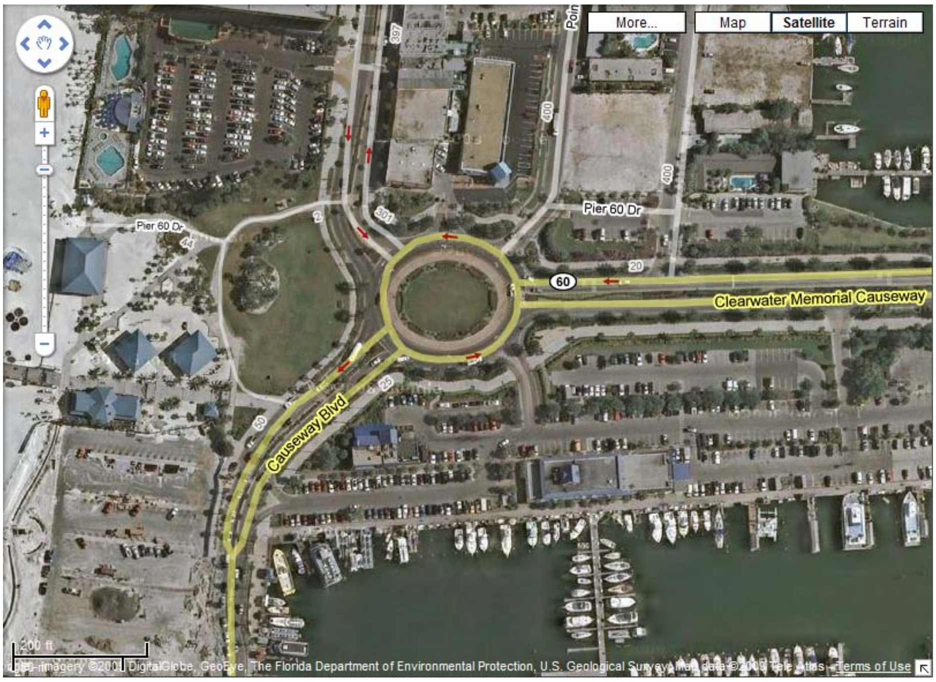


Figure 3: Clearwater Roundabout

**Real geometry details:** this double lane traffic circle is the intersection of five main roads, splitting into 8 incoming and 8 outgoing lanes. Causeway Boulevard, Clearwater Memorial Causeway and Mandalay Avenue have each two lanes per direction, while Poinsettia Avenue and the exit to the harbour have only one lane. The outer radius measures approximately 34 m and the inner radius 20 m. Statistical average speed in the traffic circle is approximately 30 km/h. The daily average traffic volume is 3100 vehicles/hour.

Mathematical model of the geometric parameters: the number of slots in the outer lane is 45 and in the inner lane is 36. The position of each lane was chosen in such a way that it respects as well as possible the angles between specific junctions.

The input data includes also the distribution of the traffic volumes for a period of 12 hours between 8 AM and 8 PM. The data was found in Clearwater Report [5] and is distributed as follows:

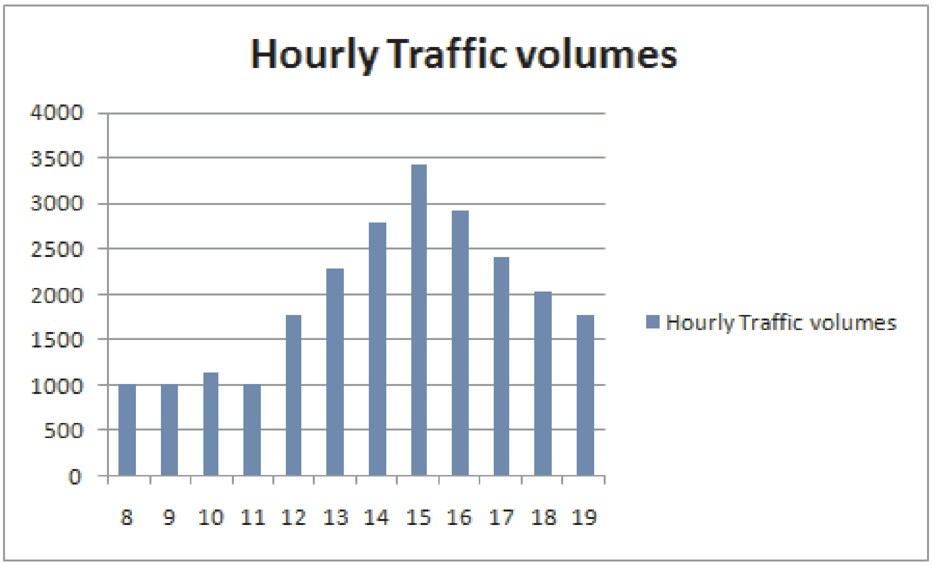


Figure 4: Clearwater Traffic Distribution

For this case study the simulation considers only configurations of priority signs, because the time needed for computing the distribution of traffic lights for this complex traffic circle would have been to long in order to include this model in the report.

For the minimum CWT, the output of the problem was the following vector $\{0, 0, 0, 0, 0, 0, 0, 0, 0\}$. This reads that none of the incoming lanes has priority and that the main stream is represented by the traffic in the circle.

The result is also in good concordance with the real design, since this is the priority rule implemented at this Clearwater traffic circle.

In order to add and optimize SOTL traffic lights, we should first analyze its most probable position taking into account the dimensions of incoming roads and the values of the traffic volumes, and then to run the program to find what which specific configuration gives a minimum CWT.

## 3.2 Case Study: Kalantos Ring, Lithuania


Figure 5: Kalantos Ring, Lithuania

*Kalantos* ring can be found in Kaunas, Lithuania. It is the place of intersection of 4 streets: *Kalantos, Gimbutienes, Masiulio (Southern stret)* and *Ateities Avenue (Northern street)*. Every street has 1 lane. This roundabout is currently being analysed by the city government for optimization.

The main traffic comes from *Kalantos* street and goes to *Masiulio* street and *Ateities* Avenue. Current major problem is increasing traffic from *Masiulio* street to *Ateities* Avenue and *Kalantos* street. This problem can be solved with the help of a properly placed traffic light.

The radius of the outer ring is 20m and of the inner one 14m. The average usage of the roundabout is 600 veh./hour. the capacity of the ring is approx. 20 vehicles.

We used the average hourly traffic data from the city traffic statistics [7], represented in the following chart:

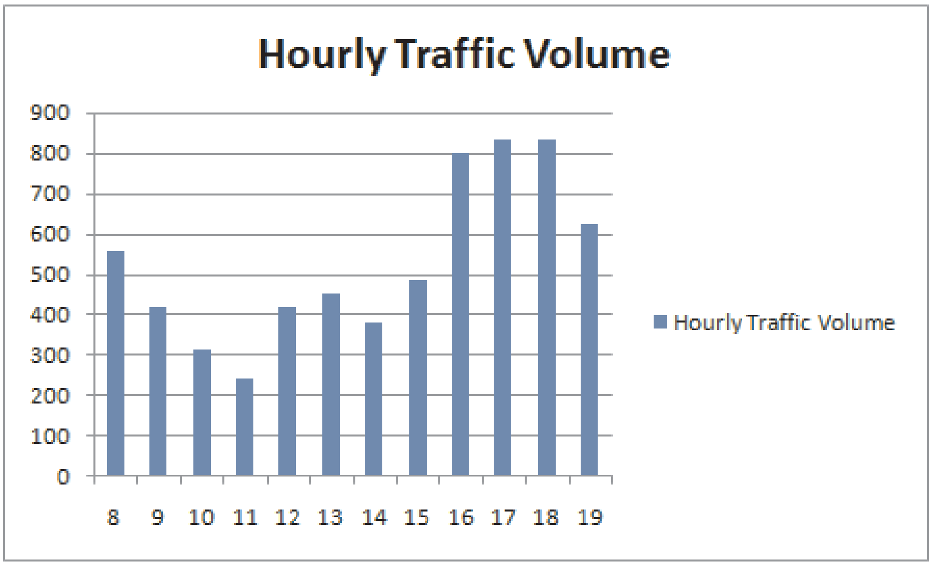


Figure 6: Kalantos Ring Traffic Volumes

During the simulation part to optimize priority sign assignments, the model gave the output: {1,0,0,0}, which means that cars from *Kalantos* street shall have the priority to enter the traffic circle, which is completely logical due to high numbers of cars entering the circle from this street and conflicting with cars getting in the circle from *Ateities* st. This conclusion does certainly contradict the conventional default priority rule.

During the second simulation optimization of the traffic lights was performed as well. The model outputted the same priority assignments as before ({1,0,0,0}) and, additionally, a traffic light in position 2 on *Masiulio* st. with queue size = 11 cars, green time = 14 and off-time = 24 seconds. In this way cars move freely from *Kalantos* st. to the circle and traffic light periodically gives the priority to the cars from *Masiulio* street.

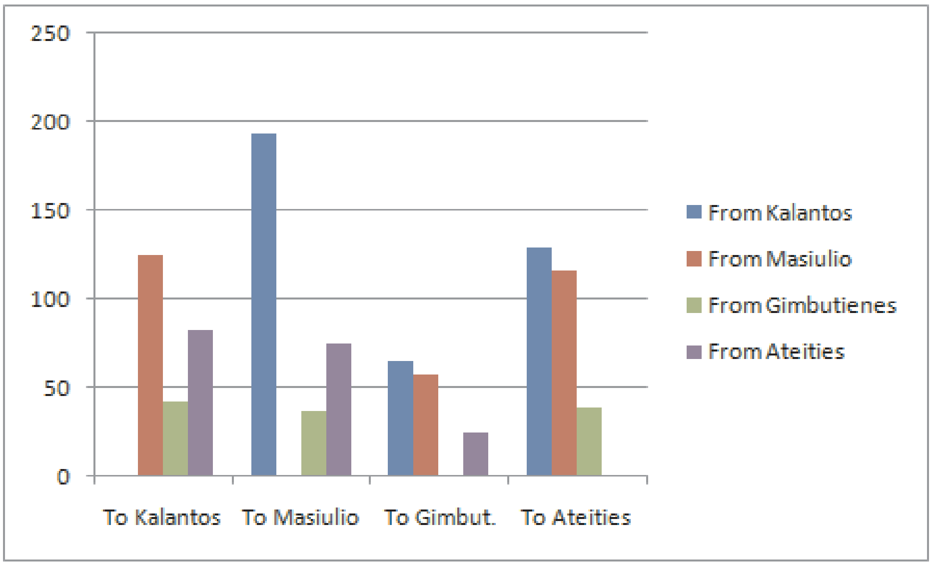


Figure 7: Kalantos Ring Traffic Volumes by street

# 4 Further Modelling

- This performance measurement technique could be further developed if we implemented an algorithm to transform the abstract value of CWT into real time units. Consequently, this model would offer the possibility to obtain concrete values for the parameters that measure the efficiency of a traffic circle control, i.e. *degree of saturation, delay (level of service)* and *queue length.*

- Another way to improve the modelling is to create an analyzer for the statistical data so that the simulation runs only for the several most probable distribution of traffic lights, since the optimization of the latter consumes most of the computational resources. This technique would decrease the complexity of the algorithm, especially when large traffic circles with multi-lane roads are modelled.

- The model could also include a simulation for pedestrian crossing and bicycle lanes as well as the optimal distance between a bus stop and the traffic circle.

- Potential car accidents could also be simulated.

# 5 Technical Summary

The program uses the Monte Carlo method to calculate the most efficient distribution of priority signs and traffic lights, referred to as rules, for a given geometry of the traffic circle.

The first step in using the program is to set the constants for a specific model:

- number of lanes in the circle and their maximum capacity, i.e. slots per lane,
- number of incoming and outgoing lanes (sum less than maximum nr of slots) and their position on the discretized circle (integer between 1 and maximum nr of slots)
- behavior of driver, i.e. the number of free slots needed to enter the traffic circle.

The input variables also require statistical data for the traffic intensities, i.e. the number of vehicles that travel from one given point to another in one hour interval. This data has to be input for hourly intervals. Then the user must run the simulation. The program chooses a random configuration of priority signs and traffic lights so that each configuration is used only once. For every arrangement, the program simulates the traffic for a period of 12 hours taking into account the hourly statistical data and calculates the Cumulative Waiting Time for all the cars. In order to improve the consistency of the result, there are performed N simulations and calculated the average CWT. The program generates all the possible configurations of rules, and chooses the optimal one as that with the smallest value for CWT.

Output consists of:

- optimal priority rules for every intersection in the roundabout (0 if the incoming lane has no priority - default rule and 1 otherwise - the incoming lane has priority)
- optimal places for traffic lights
- recommended queue sizes to trigger the traffic lights
- 'On' and 'Off' times for individual traffic lights

User can directly apply the output data to the real problem.

# References


[1] *"Roundabouts:An Informational Guide"* US Department of Transportation; available at www.tfhrc.gov/safety/00064.pdf

[2] *Self-Organizing Traffic Lights: A Realistic Simulation*; available at http://arxiv.org/abs/nlin.AO/0610040

[3] extract from *Highway Capacity Manual 2000*; available at: https://people.sunyit.edu/ lhmi/ahb40/meetings/2005-07/Draft Ch 17-C Procedure 2005-07-02.pdf

[4] *Roundabouts* http://en.wikipedia.org/wiki/Roundabout

[5] *Entryway Roundabout Review Of Operation Safety*; available at www.ourston.com/clearwater%20report.pdf

[6] *Roundabout Design Standards*; available at: www.springsgov.com/units/traffic/Roundabout %20Design%20Standards%20CTAB%20Oct%204th.pdf

[7] Department of Statistics to the Government of the Republic of Lithuania; website http://www.stat.gov.lt/lt/