1 JULI 2023

CAN A ROUNDABOUT DESIGN IMPROVE INTERSECTION OF THE HAAKSBERGERSTRAAT AND THE USSELERRONDWEG IN ENSCHEDE?

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Executive summary

The intersection of the Haaksbergerstraat and the Usselerrondweg has recently seen some changes in different areas. Due to the realisation of the new N18 the traffic pattern around the intersection has shifted. Furthermore, the traffic light application has been upgraded and a conflict of left turning traffic has been taken out. Because or in spite of the changes the municipality of Enschede still receives complaints about long waiting times and queues at the intersection. This research has been conducted to investigate whether a conventional roundabout or turbo-roundabout is better equipped to deal with the current traffic situation at the intersection. The current situation was modelled in Vissim, as were both alternative designs. An assessment of the design was made using traffic simulations in Vissim as well as a conceptual analysis of the different designs on safety. From these results a multi-criteria decision analysis was made to determine the best design. The best design that came from the multi-criteria decision analysis was the turbo-roundabout, which was the best design by quite a margin. The current situation was the second-best alternative, while the conventional roundabout was the worst design of the three.

Table of contents

1. Introduction 4
2. Context 5
   2.1 Study Area 5
   2.2 Project concepts 7
   2.3 Stakeholders 8
3. Problem statement and research objective 9
   3.1 Problem statement 9
   3.2 Research objective 9
4. Research method 10
   4.1 Data 10
   4.2 Original model 12
   4.3 Alternatives 14
      4.3.1 Alternative 1: conventional roundabout 14
   4.3.2 Alternative 2: turbo-roundabout 15
   4.4 Validation 16
   4.5 Number of runs 18
   4.6 MCDA 18
5. Simulation results 19
   5.1 Results non-peak 19
   5.2 Results average peak 21
   5.3 Results extreme peak 22
6. Safety 24
   6.1 Conflict zones 24
   6.2 Approach speed 25
   6.3 Literature 25
7. MCDA 27
   7.1 Weights of criteria 27
   7.2 Rankings per criteria 28
   7.3 MCDA outcome 29
8. Conclusion 31
9. Discussion 31
10. Future research 32
11. References 33

Appendix 34
   Appendix 1: Results validation tests 34

Appendix 1a: Internal validity test 34
Appendix 1b: Degeneracy test 40
Appendix 1c: Extreme condition test 41
Appendix 1d: Face validity test........ 42
Appendix 2: Calculations number of runs 44

1. Introduction

Nobody likes them, the long queues at intersections when driving to or from work. They seem to take forever and every time you think you can make the light it turns red just when you are about the get up to speed. The intersection of the Haaksbergerstraat and the Usselerrondweg is one of those intersections, where long queues and waiting times have been reported. The intersection, which lies in the municipality of Enschede, will therefore be assessed to investigate whether a different type of traffic solution can fix this problem. The main factors with which the different designs in this report are assessed are performance and safety. These factors, the exact definitions of these factors are explained later in the project concepts part, are the most important factors when it comes to assessing the viability of a design. Without proper performance or safety no design will ever get further than a piece of paper. In order to be able to objective state which design will be the best design proposed in this report a multi-criteria decision analysis will be made. This allows for a fair assessment of the different design in comparison with each other and will result in a design emerging as the best when compared to the other designs.

2. Context

This section explains information which is of importance to understand the background of this project. It includes information about the location of the intersection in question and explains several key concepts which are used throughout the rest of the project. Furthermore it presents stakeholders and their interest to serve as some general background information.

2.1 Study Area

The intersection that is investigated in this project is the intersection of the Haaksbergerstraat and the Usselerrondweg just outside the city of Enschede on the south-western side of the city. The exact location within the city of Enschede can be seen in figure 1, where it is marked by the red circle. The Haaksbergerstraat is a single lane road in both directions leading from Eibergen and subsequently Haaksbergen before leading into Enschede on the south-western side of the city. The Haaksbergerstraat leads straight onto the Getfertsingel, which is part of the outer ring around the city centre of Enschede. The Usselerrondweg leads from the southern part of the city of Enschede towards the north-western part of the city, including the university and the industry and harbour district. The Usselerrondweg is the busier of the two roads, due to its connection between the southern part of the city and the connection towards the A1 highway. Just north of the intersection on the Usselerrondweg lies Intratuin Enschede, a big garden centre.

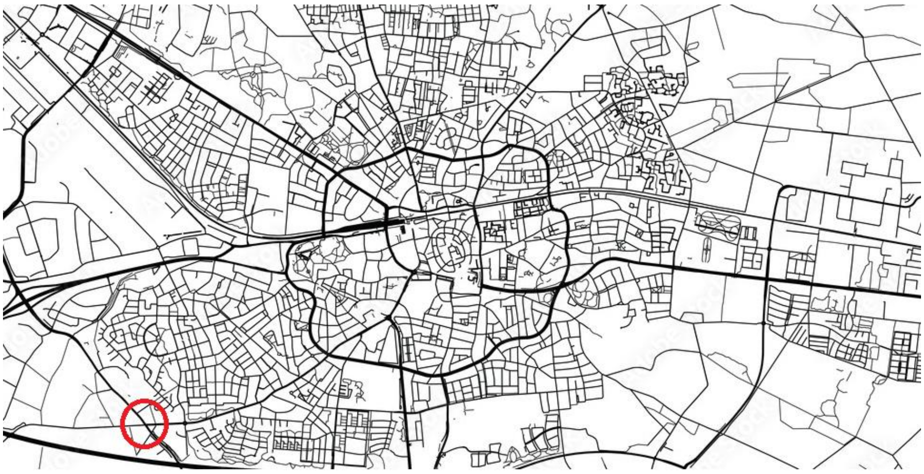

Figure 1: Location of the intersection in Enschede

The realisation of the N18 road which enters Enschede from the east has shifted the traffic pattern at the intersection of the Haaksbergerstraat and the Usselerrondweg. Before most of the traffic travelled on the Haaksbergerstraat, whereas the realisation of the N18 has caused a shift towards more traffic travelling on the Usselerrondweg. Previously traffic from Haaksbergen going towards Enschede would use the Haaksbergerstraat, currently this traffic has shifted towards the N18. The busier of the two connecting links has become the Usselerrondweg, with traffic mainly coming from the southern side of the city and moving towards the A35 highway, university and industrial district. This shift in traffic can also be seen in the current situation, with the Haaksbergerstraat having three separate lanes for each direction of travel on both sides and the Usselerrondweg having only two lanes. This can be seen in figure 2, in which lanes have been marked with red arrows. This means that the two busier directions, north and south, have fewer lanes to deal with the bigger traffic intensity.

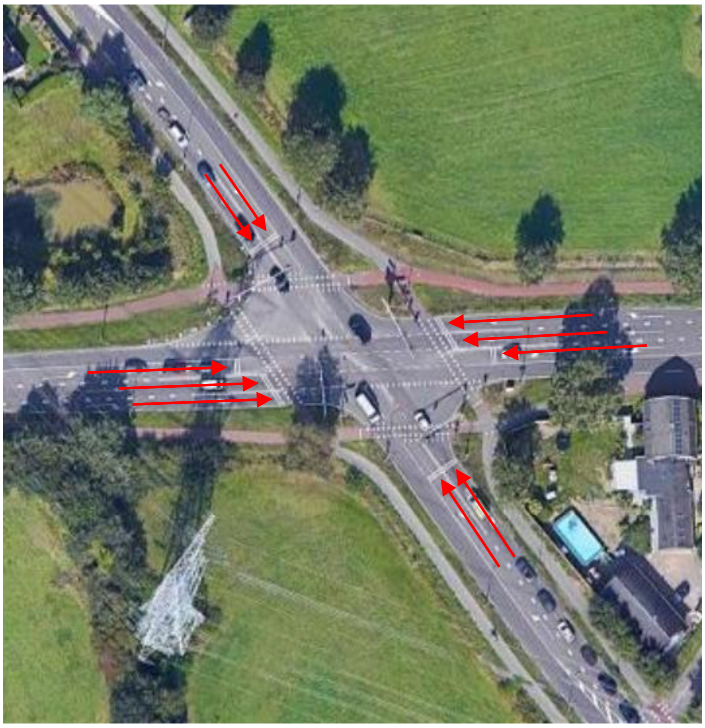

Figure 2: Lanes on intersection (Google Maps, 2023)

The current situation on the intersection of the Haaksbergerstraat and the Usselerrondweg is a regular signalised intersection. A look at the intersection from ground level, taken from the western side of the intersection of the Haaksbergerstraat, can be seen in figure 3. It has a dedicated left turn, right turn and straight lane on both sides of the intersection on the Haaksbergerstraat, which are the east and west sides of the intersection. For the Usselerrondweg, the north and south side of the intersection, it has a dedicated left turn lane and a straight and right turn combined lane on both sides. As of right now there are single lane cycling lanes that run in every direction with traffic lights in an anti-clockwise direction. This means that for cyclists who travel around the intersection in a clockwise direction there are no traffic lights. Travelling in clockwise direction is not what cyclists are meant to do at this intersection but the current lay-out with only anti-clockwise direction traffic lights does provide for more possible conflict. This would be because some cyclists will inevitably go in the clockwise direction when they do not want to travel around the entirety of the intersection. This would mean they would have to assess the situation themselves which will always leave a greater chance of conflict then with traffic lights. The cycling lanes leading up to the intersection are currently one lane cycling paths and therefore it is assumed that cycling traffic is always on the right side of the road.

Figure 3: Current situation of the intersection seen from ground level (Google Maps, 2023)

The recent changes on the intersection mentioned within the introduction include the conflict of left turning traffic from the Usselerrondweg (south and north sides) with traffic going straight on the Usselerrondweg coming from the opposite direction. In the old situation the traffic turning left would have to go between traffic going straight from the opposite direction. This would provide a situation in which the traffic turning left is in the middle of the intersection while also having to assess whether a gap is big enough for them to go and turn left. The conflict is shown in figure 4 below, in which the arrows indicate which directions have a green light at the same time and cause a potential conflict. Further changes included the replacement of the old VRI installations, which were replaced by iVRI installations. VRI means 'verkeersregelingsinstallatie' which translates to a traffic control installation. The iVRI is an intelligent version of the VRI, it can alter green and red times on the traffic intensity in real-time. This leads to a more efficient traffic control system.

The municipality of Enschede is currently planning to improve the cycling path along the Haaksbergerstraat from the intersection with the Usselerrondweg until the intersection with the Europalaan. The cycling path will be increased from a single lane cycling path to a double lane cycling path and will therefore influence the way in which the cycling situation will be on the east side of the intersection, towards Enschede itself. It will divide the oncoming cycling traffic on the east side of the intersection over the two lanes across both sides of the road. (Gemeente Enschede, 2023)

Figure 4: The intersection seen from above (Google Maps, 2023)

2.2 Project concepts

In this section some of the terms used during this project are further explained. These definitions of the concepts mentioned below are consistent throughout the project.

During this project the performance of the intersection is used as a comparison between alternative designs. The performance of the intersection in this project is defined by the following three factors: travel times, average queue lengths and the number of vehicle stops. Travel time is the time it takes a person to get from point A to point B, in this case from the point at which vehicles enter the system at one of the roads leading to the intersection to an exit point at another road leading away from the intersection. Queue length is the average length of a queue of vehicles starting from the stop line before the intersection. The number of stops is the total amount of times vehicles have to come to a stop. Safety is not considered to be part of the performance of the intersection in this project. Safety is very important and it is therefore considered as a separate part from performance. Furthermore it is difficult to quantify safety in comparison to performance factors.

The safety aspect of this project includes the number of conflict areas, the approach speed of vehicles and a part using literature review. A conflict area is a place on the intersection at which there is a possibility of vehicles meeting one another at the same time. This could for example be a bike lane crossing over a regular lane without traffic lights present. The safety part of this project will include some literature since it is very difficult to quantify safety and a combination of different sources and studies can provide a better overall look at how safe each design is and potentially draw comparisons between the different designs.

2.3 Stakeholders

In order to be able to produce alternatives/solutions that are best for the situation at hand it is important to understand and take into account the interests of the parties that are involved or influence by the project. The stakeholders in this project are mentioned below, all with at least one main interest of this stakeholder.

Municipality of Enschede
The municipality of Enschede is considered to be the most important party involved in this project. They are the ones facilitating this project and are responsible for the intersection, in terms of constructing, financing and maintaining safety. Therefore, the input of the municipality needs to be strongly considered during the design phase of the project. Their main interests in this project are to improve the performance of the intersection, as well as reducing risks of conflict and/or injury.

Road users
The road users passing through the intersection, including public transport, want to experience as little delay as possible. More importantly they want to be able to safely pass the intersection. The road users include all motorised traffic, as well as cyclists and pedestrians. The cyclists and pedestrians will often be grouped together since the pedestrians in this area use the cycling paths and are limited in number. The main interests of the road users are a safe travel across the intersection as well as a travel time across the intersection that is as low as possible and the lowest amount of delay possible.

Emergency services
It is of significant importance to emergency services to be able to pass the intersection as quick as possible, with the least number of interfering traffic as possible. The emergency services are a smaller party of interest in this project in terms of size since the amount of emergency services traffic is significantly lower compared to regular traffic. However, they have a large interest within the project since their interests are with the safety and wellbeing of humans and should therefore be considered with a high level of importance.

Local stakeholders
The local stakeholders involved or affected by the project include the residents nearby, who are not large in number but still experience affects from the intersection, as well as the Intratuin garden centre which is close by. The main interest of the residents and the Intratuin is to experience the least amount of nuisance possible. This nuisance could be in the form of noise from traffic or from traffic blocking driveways. The local stakeholders will not have any or any considerable influence but should nonetheless be taken into account.

3. Problem statement and research objective

3.1 Problem statement

The intersection of the Haaksbergerstraat and Usselerrondweg is one that the municipality of Enschede received several complaints about. These complaints are related to long queues and high travel times across the intersection. This can be considered noteworthy though, because recent attempts have been made by the municipality to improve the intersection. Vialis, who developed the application that runs the intersections traffic lights, upgraded the VRI system to an iVRI system. Furthermore the municipality decided to eliminate the conflict mentioned previously. Lastly, the realisation of the new N18 has resulted in a shift of traffic on the intersection of the Haaksbergerstraat and the Usselerrondweg. All this led to the question whether this type of intersection is perhaps just not suited for this specific traffic situation. Or is the traffic intensity at this location just too much to deal with?

3.2 Research objective

In the Netherlands the main alternative for signalised intersections are roundabouts. It is therefore investigated whether a conventional roundabout would be better suited than the current signalised intersection. The conventional roundabout is not the only type of roundabout which is found in the Netherlands though, a so-called turbo-roundabout is also a viable alternative for the intersection in question. The main objective of this project is therefore to investigate whether a conventional roundabout or turbo-roundabout would perform better than the current situation. However it is important as well to not just be focussed on how the different designs perform, as it is very important to take safety aspect of these designs into account. Investigating the safety of the alternatives, as well as the safety of the current situation is therefore also an objective in this project. The difference in nature of the roundabouts and the signalised intersection does beg the question though: how can the different design be fairly compared?

4. Research method

During this project the simulation software that is used is called Vissim. According to the creators of Vissim it is the worlds most advanced and flexible traffic simulation software and is the standard traffic simulation software used in over 2500 cities worldwide (PTV-GROUP, 2023). It is a microsimulation software for simulating traffic flows outputting a variety of variables that include travel time, travel delay and average speed among others. These can be obtained per vehicle, as well as an average of all vehicles over one simulation run. Within Vissim one can 'draw' the road network needed for their simulations in a visualized editor, including features like roundabouts and traffic lights. Simulations are conducted instead of real-life experiments because real life experiments are often expensive, time consuming and unpractical in nature. Furthermore, there are also more uncontrollable external factors, like the weather for example. It can however not be designed and just implemented either, this would open the possibility that a faulty design is implemented and causes problems. Therefore, it is important to perform simulations of the situation to assess how it works in theory. All in all, simulations are a cheaper and more time effective method of testing the implementation of design in traffic infrastructure. For this project this also leads to a fairer comparison between the designs since conditions can be kept the same and external factors are basically eliminated.

4.1 Data

The data used as input into the Vissim models is gathered via twente.verkeer.nu, which is a website operated by Vialis with all data gathered by the traffic detectors at several intersections in Enschede. The sample period from which the data was gathered was from the 17th of March 2023 until the 16th of April 2023. The easter holiday was not included in the data since it was observed in the original data sets that the traffic intensity during this holiday is significantly lower than traffic would be any other regular day.

The data that was obtained was the data collected via the detection loops in the road before reaching the traffic light. This data is expressed in vehicles per hour per direction of travel. From this an average traffic intensity per hour per direction was calculated for each separate day. From the average traffic intensity per hour for each day the average intensity per hour over the entire period was calculated. The outcome of this can be seen as the OD-matrix seen in table 1 below and is considered to be the traffic intensity of a normal hour. After calculating the traffic intensities for a normal hour, the traffic intensities for the average peak hour would be determined. This was done by calculating the average intensity per hour over the entire sample period and determining which hour of the day is the busiest for each direction over the period. From this the average maximum traffic intensity was taken and used as the OD-matrix. The OD-matrix for the average peak hour can be seen in table 2 below. Lastly, the maximum traffic intensity per hour per direction over the entire sample period was taken. This serves as the input for the OD-matrix for the busiest the intersection could be for one hour. This OD-matrix for the extreme peak hour can be seen in table 3 below.

In the current design of the intersection the Usselerrondweg is on both sides split into two lanes for three directions. The right-turn and straight lanes are a combined lane and light. The data that is used as input for the model of the original situation is measured via traffic loops in the lanes just before the traffic lights. Therefore, the right-turning and straight going traffic on the Usselerrondweg are combined within the original data set. In order to split the total amount of traffic in this lane into right turning and straight going traffic amounts the latest physical traffic counts that are available were used to determine the percentage of traffic that turns right. The latest traffic counts of the intersection date back to 2017, it therefore might not be completely accurate to state that this percentage still holds today. It does give a solid indication however to the amount of traffic that turns right from the combined lane.

The data available was data from the 3 of October 2017. This data was gathered using traffic counts that were conducted during 2-hour periods in the morning, from 7:30 to 9:30, and in the afternoon, from 16:00 to 18:00. The data was subsequently assessed for both morning and afternoon traffic for the directions north-west, north-south, south-east and south-north. From this an average percentage of 20% of traffic travels in the south-east direction from the combined lane for south-east and south-west. On the other side of the intersection the percentage was calculated to be 30% of traffic travelling in the north-west direction from the combined lane for north-west and north-south.

Table 1: OD-matrix for normal hour

Veh/h		Destination			
		East	South	West	North
Origin	East	-	96	85	93
	South	64	-	49	255
	West	78	53	-	32
	North	66	169	72	-

Table 2: OD-matrix for average peak hour

Veh/h		Destination			
		East	South	West	North
Origin	East	-	230	188	201
	South	116	-	93	466
	West	172	146	-	73
	North	167	391	168	-

Table 3: OD-matrix for extreme peak hour

Veh/h		Destination			
		East	South	West	North
Origin	East	-	269	263	309
	South	161	-	134	644
	West	221	194	-	113
	North	214	510	218	-

The next step is to determine the percentage of traffic that is truck traffic. To determine the percentage of trucks the data of trucks per direction per hour was used to calculate an average percentage of trucks. This percentage was calculated to be 5,5% of total traffic. This can be implemented within Vissim by changing the vehicle composition to 94,5% cars and 5,5% trucks.

Since there is not any data from detection loops for cyclists the OD-matrix used for the cyclists must be determined using older manual traffic counts. With this traffic count the percentage of total traffic that are cyclists is determined. This percentage is then applied to the OD-matrix for motorised traffic and from that the OD-matrix for cyclists can be determined. The manual traffic counts are from the third of October 2017. Even though these percentage might not be fully accurate, it does give an indication of the amount of traffic that are cyclists. The biggest caveat with this method is

that it does not consider whether the number of cyclists travelling a certain route has a direct relation to the amount of motorised traffic travelling the same route. Even though this is not an ideal situation it does not affect the total amount of cyclists travelling through the intersection. It is therefore assumed that this does not have a great effect on travel times or travel delays overall compared to a potentially more accurate situation which would better represent the distribution of cyclists across the different directions of travel.
It was determined via this method that 15% of total traffic are cyclists. The OD-matrices that follow can be seen in tables 4, 5 and 6 below, for the non-peak, average peak and extreme peak hours respectively.

Table 4: OD-matrix for cyclists for normal hour

Cyc/h		Destination			
		East	South	West	North
Origin	East	-	32	28	31
	South	21	-	16	85
	West	26	18	-	11
	North	22	56	24	-

Table 5: OD-matrix for cyclists for average peak hour

Cyc/h		Destination			
		East	South	West	North
Origin	East	-	77	63	67
	South	39	-	31	155
	West	57	49	-	24
	North	56	130	56	-

Table 6: OD-matrix for cyclists for extreme peak hour

Cyc/h		Destination			
		East	South	West	North
Origin	East	-	90	88	103
	South	54	-	45	215
	West	74	65	-	38
	North	71	170	73	-

4.2 Original model

The current situation of the intersection has previously been described in the study area section of this report. This section will therefore focus on the model of the original situation within Vissim and how this was constructed. In figure 5 below the Vissim model of the original situation can be seen. From the figure it can be seen that the intersection has several 'holes' in it. This would, in real life, be filled up with asphalt. Vissim however only visualises the lanes of travel of vehicles and therefore these holes are visible within the model but would not be there in real life. As with all alternatives discussed later vehicle traffic is generated in parking lots on the edges of the incoming lanes and they disappear in parking lots on the edges of outgoing lanes. These parking lots do not function as parking lots would in real-life. These just serve as the way in which Vissim generates traffic in the system. It can therefore be seen more as a spawning point than an actual parking lot. The current traffic light control system for the original situation was created with the help of employees of Vialis, who were helpful enough to help implement the control system within this model. Vialis provided a separate extension which operates the traffic lights using vehicle detectors within the system in Vissim. This simulates the same signal control scheme as would appear at the real-life version of the intersection.

The model was constructed using an image from google maps being placed into Vissim as a background image. This background image was subsequently scaled and used to determine where links should be placed. The width of a lane was determined via the measuring tool within google maps. A regular lane was determined to be 2,75 m in width and cycling lanes were determined to be 2 m in width. Although this has no influence on the behaviour of traffic in Vissim it is of importance for the amount of space the intersection takes on, as well as making the model visually more accurate. Also using the background image the traffic light signal heads could be placed. These are not in the exact same position as in real life since the traffic in Vissim stops at the signal head and therefore they must be placed at the stop lines instead of at the real-life spot of the signal heads. The exact location of the signal heads can be seen as the red lines across the lanes approaching the intersection in figure 6, which presents a zoomed-in look at the intersection itself. Figure 7 shows the reduced speed zones, which are marked in yellow and in which the speeds of vehicles are adjusted to represent the vehicle making a turn. Left-hand turns are set at 35 km/h while right-hand turns are set at 30 km/h.

Figure 5: Original situation of intersection seen from above

Figure 6: Zoomed in view of intersection with signal heads

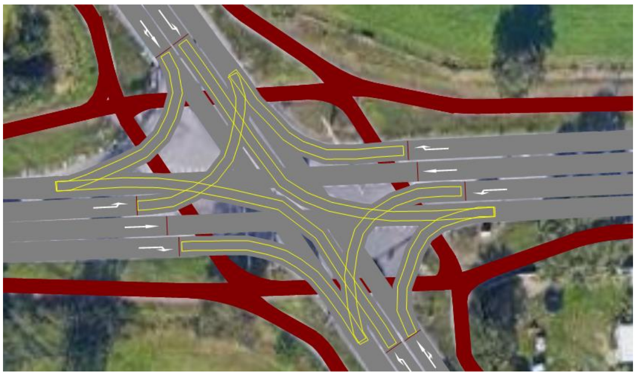

Figure 7: Reduced speed zones on intersection

4.3 Alternatives

In this section the two alternatives which were simulated are presented. As mentioned previously these two alternatives are a conventional roundabout and a turbo-roundabout. Both alternatives are simulated using the same OD-matrices as the original situation model was. Since it is virtually impossible to predict from which side of the Haaksbergerstraat cyclists would approach the intersection from the east it has been chosen to maintain single lane cycling paths.

4.3.1 Alternative 1: conventional roundabout

The first alternative created is a conventional roundabout design. It is a single lane roundabout with single lanes leading up to and away from the roundabout. Bicycle traffic can only travel in the direction of the roundabout and follows the same bike paths that are currently there, with the northern and southern lanes around the side of the intersection only slightly moved outwards. The width of the lane of the roundabout itself is 5,25 m while the diameter of the roundabout is 35 m and the inner circle has a diameter of 25 m. The minimum width of a lane on a roundabout outside city-limits is 5,25 m, while the minimum diameter of the inner circle of a roundabout outside city-limits is 20 m (Kennisplatform CROW, 2015). According to Kennisplatform Crow (2015) the maximum speed at single lane roundabouts is 35 km/h, this is therefore assumed to be the speed at which vehicles travel across the roundabout itself. Motorised traffic has the right of way in favour of cycling traffic since the intersection is located outside of city limits and policy in the Netherlands indicates that in this situation motorised traffic has the right of way (DTV consultants, 2019). Figure 8 below shows an overview of the roundabout, moreover figure 9 shows the reduced speed zones in which the speed is adjusted to 35 km/h.

Figure 8: Overview of roundabout

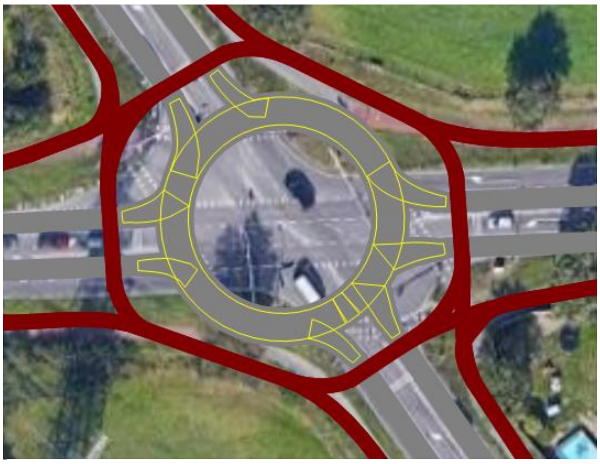

Figure 9: Reduced speed zones on roundabout

4.3.2 Alternative 2: turbo-roundabout

The second alternative is also a type of roundabout. However, this time it is a turbo-roundabout. It is a more comprehensive type of roundabout which aims to deal with the issue of vehicles stacking up on the approach to the roundabout. Vehicles making a right turn on the intersection stay on the outer part of the roundabout and therefore they do not hinder traffic from other directions that want to turn into the inner part of the roundabout to either turn left or go straight. They also exit the system as quick as possible, reducing the number of vehicles on the inner part of the roundabout and therefore travel times and queues. This creates a situation in which traffic arriving to the roundabout get divided into two lanes while the right-turning traffic is no hindrance to any other traffic around the roundabout, further reducing the density per lane around the intersection. Reducing the amount of traffic waiting to enter the roundabout will ensure a more efficient and quicker travel across the roundabout in every direction. To be able to implement the turbo-roundabout some land around the intersection is required. This is caused by the extra exit lane that is created on both the northern and southern edge of the roundabout for the outer part of the roundabout. This land is currently not build-up area, it is farmland, and the municipality would have to acquire these small patches of land for this design to be able to be constructed. Since the intersection lies outside city limits motorised traffic has the right of way. As with the normal roundabout described above the assumed speed around the roundabout is 35 km/h.

For the case of the Haaksbergerstraat and the Usselerrondweg the problem of the shifted traffic intensities is addressed by the fact that the northern and southern sides of the turbo-roundabout have double exit lanes. This makes the exiting of vehicles towards these directions more efficient and quicker. For the eastern and western sides a single exit lane is considered to be sufficient, since the intensity that exits the system in these directions is lower than the northern and southern sides.

In figure 10 below a top-down view of the turbo-roundabout can be seen. In figure 11 an image from Royal HaskoningDHV can be seen, which was used as an inspiration and sort of blueprint for this design. This image also gives a better look of how it should look like in real life. Furthermore, in figure 12 the reduced speed zones of the turbo-roundabout can be seen marked in yellow, in which the speed of vehicles is reduced to 35 km/h.

Figure 10: Overview turbo-roundabout

Figure 11: Image used as inspiration (Royal HaskoningDHV)

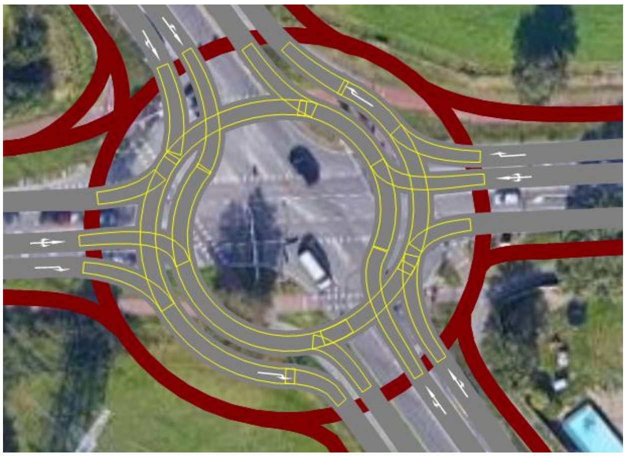

Figure 12: Overview of reduced speed zones

4.4 Validation

To be able to say that the Vissim models created can be assumed to give reliable results the models will be validated using the validation method of Sargeant. Sargeant states that using knowledge and common sense a model can be fully or partially validated mainly by the simple question: Does the tests performed come to logical outcomes? The method of Sargeant includes several validation techniques to validate a model. Some of these techniques that will be used to validate the Vissim models are explained shortly below. (Sargent, 1998)

Internal validity test

Several simulation runs are performed to test whether the model is consistent in its output. For example, a test is performed 10 times to investigate whether these 10 runs give out consistent results.

For the internal validity test the models are simulated ten times. The results of these ten simulations runs will be compared and it will be investigated whether these results are comparable and in the same order of magnitude as each other. From the results it can be concluded that the results of all the models are comparable per run and all results are in the same order of magnitude. This can be derived from the fact that the standard deviations during the simulations for the original situation and turbo-roundabout are small and therefore, there are no extremely high or low travel times. For the normal roundabout the standard deviation is higher, this however can be attributed to the nature of the roundabout causing more natural variance in the travel times measured. All in all it can be concluded that all models are internally valid. The full list of results from the ten simulation runs can be seen in appendix 1a.

Degenerate tests

Testing the degeneracy of the model by choosing appropriate values for input variables and internal parameters. For example, testing whether a travel delay around an intersection will increase when more vehicles arrive at the intersection than can leave at one time.

The models are run five times for both a normal hour as well as a peak hour. This test is used to determine whether the different models are in a similar class and can therefore be compared. If the model is valid the results of the normal hour should indicate a lower travel time than during a peak hour. The averages over the five runs are compared to make this assumption. From the simulations for car traffic the travel times increase for peak hours, validating that the model correctly deals with more traffic. For cycling traffic the travel times do not increase a lot, if at all. This can be explained by the average speed of cyclists and the lower amount of cycling traffic in general compared to motorised traffic, which means that cycling traffic is almost not affected by the increase in traffic in this case. This does not invalidate the model though. The exact results of the five simulations can be seen in appendix 1b.

Extreme condition tests
Testing whether an extreme value or unlikely combination of factors give a plausible outcome. For example, if no vehicles enter or exit an intersection the average travel time over that intersection should be zero. This is a basic test that can be performed to check whether the model makes sense on the most basic level.
For the extreme condition test one specific direction of travel will have its number of vehicles doubled. This should lead to a significant increase in travel times for this specific travel direction. The direction East-North was chosen to perform this test with. It was chosen to do this for a right-hand turn in order to mostly keep travel times for other directions of travel relatively equal. From the results of the original situation it can be seen that the East-North travel times are increased. However, the biggest increase in travel times is for the traffic coming from the south. This could be explained by the fact that more traffic from the east is travelling towards the main destination of traffic coming from the south, which is the northern exit. Because of this the amount of green light for traffic coming from the south could be reduced compared to the normal situation since East-North direction could get more green light time than in the usual situation. For the turbo-roundabout the results show that the travel times have increased for traffic coming from the east while remaining equal for all other directions of travel. This is a logical outcome since the traffic from the east will have a longer queue and therefore a higher travel time. The results for the regular roundabout show major amounts of traffic unable to enter the system from the east, as well as some from the south. Because of this the travel times measured are not realistic and cannot be used to validate. Instead the assumption can be made that the amount of traffic unable to enter the system from the east is a logical result of the increase of traffic in the East-North direction. The full results of the simulations can be found in appendix 1c.

Face validity
Testing whether the results of the model are reasonable. This technique is used to determine if the logic in the conceptual model is correct and whether the models input and output relation is reasonable.
Five simulation runs with the percentage of motorised traffic that is trucks increased from the regular 5,5% to 50% will be conducted. This will test whether the trucks are properly integrated within the models. If this is the case the travel times for motorised traffic should increase. The results of the simulations show an increase in travel times and vehicles not able to exit the system for both the original design and the turbo-roundabout and it can therefore be concluded that this validates these models for this aspect. For the regular roundabout the number of vehicles unable to exit system is very high. The travel times are for some directions lower, but this is not very representative because of the very high number of vehicles unable to enter the system. It can however be concluded that the model is validated since it means that the queues extend into the parking lots and this can be assumed to be a logical conclusion of the increase of truck traffic. The results of the simulations can be found in appendix 1d.

4.5 Number of runs

In order to be able to be sure that results from the model are representative and account for variation in the model output, a minimum number of runs needs to be determined. This can be done by deriving the number of runs from the confidence interval equation seen below.

$$CI = mean \pm z * \frac{std}{\sqrt{n}}$$

Where:

- mean is the average value
- z is the confidence level value
- std is the sample standard deviation
- n is the sample size

For this project a confidence of 95% will be maintained. This means that the results of the model simulations can be considerate accurate.
The following equation can be derived from the confidence interval equation to determine the number of runs:

$$n = (\frac{t^{95} * std_5}{0.05 * mean_5})^2$$

Where:

- t^{95} is the t-value of the 95% confidence interval
- std_5 is the standard deviation
- $mean_5$ is the estimated average value

The original situation was simulated five times with average peak intensity to obtain the standard deviation and mean for every direction of travel. Subsequently it was determined that the t-value that belongs to this is 2,776. From this the number of runs required per direction of travel per design were calculated. The highest number of runs found was 29 and this will be the number of runs used. This number will give a confidence of 95% that the results used later in the project are accurate and not for example, as mentioned earlier, outliers. The simulation results used to calculate the number of runs, as well as the actual number of runs calculated for each direction of travel can be seen in appendix 2.

4.6 MCDA

In order to compare the different designs presented in above an MCDA will be performed. The performance criteria that the MCDA will consider will include travel times, queue lengths and number of stops. Furthermore, it will also include safety, including criteria like amount of conflict zones, approach speeds and some literature review. A conflict zone is an area in the system at which two vehicles or bicycles can meet at the same time. For example the point at which vehicles enter a roundabout is a point at which a collision can occur. The criteria which rely on the Vissim simulations will all be analysed for the non-peak hour, average peak hour and extreme peak hour. The factors will have weights which will indicate the importance of the specific criteria in relation to the other criteria. The designs are subsequently ranked in each category and eventually, considering the weight of the respective criteria, one design will emerge as the best design according to these criteria.

5. Simulation results

The simulations are conducted for every design, with every simulation being 2 hours long. The simulations contain 29 runs, in accordance with what was determined in the previous section. The length per simulation was chosen to be 2 hours to represent a traffic peak during workdays. A warm-up period of 15 minutes was chosen to allow regular conditions to apply, this 15-minute period is not part of the 2-hour simulation. This warm-up period is chosen to avoid the measurements of the first vehicles, which are not under the same conditions as most other traffic. This is the case since the amount of traffic within the system has not reached normal levels at this point. The simulations were performed for a normal hour, average peak hour and extreme peak hour. The normal hour is to investigate how the different design deal with lower traffic demands during regular hours when people are working or at school for example. The average peak hour is to investigate how the different designs deal with a traffic peak for an average day, whereas the extreme peak investigates how the designs deal with extreme traffic demands where all directions are as busy as they can be. All in all these three different intensities will give a great look at how the designs deal with varying intensities for different period of the day.

The travel time measurements all have a length of 375 m and start at the same points for each design. They car therefore be directly compared between designs. For the queue counter results this is different, since the number of lanes leading up to the intersection in the different designs is different for each design. Each general direction can be compared though, for example from the North. If the queue is measured to be more than 410 m it is likely that the queue extends all the way up to the parking lot and that some traffic may not have been able to leave the system during the simulation. This indicates that the queue is very long and it can be assumed that the queue could be even longer if there was more road between the parking lot and the intersection. This would lead to higher average travel times. The fact that traffic is unable to exit the system however is an indication that the design is not capable of dealing with the traffic intensity and conclusions can be drawn from this. The queue results are divided into three separate categories, namely total number of stops, longest queue measured and average queue.

The results of all simulation runs are compiled and the averages are taken to be compared between designs. This was subsequently ranked from best to worst with the best being marked green, the second best marked yellow and the worst design marked red. A total is also compiled in which all directions are added up. This gives a total picture of how the different designs stack up to one another per criteria.

5.1 Results non-peak

For the non-peak results the turbo-roundabout performs the best in all aspects of travel times and queue results. It can be seen from figure 13 below that the turbo-roundabout performs best in terms of travel times for especially motorised traffic. Furthermore it also performs the best in all three categories of the queue results, which can be seen in the figures 14, 15 and 16. It can also be observed that the original situation performs the worst out of the three designs in all categories considered. This can be seen as logical though, since the roundabouts don’t stop traffic and are, with the low amount of traffic, more efficient in dealing with traffic than signalised intersections. The original situation actually performs the worst by quite some distance to both types of roundabouts.

Travel time results:			
	Original situation	Turbo-roundabout	Roundabout
1: North-West	37,05	24,79	25,10
2: North-South	34,04	25,79	26,61
3: North-East	41,01	26,51	27,65
4: East-North	34,73	27,40	29,64
5: East-West	33,50	28,39	30,33
6: East-South	43,59	30,35	31,55
7: South-East	40,84	22,80	25,02
8: South-North	38,54	24,51	26,66
9: South-West	44,17	26,12	27,28
10: West-South	34,68	25,19	25,65
11: West-East	34,54	26,45	26,69
12: West-North	43,72	28,37	28,27
13: Cycle North-West	93,00	86,75	88,71
14: Cycle North-South	93,25	79,15	78,76
15: Cycle North-East	107,56	80,31	80,63
16: Cycle East-North	95,23	77,91	77,75
17: Cycle East-West	87,30	80,18	79,82
18: Cycle East-South	101,49	81,10	80,11
19: Cycle South-East	95,12	77,77	90,02
20: Cycle South-North	94,19	79,25	79,78
21: Cycle South-West	107,10	81,27	81,72
22: Cycle West-South	96,09	77,97	77,67
23: Cycle West-East	88,73	79,70	80,14
24: Cycle West-North	104,49	80,58	80,95
Total	1623,95	1278,61	1306,50

Figure 13: Travel time results for non-peak

Queue counter results:	Total number of stops per direction		
	Signalised intersection	Turbo-roundabout	Roundabout
1: North	414	66	121
2: East	308	92	196
3: South	561	52	147
4: West	228	47	75
5: Cycle North	161	60	44
6: Cycle East	156	47	0
7: Cycle South	137	29	29
8: Cycle West	212	51	48
Total	2177	444	660

Figure 14: Total number of stops per direction for non-peak

Queue counter results:	Biggest average queue		
	Signalised intersection	Turbo-roundabout	Roundabout
1: North	4,39	0,14	0,60
2: East	2,48	0,41	1,10
3: South	8,88	0,1	0,73
4: West	1,35	0,23	0,22
5: Cycle North	0,70	0,06	0,03
6: Cycle East	1,50	0,10	0,00
7: Cycle South	0,72	0,02	0,02
8: Cycle West	2,19	0,11	0,10
Total	22,20	1,17	2,80

Figure 15: Longest measured queue for non-peak

Queue counter results:	Longest measured queue		
	Signalised intersection	Turbo-roundabout	Roundabout
1: North	52,25	22,61	37,79
2: East	34,27	29,58	42,35
3: South	80,01	24,18	45,99
4: West	27,6	24,81	24,95
5: Cycle North	15,51	15,04	4,81
6: Cycle East	12,56	18,28	0,00
7: Cycle South	14,26	4,65	4,77
8: Cycle West	23,63	17,14	28,88
Total	260,10	156,30	189,53

Figure 16: Average queue for non-peak

5.2 Results average peak

For the average peak the best design is no different to the non-peak results. The turbo-roundabout still performs the best out of all the designs. It can be stated as well that the turbo-roundabout actually performs better by a bigger margin that for the non-peak results. The original situation does perform better than the roundabout however. From the results of both the travel times and the queue results it can be concluded that the roundabout design is not able to handle the increase in traffic very well. It is by far the worst design in every category. From figure 17 it can be seen that for the travel times for motorised traffic the turbo-roundabout performs the best, the original situation is second best and the conventional roundabout performs the worst. For the bicycle traffic it is a very different story. The conventional roundabout performs much better for bicycle traffic, indicating that the conventional roundabout can deal with the number of cyclists in the system. This can be explained by the fact that a conventional roundabout does not stop cyclists like at signalised intersections and the number of lanes to cross is lower at a conventional roundabout compared to a turbo-roundabout. When all travel times are added up the conventional roundabout does still perform worse, with the travel times for the motorised traffic compared to the other designs being considerably higher. Figures 18, 19 and 20 show a very mixed picture for every category of the queue results between the different designs over the different directions of travel. When added up though, the turbo-roundabout still comes out on top by a large margin for all three categories of the queue results. For the regular roundabout there is a small amount, around 5%, of traffic that is unable to enter the system. This could be of influence on the results, but since the percentage is relatively small it is assumed that it does not affect the results significantly.

Travel time results:			
	Original situation	**Turbo-roundabout**	**Roundabout**
1: North-West	81,43	30,86	98,28
2: North-South	78,93	31,28	100,01
3: North-East	89,70	31,40	101,23
4: East-North	48,10	37,98	151,80
5: East-West	47,60	45,02	152,84
6: East-South	68,40	46,92	155,00
7: South-East	73,72	28,61	127,36
8: South-North	70,79	31,23	129,64
9: South-West	80,05	30,74	130,42
10: West-South	46,49	30,87	104,82
11: West-East	47,06	37,60	105,95
12: West-North	69,97	40,71	107,72
13: Cycle North-West	96,33	89,19	92,56
14: Cycle North-South	107,60	82,98	79,74
15: Cycle North-East	140,13	88,04	87,94
16: Cycle East-North	94,81	79,49	77,56
17: Cycle East-West	102,54	87,65	86,93
18: Cycle East-South	124,29	91,24	87,17
19: Cycle South-East	106,60	78,21	92,12
20: Cycle South-North	119,04	84,55	84,20
21: Cycle South-West	147,13	92,48	93,30
22: Cycle West-South	94,87	78,83	77,83
23: Cycle West-East	106,06	84,09	85,74
24: Cycle West-North	132,94	90,60	89,89
Total	2174,59	1450,57	2500,05

Figure 17: Travel time results for average peak

Queue counter results:	Total number of stops per direction		
	Signalised intersection	Turbo-roundabout	Roundabout
1: North	4897	719	10938
2: East	848	1009	9560
3: South	2054	598	12600
4: West	130	570	2381
5: Cycle North	393	277	234
6: Cycle East	378	239	0
7: Cycle South	319	170	186
8: Cycle West	551	329	246
Total	9570	3911	36145

Figure 18: Total number of stops per direction for average peak

Queue counter results:	Longest measured queue		
	Signalised intersection	Turbo-roundabout	Roundabout
1: North	394,86	92,3	419,49
2: East	72,18	149,49	419,53
3: South	357,35	94	416,47
4: West	65,91	86,52	264,83
5: Cycle North	22,27	24,06	6,52
6: Cycle East	21,01	27,36	0,00
7: Cycle South	21,02	6,30	6,58
8: Cycle West	26,42	37,22	29,27
Total	981,01	517,25	1562,69

Figure 19: Longest measured distance for average peak

Queue counter results:	Biggest average queue		
	Signalised intersection	Turbo-roundabout	Roundabout
1: North	158,35	3,78	318,19
2: East	9,29	15,16	335,36
3: South	88,5	3,21	368,31
4: West	6,89	7	79,92
5: Cycle North	3,90	0,76	0,31
6: Cycle East	5,78	0,57	0,00
7: Cycle South	3,36	0,29	0,23
8: Cycle West	5,69	1,11	1,80
Total	281,76	31,89	1104,11

Figure 20: Average queue for average peak

5.3 Results extreme peak

For the extreme peak it is a lot more difficult to determine the actual results of the simulations. The number of vehicles that are unable to enter the system due to the queues leading all the way up to the parking lots is high. For the turbo-roundabout, which has the lowest number vehicles unable to leave the system, the number of vehicles unable to enter the system is at 10% average over all simulation runs. For the original situation it is nearly 20%, while for the roundabout it is as high as 39%. Therefore the results of at least the regular roundabout cannot be used to draw conclusions, since too many vehicles are unable to leave the system to give an accurate representation. Furthermore the results of the turbo-roundabout and original situation are not entirely accurate but most likely do present a fairly accurate representation. It can however be stated that for the queue results the turbo-roundabout performs best, since that design allows the most vehicles to exit the system of the three designs. The regular roundabout would obviously perform the worst out of the three designs in this category due to the high mount of traffic that is unable to exit the system. The travel time results for the extreme peak simulations, which can be seen in figure 21, show that the turbo-roundabout performs best for this criterion, with the original situation not far behind. It is interesting to note for the extreme peak that the performance per designs is different for different origins. For traffic coming from the north and south the turbo-roundabout performs significantly better, while for the eastern and western directions the original situation performs the best. Overall the turbo-roundabout still performs the best in terms of travel times, with the original situation second best and the regular roundabout performing the worst. Figures 22, 23 and 24 show the results of the queue results, which might not be representable since significant numbers of vehicles are unable to exit the system during the simulations.

Travel time results:			
	Original situation	Turbo-roundabout	Roundabout
1: North-West	117,84	54,33	105,65
2: North-South	113,65	53,30	107,46
3: North-East	125,40	51,89	108,79
4: East-North	59,59	114,23	160,21
5: East-West	56,52	135,46	161,12
6: East-South	80,85	136,86	162,30
7: South-East	113,44	77,09	134,29
8: South-North	109,16	78,85	136,12
9: South-West	115,43	74,78	136,12
10: West-South	54,55	86,44	184,83
11: West-East	55,30	113,00	186,87
12: West-North	72,95	116,63	188,38
13: Cycle North-West	96,66	88,93	92,81
14: Cycle North-South	114,07	90,04	79,90
15: Cycle North-East	156,16	102,71	88,45
16: Cycle East-North	95,22	83,76	77,85
17: Cycle East-West	109,53	99,35	87,80
18: Cycle East-South	135,97	108,76	87,18
19: Cycle South-East	121,38	78,86	93,18
20: Cycle South-North	135,38	94,32	85,29
21: Cycle South-West	168,33	109,01	95,98
22: Cycle West-South	93,25	79,19	77,90
23: Cycle West-East	120,38	91,28	86,20
24: Cycle West-North	153,15	106,28	90,69
Total	2574,15	2225,36	2815,38

Figure 21: Travel time results for extreme peak

Queue counter results:	Total number of stops per direction		
	Signalised intersection	Turbo-roundabout	Roundabout
1: North	10463	3573	12440
2: East	1926	9489	10794
3: South	6649	7561	12905
4: West	940	4491	8645
5: Cycle North	551	494	308
6: Cycle East	607	491	0
7: Cycle South	437	293	255
8: Cycle West	729	632	324
Total	22302	27024	45671

Figure 22: Total number of stops per direction for extreme peak

Queue counter results:	Longest measured queue		
	Signalised intersection	Turbo-roundabout	Roundabout
1: North	411,51	248,2	419,81
2: East	348,55	327,3	419,39
3: South	408,82	259,5	416,60
4: West	123,1	284,53	418,72
5: Cycle North	36,98	43,15	7,86
6: Cycle East	29,74	34,43	0,00
7: Cycle South	24,74	8,68	6,81
8: Cycle West	26,62	39,64	29,27
Total	1410,06	1245,43	1718,46

Figure 23: Longest measured queue for extreme peak

Queue counter results:	Biggest average queue		
	Signalised intersection	Turbo-roundabout	Roundabout
1: North	371,26	44,78	385,48
2: East	23,87	295,75	397,98
3: South	365,97	124,79	390,08
4: West	12,85	126,7	391,36
5: Cycle North	6,11	2,65	0,46
6: Cycle East	9,08	1,92	0,00
7: Cycle South	5,00	0,84	0,33
8: Cycle West	7,27	4,01	2,63
Total	801,40	601,44	1568,32

Figure 24: Average queue for extreme peak

6. Safety

Safety is not a factor that can be measured easily in numbers. It depends on personal experiences, preferences and overall perception. Therefore, the safety aspect of the intersection designs is not analysed in a statistical way. Instead it will be analysed in a more conceptual way, in which several factors concerning safety are discussed in the context of the designs.

6.1 Conflict zones

One of the few measurable factors concerning safety in this project is the amount of conflict zones. In theory, when everything goes as it is designed to, there are very little conflict zones at a signalised intersection. By design signalised intersections are designed to limit the amount of conflict zones as much as possible. Therefore, on the intersection itself there are no motorised traffic streams that meet each other in one place at one time. However, motorised traffic turning right can encounter cycling traffic crossing straight when the vehicles make the right-hand turn. This is by design and obviously creates a conflict between the motorised traffic turning right and the cycling traffic going across the intersection. The cyclists have the right of way and the vehicles are warned by a sign just before the right-hand turn. This can still create conflict and can be considered the most dangerous part of the intersection. It is important to mention that the assumption of no conflict zones between motorised traffic rests on the theoretical case of every car in the system adhering to all traffic laws. In practice though this does not hold up all the time. Some vehicles will inevitably ignore red lights and with that cause additional conflict zones. From the same data sets that were used to make the OD-matrices the percentage of vehicles travelling through a red light could be obtained. The average percentage of vehicles travelling through a red light for a one-month period was determined to be 0,4%. This is low enough that it will not be separately considered in the MCDA. Furthermore, the ideal situation is also used for the other situations and therefore a fair comparison can be made.

Roundabouts however, by nature, have a lot more conflict zones in comparison to signalised intersections. On the regular roundabout there are four main conflict zones between motorised traffic and eight conflict zones between motorised traffic and cyclists. The conflict zones between motorised traffic are the points at which traffic from the approaching links merge onto the roundabout itself. These points create situations in which motorists must estimate themselves whether they can or cannot merge onto the roundabout. This human factor naturally brings a margin of error with it, which creates the possibility of conflict between motorists. An example of this could be that a motorist entering the roundabout misjudges traffic already on the roundabout and enters the roundabout at the same moment a car travelling around the roundabout is passing the entry way. This would lead to the two motorists colliding with each other.

The turbo-roundabout has even more conflict zones than a regular roundabout. It has not just four entry points to the roundabout but eight entry points. Furthermore, traffic merging onto the roundabout at several point must cross over one lane and merge into another lane. This creates a total of seven conflict zones on the roundabout itself. Furthermore because of the increase in approaching lanes compared to the regular roundabout the amount of conflict zones between motorised traffic and cyclists is increased from eight to fourteen conflict zones. Furthermore the turbo-roundabout by its design creates a situation in which cyclists must cross two lanes at once on their own. When it is very busy this could lead to dangerous situations in which cyclists get impatient and attempt to cross in between small gaps.

It can be concluded that in terms of conflict zones the signalised intersection is the best design among the ones presented. The regular roundabout is second best while the turbo-roundabout is the ‘worst’ performing intersection in this category. Furthermore the fact that cyclists must cross double lanes in the turbo-roundabout further makes the point that the turbo-roundabout is the 'worst' design for this criterion. It must be noted however that this does not automatically mean that at the turbo-roundabout there would be a significantly higher number of crashes. Instead, it indicates that the chances of crashes are higher.

6.2 Approach speed

One of the important factors pertaining to safety is speed. The higher the speed a vehicle travels, the greater the likelihood of serious injury or death in case of a crash (Brake.org, 2023). This mainly is caused by the higher amount of energy released during a crash at higher speeds. In theory roundabouts, by nature, take out the element of high-speed collisions completely. The roundabouts can only be traversed at speeds under 40 km/h, resulting in each potential conflict only resulting in low potential damages in comparison to other types of intersection designs. Only freak accidents like someone passing out could be an exception to this. This is not considered however, since these events are very rare and can happen at any intersection of any design type. At signalised intersection the potential of major injury or death is higher than at roundabouts. The speed at which a car approaches the intersection is not, by nature, reduced by any sort of factor when the light is green. Conflict could be caused by a person misjudging traffic lights or ignoring them altogether. Since the approach speed is much higher the potential of major damage, injury or even death is greatly increased per crash for signalised intersections.

To conclude, the chances of conflict are much lower at signalised intersections compared to roundabout designs. However, in case of a crash the potential of major damage, injury or death is much greater at signalised intersections compared to roundabouts, mainly caused by the difference in approach speed.

6.3 Literature

In this section the safety aspect of intersections and roundabouts is assessed using literature. Several sources will be discussed and presented below.

The ANWB, the Dutch organization for traffic and tourism, states that roundabouts are safer than regular intersections. According to stats presented by the ANWB there are 50% less traffic accidents and 75% less injuries and fatalities at roundabouts compared to intersections with traffic lights. (ANWB, 2023)

Elvik (2017) performed a study based on 44 intersection safety studies which were carried out during the period 1975-2014 in Europe, Australia and the US. These focussed on the road safety effects of the conversion from junctions to roundabouts. The conclusion from this research is that "it is clear beyond reasonable doubt that roundabouts improve road safety and are particularly effective in reducing fatal accidents". It came to a reduction of 65% of fatal accidents and 40% of accidents leading to injury.

DTV consultants conducted a study commissioned by the Ministry of Infrastructure and Water called 'Verkenning verkeersveiligheid op rotondes in Nederland' which investigates the traffic safety at roundabouts in the Netherlands. The study shows that during the period of 2015-2018 only at 1,6% of the 5.585 roundabout in the Netherlands three or more serious accidents involving cyclists were recorded. Furthermore the study states that only 2% of all accidents that involve cyclists are registered at roundabouts. (DTV consultants, 2019)

According to a study conducted by Vasconcelos et al. (2014) their simulations show turbo-roundabouts have fewer conflicts than regular single-lane roundabouts. The severity of conflicts at the turbo-roundabout is higher because of the increased angle between the entry and circulating trajectories. This all was concluded based on the SSAM method, which is a method which operates by processing data describing the trajectories of vehicles driving through a traffic facility and identifying conflicts. SSAM determines per vehicle whether an interaction satisfies the criteria to be deemed a conflict.

From the above it can be concluded that the turbo-roundabout is likely to be the safest when looking at literature. The regular roundabout would likely be second best while the signalised intersection likely would be the worst. While his is based on several different sources, it cannot be definitively stated that this is true. According to these sources though this is the most likely outcome.

7. MCDA

The MCDA will include several criteria related to the performance and safety of the previously presented designs. These criteria include travel time performance, queue length performance, number of stops, amount of conflict areas, approach speed and safety based on literature. The performance criteria, understood to be travel times, queue lengths and number of stops, were measured using three different traffic intensities and will therefore be ranked separately for each traffic intensity.

7.1 Weights of criteria

Firstly these criteria will have to be given a weight, based on the importance of the factor to this project. Because travel times, queue lengths and number of stops are input for the MCDA for three separate traffic intensities the weight of the performance criteria is naturally lower. Otherwise the performance criteria would attribute too greatly to the overall outcome of the MCDA in comparison the safety criteria. Furthermore the cyclists are separately taking into account in the same way as the motorised traffic. In the table below the eventual weights that have been given to the different criteria can be seen. Note that the three safety criteria include cyclists while the performance criteria for motorised traffic and cyclists is split. All weights of the different criteria can be seen in table 7 below.

Table 7: Weights of criteria

Criteria	**Weight**
Travel times non-peak	2
Travel times average peak	5
Travel times extreme peak	3
Number of stops non-peak	1
Number of stops average peak	4
Number of stops extreme peak	2
Average queue non-peak	1
Average queue average peak	4
Average queue extreme peak	2
Cycling travel times non-peak	1
Cycling travel times average peak	3
Cycling travel times extreme peak	1
Cyclists number of stops non-peak	1
Cyclists number of stops average peak	2
Cyclists number of stops extreme peak	1
Cyclists average queue non-peak	1
Cyclists average queue average peak	2
Cyclists average queue extreme peak	1
Conflict zones	15 (originally 5)
Approach speed	9 (originally 3)
Literature	6 (originally 2)

Initially all criteria were ranked on a scale of 1-5. Since the performance criteria are all considered three times in the MCDA (for all three densities) and the safety criteria are considered once, the safety criteria have been multiplied by a factor 3 to equal this out. For the different traffic intensities it has been chosen to award different weights to the different intensities. To start the non-peak intensity is decided to be the least important, since there is insufficient traffic to cause long waiting times or queues. Furthermore the extreme peak intensity is considered to be less important than the average peak intensity because it occurs very rarely. The criteria concerning performance and cyclists are the least important of the ones mentioned, since there are few cyclists compared to motorised traffic and there are currently no complaints or problems with cyclists concerning travel times. Queues are less important than the actual travel times because travel times give a better overall indication of the performance of the intersection as a whole. A great example of this is the natural creation of queues at signalised intersections. This might not automatically lead to slower travel times though, since vehicles can traverse across the intersection at higher speed and the distance to be traversed is smaller.

The prevention of accidents is considered to be better than minimizing serious damage and injury per crash. Therefore the amount of conflict zones, which can be directly linked to the chance of an accident occurring, is considered the most important criteria of safety and gets a weight of 5 while the approach speed has been given a weigh of 3. The literature part of safety is considered less important since it is more difficult to say that the conditions described in the literature examples and studies are comparable to the designs in this project. Therefore the literature part has a weight of 2.

7.2 Rankings per criteria

From the simulation results, as well as from the analysis on safety the alternatives can be ranked from 1st to 3rd for each criterion. In table 8 below the rankings for the performance criteria for motorised traffic are shown.

Table 8: Ranking performance criteria

Motorised traffic	**1st**	**2nd**	**3rd**
Travel times non-peak	Turbo-roundabout	Roundabout	Signalised intersection
Travel times average peak	Turbo-roundabout	Signalised intersection	Roundabout
Travel times extreme peak	Signalised intersection	Turbo-roundabout	Roundabout
Number of stops non-peak	Turbo-roundabout	Roundabout	Signalised intersection
Number of stops average peak	Turbo-roundabout	Signalised intersection	Roundabout
Number of stops extreme peak	Signalised intersection	Turbo-roundabout	Roundabout
Queue lengths non-peak	Turbo-roundabout	Roundabout	Signalised intersection
Queue lengths average peak	Turbo-roundabout	Signalised intersection	Roundabout
Queue lengths extreme peak	Turbo-roundabout	Signalised intersection	Roundabout

The next table, table 9, shows the performance criteria for the cyclists.

Table 9: Ranking cycling performance criteria

Cyclists	**1st**	**2nd**	**3rd**
Travel times non-peak	Turbo-roundabout	Roundabout	Signalised intersection
Travel times average peak	Turbo-roundabout	Roundabout	Signalised intersection
Travel times extreme peak	Roundabout	Turbo-roundabout	Signalised intersection
Number of stops non-peak	Roundabout	Turbo-roundabout	Signalised intersection
Number of stops average peak	Roundabout	Turbo-roundabout	Signalised intersection
Number of stops extreme peak	Roundabout	Turbo-roundabout	Signalised intersection
Queue lengths non-peak	Roundabout	Turbo-roundabout	Signalised intersection
Queue lengths average peak	Roundabout	Turbo-roundabout	Signalised intersection
Queue lengths extreme peak	Roundabout	Turbo-roundabout	Signalised intersection

Lastly in table 10 the rankings for the safety criteria can be found.

Table 10: Ranking safety criteria

Safety	**1st**	**2nd**	**3rd**
Number of conflict zones	Signalised intersection	Roundabout	Turbo-roundabout
Approach speed	Roundabout	Turbo-roundabout	Signalised intersection
Literature	Turbo-roundabout	Roundabout	Signalised intersection

7.3 MCDA outcome

After the criteria have been ranked it is clear which design performs better compared to the other designs for each category. Because the 1,2,3 system would not consider the difference in end values it is decided that the alternatives instead will be assigned a value between 1 and 10 based on the differences in end values. For example, the conventional roundabout performs 3x worse than the turbo-roundabout for the average peak. In this ranking system the higher the number, the worse a design performs for the given criteria. The best design will therefore have the lowest score.

Table 11: MCDA

Criteria	Weight	Signalised intersection	Turbo-roundabout	Roundabout
Travel times				
Non-peak	2	8	1	3
Average peak	5	4	1	10
Extreme peak	3	2	3	8
Number of stops				
Non-peak	1	9	1	3
Average peak	4	3	1	10
Extreme peak	2	1	4	10
Average queue				
Non-peak	1	9	1	3
Average peak	4	3	1	10
Extreme peak	2	4	2	10
Cyclists travel times				
Non-peak	1	5	1	3
Average peak	3	5	1	3
Extreme peak	1	5	2	1
Cyclists number of stops				
Non-peak	1	8	3	1
Average peak	2	5	3	1
Extreme peak	1	6	4	1
Cyclists average queue				
Non-peak	1	10	3	1
Average peak	2	8	2	1
Extreme peak	1	9	3	1
Safety				
Conflict zones	15	1	6	4
Approach speed	9	7	3	2
Literature	6	5	2	3
Total		286	202	323

From the MCDA, table 11, above it becomes clear that the turbo-roundabout is clearly the best design option for this traffic situation. It has the best score by a large margin when all criteria are multiplied with their respective weight and then added for one design. The conventional roundabout is the design that is the worst out of the three. As can be seen from the MCDA table this is mainly caused by its inability to deal with high traffic intensities. This can be seen as very logical since the conventional roundabout is meant for lower traffic intensities and that is not the case at this intersection. Furthermore, the turbo-roundabout specifically improves upon the conventional roundabout to deal with higher traffic intensities. In that regard it clearly be stated that this can be seen from the results of the MCDA analysis. The average performance of the signalised intersection can be attributed to its poor performance in regard to cycling traffic and lower traffic intensities. Both factors can be explained by the fact that the traffic lights by nature stop traffic, while roundabout designs are meant to keep traffic flowing. This will inevitably lead to higher travel times and queue lengths for lower traffic intensities for signalised intersections compared to roundabouts.

8. Conclusion

The goal of this project was to investigate whether a roundabout could improve the performance of the intersection of the Haaksbergerstraat and the Usselerrondweg. Two alternative designs, a conventional roundabout and a turbo-roundabout, as well as the current situation were assessed. From traffic simulations in Vissim, as well as a conceptual analysis of safety it can be concluded that the intersection of the Haaksbergerstraat and the Usselerrondweg can be improved by one type of roundabout. This type of roundabout is the turbo-roundabout, which scores the best on an MCDA analysis including criteria from both performance and safety. It can also be concluded that a conventional roundabout does not improve upon the current situation. Tt does have better travel times for lower traffic intensities but performs very poorly when faced with high traffic intensities. It performs so bad for these high traffic intensities that it completely rules out this design just by this factor. For cyclists the signalised intersection is the worst design of the three, due to the nature of signalised intersections stopping traffic. The conventional roundabout performs the best for cyclists but only marginally compared to the turbo-roundabout. All in all the MCDA provides a clear picture of which designs are best in each category, as well as showing which design performs best overall.

9. Discussion

At the start of the project it was looked at whether different design with traffic lights could be assessed as well. Unfortunately it was discovered that this would not be possible within the time frame and would have to include programmers from Vissim. Therefore it was decided early in the project that the research would focus on the potential of roundabouts.

The safety aspect of the project was difficult to research. Safety as a whole is, for a large part, subjective. Everybody has a different opinion on situations and whether they should be deemed safe. Furthermore, doing a small literature study about safety on intersections provided some extra insight but it was difficult to compare situations between each other. This made for a general line from which some conclusions could be drawn but it did not give a fully clear picture of the designs assessed in this project. This can mainly be attributed to the fact that almost no traffic situation is fully comparable to another, making it very difficult to draw conclusions for one situation based on another.

For the models in Vissim the approach roads were 400 m long before connecting to the intersection links. This, as it turned out during the simulations, was not sufficient to generate all traffic in some simulations. In hindsight it would have been preferable to have made the links longer than 400 m. This would also have made the conclusions regarding travel times more accurate, since more vehicles would be measured. The simulations were conducted for a timeframe of 2 hours, to represent a peak during a workday. Vissim then generates the vehicles across this 2-hour period. This does not take into account however that within this 2 hour peak the traffic intensity can vary even every 15 minutes. Therefore, in hindsight, it might have been preferable if the data was gathered for 15-minute intervals rather than 1-hour intervals. This would have given a more realistic picture of the absolute busiest the intersection can be at one time.

The implementation of the traffic light application from Vialis into Vissim was a bit more difficult than expected. The application send over by employees of Vialis initially was designed to run on a different version of Vissim with which Vialis works. This had to be sorted out and unfortunately took a bit of time.

Determining the weights of the criteria for the MCDA was, as with the safety aspect, a bit challenging considering this also is subjective. The same holds for the 1-10 ranking that was done for each criterion for every design. The MCDA will therefore likely not be an exact representation of the view of everyone, however it does provide a reasonable base to draw conclusions from.

10. Future research

Due to the short nature of this project not every aspect of the designs was analysed. It could be further examined what each alternative would cost or how easy each design is to implement in real life. Another interesting follow up research could be to investigate what the impact of moving the city limits to include the intersection within city limits would be. This would change the right of way towards cyclists and could have effects on both vehicle and cycling travel times.

Further research could also be done about other design featuring traffic lights for this intersection. As mentioned previously this was outside the scope of this project and could therefore be an interesting research subject for a future project. This could potentially attempt to improve the intersection by splitting the right-turn and straight lane into two separate lanes, which adds an extra lane, on both the northern and southern side of the intersection.

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Appendix

Appendix 1: Results validation tests

Appendix 1a: Internal validity test

Original situation

SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)
1	900-8100	1: North-West	337	68,81
1	900-8100	2: North-South	774	66,48
1	900-8100	3: North-East	338	76,93
1	900-8100	4: East-North	409	43,94
1	900-8100	5: East-West	383	46,88
1	900-8100	6: East-South	266	61,45
1	900-8100	7: South-East	226	67,65
1	900-8100	8: South-North	932	63,47
1	900-8100	9: South-West	191	71,89
1	900-8100	10: West-South	287	43,00
1	900-8100	11: West-East	339	46,76
1	900-8100	12: West-North	148	61,29
1	900-8100	13: Cycle North-West	29	92,31
1	900-8100	14: Cycle North-South	111	104,84
1	900-8100	15: Cycle North-East	45	134,51
1	900-8100	16: Cycle East-North	60	90,88
1	900-8100	17: Cycle East-West	56	100,65
1	900-8100	18: Cycle East-South	66	115,88
1	900-8100	19: Cycle South-East	43	85,10
1	900-8100	20: Cycle South-North	176	107,76
1	900-8100	21: Cycle South-West	31	123,78
1	900-8100	22: Cycle West-South	34	80,40
1	900-8100	23: Cycle West-East	51	101,66
1	900-8100	24: Cycle West-North	22	120,96
2	900-8100	1: North-West	331	57,41
2	900-8100	2: North-South	788	54,64
2	900-8100	3: North-East	348	67,30
2	900-8100	4: East-North	419	43,39
2	900-8100	5: East-West	376	47,69
2	900-8100	6: East-South	263	60,71
2	900-8100	7: South-East	235	61,48
2	900-8100	8: South-North	924	60,57
2	900-8100	9: South-West	187	64,91
2	900-8100	10: West-South	291	40,68
2	900-8100	11: West-East	348	48,30
2	900-8100	12: West-North	147	59,30
2	900-8100	13: Cycle North-West	28	97,68
2	900-8100	14: Cycle North-South	113	107,90
2	900-8100	15: Cycle North-East	43	129,50
2	900-8100	16: Cycle East-North	62	93,09
2	900-8100	17: Cycle East-West	55	94,91
2	900-8100	18: Cycle East-South	65	115,18
2	900-8100	19: Cycle South-East	41	91,76
2	900-8100	20: Cycle South-North	172	110,32
2	900-8100	21: Cycle South-West	32	138,61
2	900-8100	22: Cycle West-South	37	98,71
2	900-8100	23: Cycle West-East	48	95,32
2	900-8100	24: Cycle West-North	20	124,29
3	900-8100	1: North-West	323	64,18
3	900-8100	2: North-South	773	61,89
3	900-8100	3: North-East	339	68,52
3	900-8100	4: East-North	405	43,96
3	900-8100	5: East-West	379	45,06
3	900-8100	6: East-South	255	61,31
3	900-8100	7: South-East	227	67,00
3	900-8100	8: South-North	918	64,13
3	900-8100	9: South-West	187	71,25
3	900-8100	10: West-South	300	40,91
3	900-8100	11: West-East	353	49,48
3	900-8100	12: West-North	152	63,71
3	900-8100	13: Cycle North-West	28	92,60
3	900-8100	14: Cycle North-South	110	103,29
3	900-8100	15: Cycle North-East	42	134,61
3	900-8100	16: Cycle East-North	63	109,68
3	900-8100	17: Cycle East-West	56	94,82
3	900-8100	18: Cycle East-South	63	114,99
3	900-8100	19: Cycle South-East	44	110,82
3	900-8100	20: Cycle South-North	170	109,42
3	900-8100	21: Cycle South-West	34	139,22
3	900-8100	22: Cycle West-South	35	98,45
3	900-8100	23: Cycle West-East	57	99,99
3	900-8100	24: Cycle West-North	23	128,69
4	900-8100	1: North-West	339	62,48
4	900-8100	2: North-South	780	58,65
4	900-8100	3: North-East	337	70,27
4	900-8100	4: East-North	408	43,32
4	900-8100	5: East-West	378	45,21
4	900-8100	6: East-South	251	63,92
4	900-8100	7: South-East	233	59,26
4	900-8100	8: South-North	954	56,61
4	900-8100	9: South-West	196	68,02
4	900-8100	10: West-South	296	43,63
4	900-8100	11: West-East	355	47,67
4	900-8100	12: West-North	144	60,96
4	900-8100	13: Cycle North-West	25	91,37
4	900-8100	14: Cycle North-South	113	106,76
4	900-8100	15: Cycle North-East	45	128,94
4	900-8100	16: Cycle East-North	62	86,02
4	900-8100	17: Cycle East-West	57	99,29
4	900-8100	18: Cycle East-South	62	117,51
4	900-8100	19: Cycle South-East	41	98,23
4	900-8100	20: Cycle South-North	173	108,24
4	900-8100	21: Cycle South-West	30	140,23
4	900-8100	22: Cycle West-South	38	96,60
4	900-8100	23: Cycle West-East	54	96,29
4	900-8100	24: Cycle West-North	25	131,92
5	900-8100	1: North-West	342	67,04
5	900-8100	2: North-South	790	62,44
5	900-8100	3: North-East	339	74,96
5	900-8100	4: East-North	406	42,84
5	900-8100	5: East-West	368	49,54
5	900-8100	6: East-South	267	62,25
5	900-8100	7: South-East	239	69,24
5	900-8100	8: South-North	918	67,73
5	900-8100	9: South-West	182	75,70
5	900-8100	10: West-South	297	42,60
5	900-8100	11: West-East	341	48,62
5	900-8100	12: West-North	147	62,07
5	900-8100	13: Cycle North-West	29	87,16
5	900-8100	14: Cycle North-South	108	104,16
5	900-8100	15: Cycle North-East	45	139,71
5	900-8100	16: Cycle East-North	63	96,18
5	900-8100	17: Cycle East-West	57	98,74
5	900-8100	18: Cycle East-South	64	122,11
5	900-8100	19: Cycle South-East	44	99,16
5	900-8100	20: Cycle South-North	173	110,57
5	900-8100	21: Cycle South-West	32	143,98
5	900-8100	22: Cycle West-South	35	105,38
5	900-8100	23: Cycle West-East	57	102,89
5	900-8100	24: Cycle West-North	24	137,52
6	900-8100	1: North-West	337	60,62
6	900-8100	2: North-South	787	57,81
6	900-8100	3: North-East	336	67,23
6	900-8100	4: East-North	404	43,06
6	900-8100	5: East-West	373	44,88
6	900-8100	6: East-South	270	61,55
6	900-8100	7: South-East	237	58,41
6	900-8100	8: South-North	929	56,10
6	900-8100	9: South-West	182	66,40
6	900-8100	10: West-South	302	41,27
6	900-8100	11: West-East	346	49,36
6	900-8100	12: West-North	139	63,10
6	900-8100	13: Cycle North-West	29	99,31
6	900-8100	14: Cycle North-South	112	104,74
6	900-8100	15: Cycle North-East	44	129,62
6	900-8100	16: Cycle East-North	62	92,87
6	900-8100	17: Cycle East-West	56	97,85
6	900-8100	18: Cycle East-South	61	114,93
6	900-8100	19: Cycle South-East	43	98,50
6	900-8100	20: Cycle South-North	162	111,12
6	900-8100	21: Cycle South-West	34	134,85
6	900-8100	22: Cycle West-South	36	84,98
6	900-8100	23: Cycle West-East	51	96,86
6	900-8100	24: Cycle West-North	21	126,50
7	900-8100	1: North-West	340	61,98
7	900-8100	2: North-South	794	61,76
7	900-8100	3: North-East	339	72,36
7	900-8100	4: East-North	406	40,94
7	900-8100	5: East-West	376	45,54
7	900-8100	6: East-South	249	64,70
7	900-8100	7: South-East	229	65,39
7	900-8100	8: South-North	935	61,64
7	900-8100	9: South-West	193	70,96
7	900-8100	10: West-South	284	40,53
7	900-8100	11: West-East	343	47,81
7	900-8100	12: West-North	146	64,99
7	900-8100	13: Cycle North-West	28	105,19
7	900-8100	14: Cycle North-South	109	102,80
7	900-8100	15: Cycle North-East	43	137,59
7	900-8100	16: Cycle East-North	62	90,89
7	900-8100	17: Cycle East-West	53	96,91
7	900-8100	18: Cycle East-South	65	119,08
7	900-8100	19: Cycle South-East	36	100,96
7	900-8100	20: Cycle South-North	169	109,53
7	900-8100	21: Cycle South-West	33	140,55
7	900-8100	22: Cycle West-South	36	89,93
7	900-8100	23: Cycle West-East	49	97,15
7	900-8100	24: Cycle West-North	22	129,79
8	900-8100	1: North-West	330	66,87
8	900-8100	2: North-South	791	64,11
8	900-8100	3: North-East	325	73,36
8	900-8100	4: East-North	394	43,17
8	900-8100	5: East-West	377	45,39
8	900-8100	6: East-South	264	62,46
8	900-8100	7: South-East	229	64,07
8	900-8100	8: South-North	932	60,84
8	900-8100	9: South-West	183	68,25
8	900-8100	10: West-South	285	43,49
8	900-8100	11: West-East	353	47,41
8	900-8100	12: West-North	144	62,12
8	900-8100	13: Cycle North-West	29	80,09
8	900-8100	14: Cycle North-South	115	105,46
8	900-8100	15: Cycle North-East	45	130,96
8	900-8100	16: Cycle East-North	62	103,97
8	900-8100	17: Cycle East-West	56	100,15
8	900-8100	18: Cycle East-South	61	115,27
8	900-8100	19: Cycle South-East	41	90,25
8	900-8100	20: Cycle South-North	174	113,20
8	900-8100	21: Cycle South-West	32	137,16
8	900-8100	22: Cycle West-South	35	93,59
8	900-8100	23: Cycle West-East	54	100,58
8	900-8100	24: Cycle West-North	23	119,05

9	900-8100	1: North-West	338	67,18
9	900-8100	2: North-South	768	63,04
9	900-8100	3: North-East	327	71,56
9	900-8100	4: East-North	397	43,54
9	900-8100	5: East-West	373	49,52
9	900-8100	6: East-South	259	62,77
9	900-8100	7: South-East	233	65,45
9	900-8100	8: South-North	938	62,58
9	900-8100	9: South-West	185	73,56
9	900-8100	10: West-South	294	40,60
9	900-8100	11: West-East	341	47,54
9	900-8100	12: West-North	143	63,48
9	900-8100	13: Cycle North-West	26	87,00
9	900-8100	14: Cycle North-South	108	104,83
9	900-8100	15: Cycle North-East	44	137,65
9	900-8100	16: Cycle East-North	63	92,02
9	900-8100	17: Cycle East-West	56	101,46
9	900-8100	18: Cycle East-South	67	119,45
9	900-8100	19: Cycle South-East	44	94,14
9	900-8100	20: Cycle South-North	175	106,78
9	900-8100	21: Cycle South-West	32	132,51
9	900-8100	22: Cycle West-South	40	88,27
9	900-8100	23: Cycle West-East	51	103,80
9	900-8100	24: Cycle West-North	21	120,69
10	900-8100	1: North-West	339	61,37
10	900-8100	2: North-South	798	57,23
10	900-8100	3: North-East	338	69,76
10	900-8100	4: East-North	394	43,95
10	900-8100	5: East-West	384	47,22
10	900-8100	6: East-South	268	59,75
10	900-8100	7: South-East	234	71,91
10	900-8100	8: South-North	950	68,43
10	900-8100	9: South-West	187	73,88
10	900-8100	10: West-South	298	41,37
10	900-8100	11: West-East	340	48,24
10	900-8100	12: West-North	149	64,60
10	900-8100	13: Cycle North-West	27	86,17
10	900-8100	14: Cycle North-South	117	104,96
10	900-8100	15: Cycle North-East	47	138,65
10	900-8100	16: Cycle East-North	54	108,02
10	900-8100	17: Cycle East-West	58	101,10
10	900-8100	18: Cycle East-South	68	118,53
10	900-8100	19: Cycle South-East	40	96,68
10	900-8100	20: Cycle South-North	175	111,98
10	900-8100	21: Cycle South-West	32	141,19
10	900-8100	22: Cycle West-South	35	91,69
10	900-8100	23: Cycle West-East	52	103,33
10	900-8100	24: Cycle West-North	25	133,72
Average	900-8100	1: North-West	336	63,79
Average	900-8100	2: North-South	784	60,80
Average	900-8100	3: North-East	337	71,23
Average	900-8100	4: East-North	404	43,21
Average	900-8100	5: East-West	377	46,69
Average	900-8100	6: East-South	261	62,09
Average	900-8100	7: South-East	232	64,99
Average	900-8100	8: South-North	933	62,21
Average	900-8100	9: South-West	187	70,48
Average	900-8100	10: West-South	293	41,81
Average	900-8100	11: West-East	346	48,12
Average	900-8100	12: West-North	146	62,56
Average	900-8100	13: Cycle North-West	28	91,89
Average	900-8100	14: Cycle North-South	112	104,98
Average	900-8100	15: Cycle North-East	44	134,17
Average	900-8100	16: Cycle East-North	61	96,36
Average	900-8100	17: Cycle East-West	56	98,59
Average	900-8100	18: Cycle East-South	64	117,29
Average	900-8100	19: Cycle South-East	42	96,56
Average	900-8100	20: Cycle South-North	172	109,89
Average	900-8100	21: Cycle South-West	32	137,21
Average	900-8100	22: Cycle West-South	36	92,80
Average	900-8100	23: Cycle West-East	52	99,79
Average	900-8100	24: Cycle West-North	23	127,31
Standard deviation	900-8100	1: North-West	6	3,63
Standard deviation	900-8100	2: North-South	10	3,61
Standard deviation	900-8100	3: North-East	6	3,23
Standard deviation	900-8100	4: East-North	8	0,89
Standard deviation	900-8100	5: East-West	5	1,78
Standard deviation	900-8100	6: East-South	7	1,47
Standard deviation	900-8100	7: South-East	4	4,31
Standard deviation	900-8100	8: South-North	12	4,06
Standard deviation	900-8100	9: South-West	5	3,49
Standard deviation	900-8100	10: West-South	6	1,24
Standard deviation	900-8100	11: West-East	6	0,86
Standard deviation	900-8100	12: West-North	4	1,76
Standard deviation	900-8100	13: Cycle North-West	1	7,34
Standard deviation	900-8100	14: Cycle North-South	3	1,50
Standard deviation	900-8100	15: Cycle North-East	1	4,15
Standard deviation	900-8100	16: Cycle East-North	3	8,03
Standard deviation	900-8100	17: Cycle East-West	1	2,43
Standard deviation	900-8100	18: Cycle East-South	2	2,45
Standard deviation	900-8100	19: Cycle South-East	2	6,96
Standard deviation	900-8100	20: Cycle South-North	4	1,97
Standard deviation	900-8100	21: Cycle South-West	1	5,74
Standard deviation	900-8100	22: Cycle West-South	2	7,34
Standard deviation	900-8100	23: Cycle West-East	3	3,17
Standard deviation	900-8100	24: Cycle West-North	2	6,12

Turbo-roundabout

SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)
1	900-8100	1: North-West	334	30,33
1	900-8100	2: North-South	779	32,07
1	900-8100	3: North-East	338	32,78
1	900-8100	4: East-North	406	43,51
1	900-8100	5: East-West	380	52,11
1	900-8100	6: East-South	263	57,33
1	900-8100	7: South-East	227	28,59
1	900-8100	8: South-North	942	30,28
1	900-8100	9: South-West	191	30,33
1	900-8100	10: West-South	288	28,98
1	900-8100	11: West-East	339	35,93
1	900-8100	12: West-North	148	37,54
1	900-8100	13: Cycle North-West	112	90,66
1	900-8100	14: Cycle North-South	259	83,48
1	900-8100	15: Cycle North-East	109	88,76
1	900-8100	16: Cycle East-North	137	78,80
1	900-8100	17: Cycle East-West	131	87,54
1	900-8100	18: Cycle East-South	157	93,65
1	900-8100	19: Cycle South-East	84	77,61
1	900-8100	20: Cycle South-North	312	84,15
1	900-8100	21: Cycle South-West	62	90,42
1	900-8100	22: Cycle West-South	96	78,80
1	900-8100	23: Cycle West-East	115	82,92
1	900-8100	24: Cycle West-North	50	88,93
2	900-8100	1: North-West	333	29,86
2	900-8100	2: North-South	789	31,84
2	900-8100	3: North-East	347	32,79
2	900-8100	4: East-North	417	39,34
2	900-8100	5: East-West	374	49,63
2	900-8100	6: East-South	260	51,06
2	900-8100	7: South-East	238	28,82
2	900-8100	8: South-North	925	32,13
2	900-8100	9: South-West	187	31,92
2	900-8100	10: West-South	290	30,53
2	900-8100	11: West-East	347	36,29
2	900-8100	12: West-North	148	39,50
2	900-8100	13: Cycle North-West	109	93,47
2	900-8100	14: Cycle North-South	256	82,39
2	900-8100	15: Cycle North-East	113	87,31
2	900-8100	16: Cycle East-North	138	80,35
2	900-8100	17: Cycle East-West	130	88,93
2	900-8100	18: Cycle East-South	162	92,55
2	900-8100	19: Cycle South-East	77	77,32
2	900-8100	20: Cycle South-North	312	85,13
2	900-8100	21: Cycle South-West	64	93,63
2	900-8100	22: Cycle West-South	94	78,50
2	900-8100	23: Cycle West-East	119	84,09
2	900-8100	24: Cycle West-North	47	92,67
3	900-8100	1: North-West	325	32,21
3	900-8100	2: North-South	785	31,24
3	900-8100	3: North-East	343	30,57
3	900-8100	4: East-North	404	34,60
3	900-8100	5: East-West	378	41,24
3	900-8100	6: East-South	255	43,88
3	900-8100	7: South-East	229	28,27
3	900-8100	8: South-North	923	31,64
3	900-8100	9: South-West	187	31,23
3	900-8100	10: West-South	300	28,93
3	900-8100	11: West-East	355	35,33
3	900-8100	12: West-North	153	36,91
3	900-8100	13: Cycle North-West	108	85,37
3	900-8100	14: Cycle North-South	266	82,58
3	900-8100	15: Cycle North-East	116	86,69
3	900-8100	16: Cycle East-North	133	79,43
3	900-8100	17: Cycle East-West	130	86,32
3	900-8100	18: Cycle East-South	148	91,75
3	900-8100	19: Cycle South-East	81	79,73
3	900-8100	20: Cycle South-North	304	84,11
3	900-8100	21: Cycle South-West	61	92,29
3	900-8100	22: Cycle West-South	102	78,90
3	900-8100	23: Cycle West-East	113	83,83
3	900-8100	24: Cycle West-North	51	86,91
4	900-8100	1: North-West	340	29,24
4	900-8100	2: North-South	787	30,00
4	900-8100	3: North-East	341	31,29
4	900-8100	4: East-North	411	36,34
4	900-8100	5: East-West	381	41,41
4	900-8100	6: East-South	250	44,78
4	900-8100	7: South-East	232	28,11
4	900-8100	8: South-North	944	31,23
4	900-8100	9: South-West	195	31,91
4	900-8100	10: West-South	296	33,10
4	900-8100	11: West-East	357	44,66
4	900-8100	12: West-North	145	49,23
4	900-8100	13: Cycle North-West	105	85,75
4	900-8100	14: Cycle North-South	274	84,76
4	900-8100	15: Cycle North-East	110	88,50
4	900-8100	16: Cycle East-North	131	79,67
4	900-8100	17: Cycle East-West	132	87,62
4	900-8100	18: Cycle East-South	155	91,78
4	900-8100	19: Cycle South-East	78	79,04
4	900-8100	20: Cycle South-North	304	84,29
4	900-8100	21: Cycle South-West	68	91,18
4	900-8100	22: Cycle West-South	98	77,84
4	900-8100	23: Cycle West-East	113	85,03
4	900-8100	24: Cycle West-North	46	87,34
5	900-8100	1: North-West	341	29,53
5	900-8100	2: North-South	783	30,66
5	900-8100	3: North-East	341	31,08
5	900-8100	4: East-North	403	37,21
5	900-8100	5: East-West	368	42,06
5	900-8100	6: East-South	264	42,28
5	900-8100	7: South-East	241	29,45
5	900-8100	8: South-North	930	32,03
5	900-8100	9: South-West	186	32,16
5	900-8100	10: West-South	297	30,54
5	900-8100	11: West-East	341	36,71
5	900-8100	12: West-North	147	39,84
5	900-8100	13: Cycle North-West	111	87,77
5	900-8100	14: Cycle North-South	262	83,83
5	900-8100	15: Cycle North-East	115	88,82
5	900-8100	16: Cycle East-North	135	78,04
5	900-8100	17: Cycle East-West	123	89,70
5	900-8100	18: Cycle East-South	146	90,83
5	900-8100	19: Cycle South-East	81	78,33
5	900-8100	20: Cycle South-North	309	84,92
5	900-8100	21: Cycle South-West	60	90,72
5	900-8100	22: Cycle West-South	103	78,01
5	900-8100	23: Cycle West-East	112	84,81
5	900-8100	24: Cycle West-North	48	89,01
6	900-8100	1: North-West	337	31,00
6	900-8100	2: North-South	788	31,25
6	900-8100	3: North-East	338	32,89
6	900-8100	4: East-North	406	39,75
6	900-8100	5: East-West	377	46,83
6	900-8100	6: East-South	273	49,98
6	900-8100	7: South-East	236	29,61
6	900-8100	8: South-North	931	30,99
6	900-8100	9: South-West	177	29,70
6	900-8100	10: West-South	303	30,71
6	900-8100	11: West-East	349	37,95
6	900-8100	12: West-North	139	41,48
6	900-8100	13: Cycle North-West	113	88,57
6	900-8100	14: Cycle North-South	251	83,52
6	900-8100	15: Cycle North-East	114	87,76
6	900-8100	16: Cycle East-North	130	80,17
6	900-8100	17: Cycle East-West	129	87,47
6	900-8100	18: Cycle East-South	154	92,10
6	900-8100	19: Cycle South-East	81	77,95
6	900-8100	20: Cycle South-North	304	84,44
6	900-8100	21: Cycle South-West	64	91,00
6	900-8100	22: Cycle West-South	99	79,35
6	900-8100	23: Cycle West-East	114	85,09
6	900-8100	24: Cycle West-North	49	90,32
7	900-8100	1: North-West	332	29,24
7	900-8100	2: North-South	782	30,42
7	900-8100	3: North-East	340	31,25
7	900-8100	4: East-North	404	37,77
7	900-8100	5: East-West	375	42,19
7	900-8100	6: East-South	246	43,09
7	900-8100	7: South-East	230	28,07
7	900-8100	8: South-North	934	30,75
7	900-8100	9: South-West	190	30,02
7	900-8100	10: West-South	283	31,65
7	900-8100	11: West-East	341	40,16
7	900-8100	12: West-North	146	42,81
7	900-8100	13: Cycle North-West	109	88,25
7	900-8100	14: Cycle North-South	253	84,17
7	900-8100	15: Cycle North-East	116	86,26
7	900-8100	16: Cycle East-North	130	79,54
7	900-8100	17: Cycle East-West	123	87,53
7	900-8100	18: Cycle East-South	151	92,00
7	900-8100	19: Cycle South-East	76	78,49
7	900-8100	20: Cycle South-North	317	84,31
7	900-8100	21: Cycle South-West	63	89,94
7	900-8100	22: Cycle West-South	97	77,60
7	900-8100	23: Cycle West-East	114	84,06
7	900-8100	24: Cycle West-North	44	91,70
8	900-8100	1: North-West	329	32,28
8	900-8100	2: North-South	786	31,92
8	900-8100	3: North-East	322	31,02
8	900-8100	4: East-North	395	36,46
8	900-8100	5: East-West	379	41,40
8	900-8100	6: East-South	263	43,56
8	900-8100	7: South-East	230	28,39
8	900-8100	8: South-North	932	30,00
8	900-8100	9: South-West	183	30,30
8	900-8100	10: West-South	284	30,72
8	900-8100	11: West-East	354	36,60
8	900-8100	12: West-North	143	37,76
8	900-8100	13: Cycle North-West	114	87,43
8	900-8100	14: Cycle North-South	263	82,41
8	900-8100	15: Cycle North-East	116	88,84
8	900-8100	16: Cycle East-North	129	79,89
8	900-8100	17: Cycle East-West	125	86,79
8	900-8100	18: Cycle East-South	152	92,35
8	900-8100	19: Cycle South-East	78	77,53
8	900-8100	20: Cycle South-North	304	83,62
8	900-8100	21: Cycle South-West	59	93,14
8	900-8100	22: Cycle West-South	98	77,66
8	900-8100	23: Cycle West-East	110	85,06
8	900-8100	24: Cycle West-North	45	89,99

9	900-8100	1: North-West	340	33,28
9	900-8100	2: North-South	772	33,11
9	900-8100	3: North-East	330	31,21
9	900-8100	4: East-North	401	37,15
9	900-8100	5: East-West	371	43,96
9	900-8100	6: East-South	262	45,50
9	900-8100	7: South-East	232	28,11
9	900-8100	8: South-North	935	31,87
9	900-8100	9: South-West	183	32,78
9	900-8100	10: West-South	295	30,25
9	900-8100	11: West-East	341	36,89
9	900-8100	12: West-North	143	41,05
9	900-8100	13: Cycle North-West	109	94,61
9	900-8100	14: Cycle North-South	261	82,95
9	900-8100	15: Cycle North-East	115	88,83
9	900-8100	16: Cycle East-North	138	79,12
9	900-8100	17: Cycle East-West	125	85,80
9	900-8100	18: Cycle East-South	159	91,13
9	900-8100	19: Cycle South-East	81	79,03
9	900-8100	20: Cycle South-North	315	85,60
9	900-8100	21: Cycle South-West	61	91,28
9	900-8100	22: Cycle West-South	101	78,29
9	900-8100	23: Cycle West-East	112	84,56
9	900-8100	24: Cycle West-North	52	95,25
10	900-8100	1: North-West	340	29,72
10	900-8100	2: North-South	800	30,24
10	900-8100	3: North-East	338	31,03
10	900-8100	4: East-North	395	36,68
10	900-8100	5: East-West	384	44,20
10	900-8100	6: East-South	268	45,78
10	900-8100	7: South-East	236	26,76
10	900-8100	8: South-North	950	30,62
10	900-8100	9: South-West	186	30,74
10	900-8100	10: West-South	295	33,53
10	900-8100	11: West-East	340	41,83
10	900-8100	12: West-North	148	44,34
10	900-8100	13: Cycle North-West	113	89,13
10	900-8100	14: Cycle North-South	270	82,43
10	900-8100	15: Cycle North-East	110	89,13
10	900-8100	16: Cycle East-North	127	80,41
10	900-8100	17: Cycle East-West	121	88,95
10	900-8100	18: Cycle East-South	150	93,38
10	900-8100	19: Cycle South-East	75	79,13
10	900-8100	20: Cycle South-North	305	84,23
10	900-8100	21: Cycle South-West	57	91,57
10	900-8100	22: Cycle West-South	91	79,06
10	900-8100	23: Cycle West-East	118	84,42
10	900-8100	24: Cycle West-North	46	88,20
Average	900-8100	1: North-West	335	30,67
Average	900-8100	2: North-South	785	31,27
Average	900-8100	3: North-East	338	31,59
Average	900-8100	4: East-North	404	37,88
Average	900-8100	5: East-West	377	44,50
Average	900-8100	6: East-South	260	46,72
Average	900-8100	7: South-East	233	28,42
Average	900-8100	8: South-North	935	31,16
Average	900-8100	9: South-West	187	31,11
Average	900-8100	10: West-South	293	30,89
Average	900-8100	11: West-East	346	38,23
Average	900-8100	12: West-North	146	41,05
Average	900-8100	13: Cycle North-West	110	89,10
Average	900-8100	14: Cycle North-South	262	83,25
Average	900-8100	15: Cycle North-East	113	88,09
Average	900-8100	16: Cycle East-North	133	79,54
Average	900-8100	17: Cycle East-West	127	87,66
Average	900-8100	18: Cycle East-South	153	92,15
Average	900-8100	19: Cycle South-East	79	78,42
Average	900-8100	20: Cycle South-North	309	84,48
Average	900-8100	21: Cycle South-West	62	91,52
Average	900-8100	22: Cycle West-South	98	78,40
Average	900-8100	23: Cycle West-East	114	84,39
Average	900-8100	24: Cycle West-North	48	90,03
Standard deviation	900-8100	1: North-West	5	1,45
Standard deviation	900-8100	2: North-South	7	0,97
Standard deviation	900-8100	3: North-East	7	0,87
Standard deviation	900-8100	4: East-North	7	2,47
Standard deviation	900-8100	5: East-West	5	3,82
Standard deviation	900-8100	6: East-South	8	4,70
Standard deviation	900-8100	7: South-East	4	0,80
Standard deviation	900-8100	8: South-North	8	0,75
Standard deviation	900-8100	9: South-West	5	1,04
Standard deviation	900-8100	10: West-South	7	1,51
Standard deviation	900-8100	11: West-East	7	3,02
Standard deviation	900-8100	12: West-North	4	3,73
Standard deviation	900-8100	13: Cycle North-West	3	3,03
Standard deviation	900-8100	14: Cycle North-South	7	0,83
Standard deviation	900-8100	15: Cycle North-East	3	1,02
Standard deviation	900-8100	16: Cycle East-North	4	0,74
Standard deviation	900-8100	17: Cycle East-West	4	1,23
Standard deviation	900-8100	18: Cycle East-South	5	0,88
Standard deviation	900-8100	19: Cycle South-East	3	0,81
Standard deviation	900-8100	20: Cycle South-North	5	0,58
Standard deviation	900-8100	21: Cycle South-West	3	1,18
Standard deviation	900-8100	22: Cycle West-South	4	0,62
Standard deviation	900-8100	23: Cycle West-East	3	0,69
Standard deviation	900-8100	24: Cycle West-North	3	2,57

Roundabout

SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)
1	900-8100	1: North-West	315	97,92
1	900-8100	2: North-South	736	100,86
1	900-8100	3: North-East	313	101,77
1	900-8100	4: East-North	341	157,43
1	900-8100	5: East-West	328	158,06
1	900-8100	6: East-South	232	165,00
1	900-8100	7: South-East	192	123,88
1	900-8100	8: South-North	825	127,52
1	900-8100	9: South-West	163	126,48
1	900-8100	10: West-South	286	133,09
1	900-8100	11: West-East	342	130,66
1	900-8100	12: West-North	145	127,96
1	900-8100	13: Cycle North-West	111	94,52
1	900-8100	14: Cycle North-South	257	80,44
1	900-8100	15: Cycle North-East	109	86,31
1	900-8100	16: Cycle East-North	138	76,92
1	900-8100	17: Cycle East-West	130	85,21
1	900-8100	18: Cycle East-South	158	86,84
1	900-8100	19: Cycle South-East	84	88,66
1	900-8100	20: Cycle South-North	311	83,89
1	900-8100	21: Cycle South-West	62	92,45
1	900-8100	22: Cycle West-South	97	77,67
1	900-8100	23: Cycle West-East	115	86,70
1	900-8100	24: Cycle West-North	50	90,86
2	900-8100	1: North-West	312	98,61
2	900-8100	2: North-South	763	99,24
2	900-8100	3: North-East	327	99,49
2	900-8100	4: East-North	384	137,41
2	900-8100	5: East-West	342	138,31
2	900-8100	6: East-South	239	140,60
2	900-8100	7: South-East	206	126,56
2	900-8100	8: South-North	774	127,07
2	900-8100	9: South-West	157	132,30
2	900-8100	10: West-South	286	156,46
2	900-8100	11: West-East	339	155,19
2	900-8100	12: West-North	146	156,98
2	900-8100	13: Cycle North-West	111	97,83
2	900-8100	14: Cycle North-South	258	80,05
2	900-8100	15: Cycle North-East	111	86,23
2	900-8100	16: Cycle East-North	137	78,45
2	900-8100	17: Cycle East-West	130	87,12
2	900-8100	18: Cycle East-South	161	88,27
2	900-8100	19: Cycle South-East	77	91,92
2	900-8100	20: Cycle South-North	311	84,72
2	900-8100	21: Cycle South-West	64	95,23
2	900-8100	22: Cycle West-South	94	77,35
2	900-8100	23: Cycle West-East	117	84,19
2	900-8100	24: Cycle West-North	48	90,22
3	900-8100	1: North-West	304	93,88
3	900-8100	2: North-South	717	98,44
3	900-8100	3: North-East	317	98,25
3	900-8100	4: East-North	377	153,94
3	900-8100	5: East-West	345	155,57
3	900-8100	6: East-South	249	155,56
3	900-8100	7: South-East	194	128,59
3	900-8100	8: South-North	815	129,01
3	900-8100	9: South-West	168	128,40
3	900-8100	10: West-South	287	112,80
3	900-8100	11: West-East	340	108,77
3	900-8100	12: West-North	147	108,95
3	900-8100	13: Cycle North-West	109	92,06
3	900-8100	14: Cycle North-South	266	79,91
3	900-8100	15: Cycle North-East	115	87,35
3	900-8100	16: Cycle East-North	134	77,44
3	900-8100	17: Cycle East-West	129	85,99
3	900-8100	18: Cycle East-South	148	86,52
3	900-8100	19: Cycle South-East	81	93,45
3	900-8100	20: Cycle South-North	303	84,59
3	900-8100	21: Cycle South-West	62	92,01
3	900-8100	22: Cycle West-South	102	77,67
3	900-8100	23: Cycle West-East	112	86,10
3	900-8100	24: Cycle West-North	51	87,91
4	900-8100	1: North-West	318	88,20
4	900-8100	2: North-South	754	89,89
4	900-8100	3: North-East	327	94,21
4	900-8100	4: East-North	364	149,44
4	900-8100	5: East-West	347	151,43
4	900-8100	6: East-South	230	153,54
4	900-8100	7: South-East	189	126,94
4	900-8100	8: South-North	793	132,41
4	900-8100	9: South-West	153	130,54
4	900-8100	10: West-South	291	150,87
4	900-8100	11: West-East	350	147,67
4	900-8100	12: West-North	137	149,66
4	900-8100	13: Cycle North-West	107	88,79
4	900-8100	14: Cycle North-South	275	79,98
4	900-8100	15: Cycle North-East	108	85,34
4	900-8100	16: Cycle East-North	131	77,14
4	900-8100	17: Cycle East-West	132	87,99
4	900-8100	18: Cycle East-South	155	86,59
4	900-8100	19: Cycle South-East	76	93,99
4	900-8100	20: Cycle South-North	305	83,57
4	900-8100	21: Cycle South-West	68	94,46
4	900-8100	22: Cycle West-South	98	76,49
4	900-8100	23: Cycle West-East	114	86,84
4	900-8100	24: Cycle West-North	47	88,08
5	900-8100	1: North-West	310	101,46
5	900-8100	2: North-South	723	105,50
5	900-8100	3: North-East	312	107,29
5	900-8100	4: East-North	361	139,07
5	900-8100	5: East-West	339	137,44
5	900-8100	6: East-South	254	145,21
5	900-8100	7: South-East	211	123,70
5	900-8100	8: South-North	777	127,35
5	900-8100	9: South-West	153	128,88
5	900-8100	10: West-South	298	91,26
5	900-8100	11: West-East	344	92,64
5	900-8100	12: West-North	147	94,97
5	900-8100	13: Cycle North-West	112	91,55
5	900-8100	14: Cycle North-South	263	79,74
5	900-8100	15: Cycle North-East	116	86,15
5	900-8100	16: Cycle East-North	135	76,66
5	900-8100	17: Cycle East-West	123	86,78
5	900-8100	18: Cycle East-South	146	87,20
5	900-8100	19: Cycle South-East	80	88,22
5	900-8100	20: Cycle South-North	309	84,59
5	900-8100	21: Cycle South-West	59	96,58
5	900-8100	22: Cycle West-South	102	76,97
5	900-8100	23: Cycle West-East	111	85,47
5	900-8100	24: Cycle West-North	49	90,44
6	900-8100	1: North-West	315	98,00
6	900-8100	2: North-South	728	101,43
6	900-8100	3: North-East	314	103,67
6	900-8100	4: East-North	357	159,27
6	900-8100	5: East-West	339	161,42
6	900-8100	6: East-South	240	164,25
6	900-8100	7: South-East	211	126,17
6	900-8100	8: South-North	808	129,16
6	900-8100	9: South-West	163	129,25
6	900-8100	10: West-South	300	107,96
6	900-8100	11: West-East	345	112,37
6	900-8100	12: West-North	136	109,80
6	900-8100	13: Cycle North-West	114	89,25
6	900-8100	14: Cycle North-South	252	80,55
6	900-8100	15: Cycle North-East	114	86,85
6	900-8100	16: Cycle East-North	129	78,10
6	900-8100	17: Cycle East-West	129	87,72
6	900-8100	18: Cycle East-South	154	86,14
6	900-8100	19: Cycle South-East	81	93,35
6	900-8100	20: Cycle South-North	303	83,75
6	900-8100	21: Cycle South-West	64	94,08
6	900-8100	22: Cycle West-South	99	78,48
6	900-8100	23: Cycle West-East	112	86,31
6	900-8100	24: Cycle West-North	49	88,92
7	900-8100	1: North-West	313	104,72
7	900-8100	2: North-South	723	105,02
7	900-8100	3: North-East	314	108,51
7	900-8100	4: East-North	372	159,78
7	900-8100	5: East-West	335	161,29
7	900-8100	6: East-South	231	166,07
7	900-8100	7: South-East	200	123,98
7	900-8100	8: South-North	805	123,89
7	900-8100	9: South-West	167	124,32
7	900-8100	10: West-South	287	87,59
7	900-8100	11: West-East	350	91,58
7	900-8100	12: West-North	148	99,69
7	900-8100	13: Cycle North-West	109	93,33
7	900-8100	14: Cycle North-South	254	80,55
7	900-8100	15: Cycle North-East	117	88,49
7	900-8100	16: Cycle East-North	130	77,71
7	900-8100	17: Cycle East-West	121	87,87
7	900-8100	18: Cycle East-South	150	87,87
7	900-8100	19: Cycle South-East	77	96,03
7	900-8100	20: Cycle South-North	318	84,46
7	900-8100	21: Cycle South-West	65	92,03
7	900-8100	22: Cycle West-South	97	76,69
7	900-8100	23: Cycle West-East	112	87,10
7	900-8100	24: Cycle West-North	44	89,22
8	900-8100	1: North-West	311	103,35
8	900-8100	2: North-South	749	104,51
8	900-8100	3: North-East	301	106,15
8	900-8100	4: East-North	362	155,46
8	900-8100	5: East-West	351	158,00
8	900-8100	6: East-South	240	159,42
8	900-8100	7: South-East	210	125,78
8	900-8100	8: South-North	819	126,94
8	900-8100	9: South-West	158	129,56
8	900-8100	10: West-South	281	96,73
8	900-8100	11: West-East	348	107,14
8	900-8100	12: West-North	142	102,77
8	900-8100	13: Cycle North-West	113	96,88
8	900-8100	14: Cycle North-South	266	79,29
8	900-8100	15: Cycle North-East	115	86,69
8	900-8100	16: Cycle East-North	129	77,86
8	900-8100	17: Cycle East-West	124	88,87
8	900-8100	18: Cycle East-South	151	87,90
8	900-8100	19: Cycle South-East	79	88,64
8	900-8100	20: Cycle South-North	302	84,13
8	900-8100	21: Cycle South-West	61	94,97
8	900-8100	22: Cycle West-South	98	76,74
8	900-8100	23: Cycle West-East	109	85,11
8	900-8100	24: Cycle West-North	45	87,01

9	900-8100	1: North-West	336	100,74
9	900-8100	2: North-South	734	103,46
9	900-8100	3: North-East	315	104,32
9	900-8100	4: East-North	361	144,06
9	900-8100	5: East-West	340	143,39
9	900-8100	6: East-South	239	146,02
9	900-8100	7: South-East	205	131,67
9	900-8100	8: South-North	799	133,03
9	900-8100	9: South-West	146	131,90
9	900-8100	10: West-South	291	103,87
9	900-8100	11: West-East	333	103,01
9	900-8100	12: West-North	141	106,72
9	900-8100	13: Cycle North-West	109	99,38
9	900-8100	14: Cycle North-South	263	79,23
9	900-8100	15: Cycle North-East	115	87,99
9	900-8100	16: Cycle East-North	138	77,65
9	900-8100	17: Cycle East-West	124	87,91
9	900-8100	18: Cycle East-South	158	88,32
9	900-8100	19: Cycle South-East	81	93,96
9	900-8100	20: Cycle South-North	314	84,23
9	900-8100	21: Cycle South-West	61	91,36
9	900-8100	22: Cycle West-South	101	77,29
9	900-8100	23: Cycle West-East	112	85,59
9	900-8100	24: Cycle West-North	52	89,65
10	900-8100	1: North-West	309	92,74
10	900-8100	2: North-South	750	96,35
10	900-8100	3: North-East	321	97,36
10	900-8100	4: East-North	355	133,64
10	900-8100	5: East-West	345	137,44
10	900-8100	6: East-South	246	139,01
10	900-8100	7: South-East	195	126,39
10	900-8100	8: South-North	793	127,65
10	900-8100	9: South-West	160	128,69
10	900-8100	10: West-South	288	93,72
10	900-8100	11: West-East	330	102,30
10	900-8100	12: West-North	146	99,79
10	900-8100	13: Cycle North-West	111	92,30
10	900-8100	14: Cycle North-South	270	79,39
10	900-8100	15: Cycle North-East	111	88,94
10	900-8100	16: Cycle East-North	128	77,93
10	900-8100	17: Cycle East-West	121	86,36
10	900-8100	18: Cycle East-South	151	87,96
10	900-8100	19: Cycle South-East	76	91,88
10	900-8100	20: Cycle South-North	301	82,83
10	900-8100	21: Cycle South-West	57	94,33
10	900-8100	22: Cycle West-South	92	78,16
10	900-8100	23: Cycle West-East	117	87,10
10	900-8100	24: Cycle West-North	46	88,58
Average	900-8100	1: North-West	314	97,96
Average	900-8100	2: North-South	738	100,47
Average	900-8100	3: North-East	316	102,10
Average	900-8100	4: East-North	363	148,95
Average	900-8100	5: East-West	341	150,24
Average	900-8100	6: East-South	240	153,47
Average	900-8100	7: South-East	201	126,37
Average	900-8100	8: South-North	801	128,40
Average	900-8100	9: South-West	159	129,03
Average	900-8100	10: West-South	290	113,43
Average	900-8100	11: West-East	342	115,13
Average	900-8100	12: West-North	144	115,73
Average	900-8100	13: Cycle North-West	111	93,59
Average	900-8100	14: Cycle North-South	262	79,91
Average	900-8100	15: Cycle North-East	113	87,03
Average	900-8100	16: Cycle East-North	133	77,59
Average	900-8100	17: Cycle East-West	126	87,18
Average	900-8100	18: Cycle East-South	153	87,36
Average	900-8100	19: Cycle South-East	79	92,01
Average	900-8100	20: Cycle South-North	308	84,08
Average	900-8100	21: Cycle South-West	62	93,75
Average	900-8100	22: Cycle West-South	98	77,35
Average	900-8100	23: Cycle West-East	113	86,05
Average	900-8100	24: Cycle West-North	48	89,09
Standard deviation	900-8100	1: North-West	9	5,10
Standard deviation	900-8100	2: North-South	15	4,80
Standard deviation	900-8100	3: North-East	8	4,69
Standard deviation	900-8100	4: East-North	12	9,73
Standard deviation	900-8100	5: East-West	7	10,08
Standard deviation	900-8100	6: East-South	8	10,25
Standard deviation	900-8100	7: South-East	8	2,42
Standard deviation	900-8100	8: South-North	17	2,69
Standard deviation	900-8100	9: South-West	7	2,37
Standard deviation	900-8100	10: West-South	6	24,92
Standard deviation	900-8100	11: West-East	7	22,08
Standard deviation	900-8100	12: West-North	4	21,80
Standard deviation	900-8100	13: Cycle North-West	2	3,55
Standard deviation	900-8100	14: Cycle North-South	7	0,50
Standard deviation	900-8100	15: Cycle North-East	3	1,14
Standard deviation	900-8100	16: Cycle East-North	4	0,55
Standard deviation	900-8100	17: Cycle East-West	4	1,10
Standard deviation	900-8100	18: Cycle East-South	5	0,80
Standard deviation	900-8100	19: Cycle South-East	3	2,68
Standard deviation	900-8100	20: Cycle South-North	6	0,59
Standard deviation	900-8100	21: Cycle South-West	3	1,70
Standard deviation	900-8100	22: Cycle West-South	3	0,65
Standard deviation	900-8100	23: Cycle West-East	3	0,96
Standard deviation	900-8100	24: Cycle West-North	3	1,23

Appendix 1b: Degeneracy test

Original situation												
Non peak:						Peak:						
SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		Increase (%)
Average	900-8100	1: North-West	142	37,00		Average	900-8100	1: North-West	333	82,82		123,82
Average	900-8100	2: North-South	341	34,78		Average	900-8100	2: North-South	777	79,15		127,59
Average	900-8100	3: North-East	132	41,23		Average	900-8100	3: North-East	337	89,66		117,46
Average	900-8100	4: East-North	186	35,18		Average	900-8100	4: East-North	409	48,37		37,47
Average	900-8100	5: East-West	174	33,08		Average	900-8100	5: East-West	376	47,45		43,47
Average	900-8100	6: East-South	192	42,94		Average	900-8100	6: East-South	260	69,75		62,41
Average	900-8100	7: South-East	129	40,99		Average	900-8100	7: South-East	232	70,46		71,89
Average	900-8100	8: South-North	516	38,45		Average	900-8100	8: South-North	930	66,63		73,30
Average	900-8100	9: South-West	100	43,51		Average	900-8100	9: South-West	188	75,67		73,94
Average	900-8100	10: West-South	107	33,41		Average	900-8100	10: West-South	294	47,39		41,86
Average	900-8100	11: West-East	156	35,93		Average	900-8100	11: West-East	348	47,06		30,97
Average	900-8100	12: West-North	65	43,88		Average	900-8100	12: West-North	148	69,64		58,70
Average	900-8100	13: Cycle North-West	28	97,54		Average	900-8100	13: Cycle North-West	110	102,40		4,98
Average	900-8100	14: Cycle North-South	111	93,04		Average	900-8100	14: Cycle North-South	264	109,43		17,62
Average	900-8100	15: Cycle North-East	44	107,79		Average	900-8100	15: Cycle North-East	113	144,56		34,11
Average	900-8100	16: Cycle East-North	63	97,93		Average	900-8100	16: Cycle East-North	134	100,73		2,86
Average	900-8100	17: Cycle East-West	56	87,22		Average	900-8100	17: Cycle East-West	129	102,00		16,95
Average	900-8100	18: Cycle East-South	64	101,70		Average	900-8100	18: Cycle East-South	154	125,87		23,77
Average	900-8100	19: Cycle South-East	43	98,14		Average	900-8100	19: Cycle South-East	79	111,12		13,23
Average	900-8100	20: Cycle South-North	172	94,63		Average	900-8100	20: Cycle South-North	308	125,61		32,74
Average	900-8100	21: Cycle South-West	32	107,19		Average	900-8100	21: Cycle South-West	63	154,42		44,06
Average	900-8100	22: Cycle West-South	36	101,38		Average	900-8100	22: Cycle West-South	98	103,22		1,82
Average	900-8100	23: Cycle West-East	53	88,22		Average	900-8100	23: Cycle West-East	114	107,77		22,16
Average	900-8100	24: Cycle West-North	23	103,54		Average	900-8100	24: Cycle West-North	49	133,76		29,18

Turbo-roundabout:												
Non-peak:						Peak:						
SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		Increase (%)
Average	900-8100	1: North-West	141	24,77		Average	900-8100	1: North-West	334	30,25		22,12
Average	900-8100	2: North-South	339	25,72		Average	900-8100	2: North-South	784	30,71		19,39
Average	900-8100	3: North-East	132	26,51		Average	900-8100	3: North-East	341	31,07		17,21
Average	900-8100	4: East-North	186	27,45		Average	900-8100	4: East-North	408	39,47		43,78
Average	900-8100	5: East-West	174	28,56		Average	900-8100	5: East-West	375	46,25		61,97
Average	900-8100	6: East-South	192	30,26		Average	900-8100	6: East-South	259	48,14		59,11
Average	900-8100	7: South-East	129	22,86		Average	900-8100	7: South-East	234	29,96		31,07
Average	900-8100	8: South-North	517	24,58		Average	900-8100	8: South-North	934	31,95		30,00
Average	900-8100	9: South-West	100	26,01		Average	900-8100	9: South-West	189	30,59		17,62
Average	900-8100	10: West-South	107	25,02		Average	900-8100	10: West-South	294	31,49		25,82
Average	900-8100	11: West-East	157	26,44		Average	900-8100	11: West-East	347	37,57		42,09
Average	900-8100	12: West-North	65	28,86		Average	900-8100	12: West-North	148	40,45		40,17
Average	900-8100	13: Cycle North-West	28	89,82		Average	900-8100	13: Cycle North-West	109	90,82		1,12
Average	900-8100	14: Cycle North-South	110	78,74		Average	900-8100	14: Cycle North-South	263	83,25		5,72
Average	900-8100	15: Cycle North-East	45	80,39		Average	900-8100	15: Cycle North-East	112	88,01		9,47
Average	900-8100	16: Cycle East-North	62	77,71		Average	900-8100	16: Cycle East-North	135	79,17		1,87
Average	900-8100	17: Cycle East-West	56	79,66		Average	900-8100	17: Cycle East-West	129	86,98		9,18
Average	900-8100	18: Cycle East-South	64	80,84		Average	900-8100	18: Cycle East-South	153	91,37		13,02
Average	900-8100	19: Cycle South-East	43	77,87		Average	900-8100	19: Cycle South-East	80	78,43		0,72
Average	900-8100	20: Cycle South-North	173	79,26		Average	900-8100	20: Cycle South-North	308	84,70		6,86
Average	900-8100	21: Cycle South-West	31	81,18		Average	900-8100	21: Cycle South-West	63	91,87		13,16
Average	900-8100	22: Cycle West-South	36	77,15		Average	900-8100	22: Cycle West-South	99	78,26		1,44
Average	900-8100	23: Cycle West-East	53	79,02		Average	900-8100	23: Cycle West-East	114	84,09		6,41
Average	900-8100	24: Cycle West-North	23	80,55		Average	900-8100	24: Cycle West-North	48	89,56		11,19

Roundabout:												
Non-peak:						Peak:						
SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		Increase (%)
Average	900-8100	1: North-West	141	24,89		Average	900-8100	1: North-West	310	94,03		277,72
Average	900-8100	2: North-South	340	26,45		Average	900-8100	2: North-South	738	96,67		265,40
Average	900-8100	3: North-East	132	27,63		Average	900-8100	3: North-East	318	98,06		254,93
Average	900-8100	4: East-North	186	30,01		Average	900-8100	4: East-North	359	151,61		405,22
Average	900-8100	5: East-West	174	30,53		Average	900-8100	5: East-West	333	150,68		393,48
Average	900-8100	6: East-South	192	31,54		Average	900-8100	6: East-South	235	157,44		399,11
Average	900-8100	7: South-East	129	24,93		Average	900-8100	7: South-East	198	125,32		402,62
Average	900-8100	8: South-North	518	26,67		Average	900-8100	8: South-North	807	127,78		379,12
Average	900-8100	9: South-West	100	27,23		Average	900-8100	9: South-West	160	128,62		372,25
Average	900-8100	10: West-South	107	25,49		Average	900-8100	10: West-South	291	104,57		310,16
Average	900-8100	11: West-East	157	26,49		Average	900-8100	11: West-East	343	105,24		297,28
Average	900-8100	12: West-North	65	28,26		Average	900-8100	12: West-North	146	103,41		265,93
Average	900-8100	13: Cycle North-West	28	89,81		Average	900-8100	13: Cycle North-West	110	93,99		4,65
Average	900-8100	14: Cycle North-South	111	78,36		Average	900-8100	14: Cycle North-South	264	80,14		2,28
Average	900-8100	15: Cycle North-East	45	80,21		Average	900-8100	15: Cycle North-East	112	87,30		8,83
Average	900-8100	16: Cycle East-North	62	77,57		Average	900-8100	16: Cycle East-North	135	77,34		-0,30
Average	900-8100	17: Cycle East-West	56	79,32		Average	900-8100	17: Cycle East-West	129	86,69		9,28
Average	900-8100	18: Cycle East-South	64	79,64		Average	900-8100	18: Cycle East-South	154	87,02		9,27
Average	900-8100	19: Cycle South-East	43	91,48		Average	900-8100	19: Cycle South-East	80	92,36		0,96
Average	900-8100	20: Cycle South-North	172	79,69		Average	900-8100	20: Cycle South-North	308	83,74		5,08
Average	900-8100	21: Cycle South-West	32	81,60		Average	900-8100	21: Cycle South-West	63	93,06		14,05
Average	900-8100	22: Cycle West-South	36	76,74		Average	900-8100	22: Cycle West-South	99	77,24		0,65
Average	900-8100	23: Cycle West-East	53	79,97		Average	900-8100	23: Cycle West-East	114	85,64		7,09
Average	900-8100	24: Cycle West-North	23	81,40		Average	900-8100	24: Cycle West-North	49	90,07		10,65

Appendix 1c: Extreme condition test

Original situation												
Normal:						Dominant direction:						
SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		Increase (%)
Average	900-8100	1: North-West	333	82,82		Average	900-8100	1: North-West	328	90,29		9,02
Average	900-8100	2: North-South	777	79,15		Average	900-8100	2: North-South	771	87,44		10,46
Average	900-8100	3: North-East	337	89,66		Average	900-8100	3: North-East	334	95,73		6,78
Average	900-8100	4: East-North	409	48,37		Average	900-8100	4: East-North	811	55,42		14,59
Average	900-8100	5: East-West	376	47,45		Average	900-8100	5: East-West	376	49,25		3,79
Average	900-8100	6: East-South	260	69,75		Average	900-8100	6: East-South	262	69,79		0,06
Average	900-8100	7: South-East	232	70,46		Average	900-8100	7: South-East	228	100,22		42,24
Average	900-8100	8: South-North	930	66,63		Average	900-8100	8: South-North	912	96,33		44,58
Average	900-8100	9: South-West	188	75,67		Average	900-8100	9: South-West	182	100,24		32,46
Average	900-8100	10: West-South	294	47,39		Average	900-8100	10: West-South	294	47,00		-0,82
Average	900-8100	11: West-East	348	47,06		Average	900-8100	11: West-East	348	47,88		1,75
Average	900-8100	12: West-North	148	69,64		Average	900-8100	12: West-North	148	73,81		5,99
Average	900-8100	13: Cycle North-West	110	102,40		Average	900-8100	13: Cycle North-West	110	109,23		6,67
Average	900-8100	14: Cycle North-South	264	109,43		Average	900-8100	14: Cycle North-South	265	110,44		0,92
Average	900-8100	15: Cycle North-East	113	144,56		Average	900-8100	15: Cycle North-East	113	148,46		2,69
Average	900-8100	16: Cycle East-North	134	100,73		Average	900-8100	16: Cycle East-North	271	107,34		6,57
Average	900-8100	17: Cycle East-West	129	102,00		Average	900-8100	17: Cycle East-West	126	106,23		4,15
Average	900-8100	18: Cycle East-South	154	125,87		Average	900-8100	18: Cycle East-South	155	128,50		2,09
Average	900-8100	19: Cycle South-East	79	111,12		Average	900-8100	19: Cycle South-East	79	129,63		16,66
Average	900-8100	20: Cycle South-North	308	125,61		Average	900-8100	20: Cycle South-North	307	131,66		4,81
Average	900-8100	21: Cycle South-West	63	154,42		Average	900-8100	21: Cycle South-West	63	164,21		6,34
Average	900-8100	22: Cycle West-South	98	103,22		Average	900-8100	22: Cycle West-South	99	105,89		2,59
Average	900-8100	23: Cycle West-East	114	107,77		Average	900-8100	23: Cycle West-East	114	113,79		5,59
Average	900-8100	24: Cycle West-North	49	133,76		Average	900-8100	24: Cycle West-North	49	145,26		8,60

Turbo-roundabout:												
Normal:						Dominant direction:						
SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		Increase (%)
Average	900-8100	1: North-West	334	30,25		Average	900-8100	1: North-West	334	31,18		3,09
Average	900-8100	2: North-South	784	30,71		Average	900-8100	2: North-South	785	31,11		1,31
Average	900-8100	3: North-East	341	31,07		Average	900-8100	3: North-East	342	31,47		1,27
Average	900-8100	4: East-North	408	39,47		Average	900-8100	4: East-North	807	52,77		33,68
Average	900-8100	5: East-West	375	46,25		Average	900-8100	5: East-West	372	61,52		33,01
Average	900-8100	6: East-South	259	48,14		Average	900-8100	6: East-South	262	62,43		29,68
Average	900-8100	7: South-East	234	29,96		Average	900-8100	7: South-East	234	27,99		-6,57
Average	900-8100	8: South-North	934	31,95		Average	900-8100	8: South-North	934	31,97		0,06
Average	900-8100	9: South-West	189	30,59		Average	900-8100	9: South-West	189	31,92		4,32
Average	900-8100	10: West-South	294	31,49		Average	900-8100	10: West-South	294	30,02		-4,66
Average	900-8100	11: West-East	347	37,57		Average	900-8100	11: West-East	348	36,10		-3,91
Average	900-8100	12: West-North	148	40,45		Average	900-8100	12: West-North	148	40,35		-0,25
Average	900-8100	13: Cycle North-West	109	90,82		Average	900-8100	13: Cycle North-West	109	89,14		-1,86
Average	900-8100	14: Cycle North-South	263	83,25		Average	900-8100	14: Cycle North-South	263	83,02		-0,28
Average	900-8100	15: Cycle North-East	112	88,01		Average	900-8100	15: Cycle North-East	112	87,56		-0,51
Average	900-8100	16: Cycle East-North	135	79,17		Average	900-8100	16: Cycle East-North	273	80,80		2,06
Average	900-8100	17: Cycle East-West	129	86,98		Average	900-8100	17: Cycle East-West	126	90,60		4,17
Average	900-8100	18: Cycle East-South	153	91,37		Average	900-8100	18: Cycle East-South	155	95,27		4,27
Average	900-8100	19: Cycle South-East	80	78,43		Average	900-8100	19: Cycle South-East	80	78,48		0,06
Average	900-8100	20: Cycle South-North	308	84,70		Average	900-8100	20: Cycle South-North	308	88,57		4,57
Average	900-8100	21: Cycle South-West	63	91,87		Average	900-8100	21: Cycle South-West	63	98,70		7,43
Average	900-8100	22: Cycle West-South	99	78,26		Average	900-8100	22: Cycle West-South	99	78,37		0,15
Average	900-8100	23: Cycle West-East	114	84,09		Average	900-8100	23: Cycle West-East	114	84,30		0,26
Average	900-8100	24: Cycle West-North	48	89,56		Average	900-8100	24: Cycle West-North	48	93,22		4,09

Roundabout:												
Normal:						Dominant direction:						
SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		Increase (%)
Average	900-8100	1: North-West	310	94,03		Average	900-8100	1: North-West	331	65,34		-30,52
Average	900-8100	2: North-South	738	96,67		Average	900-8100	2: North-South	775	67,65		-30,02
Average	900-8100	3: North-East	318	98,06		Average	900-8100	3: North-East	338	68,54		-30,10
Average	900-8100	4: East-North	359	151,61		Average	900-8100	4: East-North	543	156,03		2,92
Average	900-8100	5: East-West	333	150,68		Average	900-8100	5: East-West	247	156,73		4,02
Average	900-8100	6: East-South	235	157,44		Average	900-8100	6: East-South	171	158,54		0,70
Average	900-8100	7: South-East	198	125,32		Average	900-8100	7: South-East	197	126,01		0,55
Average	900-8100	8: South-North	807	127,78		Average	900-8100	8: South-North	793	128,38		0,47
Average	900-8100	9: South-West	160	128,62		Average	900-8100	9: South-West	159	131,26		2,06
Average	900-8100	10: West-South	291	104,57		Average	900-8100	10: West-South	292	106,87		2,20
Average	900-8100	11: West-East	343	105,24		Average	900-8100	11: West-East	344	109,69		4,23
Average	900-8100	12: West-North	146	103,41		Average	900-8100	12: West-North	145	109,68		6,07
Average	900-8100	13: Cycle North-West	110	93,99		Average	900-8100	13: Cycle North-West	110	92,24		-1,86
Average	900-8100	14: Cycle North-South	264	80,14		Average	900-8100	14: Cycle North-South	264	80,03		-0,13
Average	900-8100	15: Cycle North-East	112	87,30		Average	900-8100	15: Cycle North-East	112	87,13		-0,19
Average	900-8100	16: Cycle East-North	135	77,34		Average	900-8100	16: Cycle East-North	272	77,62		0,37
Average	900-8100	17: Cycle East-West	129	86,69		Average	900-8100	17: Cycle East-West	126	87,38		0,81
Average	900-8100	18: Cycle East-South	154	87,02		Average	900-8100	18: Cycle East-South	155	88,01		1,14
Average	900-8100	19: Cycle South-East	80	92,36		Average	900-8100	19: Cycle South-East	79	92,49		0,14
Average	900-8100	20: Cycle South-North	308	83,74		Average	900-8100	20: Cycle South-North	307	84,18		0,53
Average	900-8100	21: Cycle South-West	63	93,06		Average	900-8100	21: Cycle South-West	63	95,13		2,22
Average	900-8100	22: Cycle West-South	99	77,24		Average	900-8100	22: Cycle West-South	99	77,23		-0,01
Average	900-8100	23: Cycle West-East	114	85,64		Average	900-8100	23: Cycle West-East	114	85,58		-0,07
Average	900-8100	24: Cycle West-North	49	90,07		Average	900-8100	24: Cycle West-North	49	90,33		0,29

Roundabout simulation:

Time	Prio...	Type	ID	Message text
Simulation run 1				
07.06.2023 0...	War...	Parking L...	1	453 vehicles could not leave parking lot 1.
07.06.2023 0...	War...	Parking L...	3	205 vehicles could not leave parking lot 3.
Simulation run 2				
07.06.2023 0...	War...	Parking L...	1	497 vehicles could not leave parking lot 1.
07.06.2023 0...	War...	Parking L...	3	167 vehicles could not leave parking lot 3.
Simulation run 3				
07.06.2023 0...	War...	Parking L...	1	529 vehicles could not leave parking lot 1.
07.06.2023 0...	War...	Parking L...	3	156 vehicles could not leave parking lot 3.
Simulation run 4				
07.06.2023 0...	War...	Parking L...	1	507 vehicles could not leave parking lot 1.
07.06.2023 0...	War...	Parking L...	3	150 vehicles could not leave parking lot 3.
Simulation run 5				
07.06.2023 0...	War...	Parking L...	1	501 vehicles could not leave parking lot 1.
07.06.2023 0...	War...	Parking L...	3	186 vehicles could not leave parking lot 3.

Appendix 1d: Face validity test

Original situation

Normal trucks:						High trucks:						
SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		Increase (%)
Average	900-8100	1: North-West	333	82,82		Average	900-8100	1: North-West	257	99,41		20,03
Average	900-8100	2: North-South	777	79,15		Average	900-8100	2: North-South	602	98,07		23,90
Average	900-8100	3: North-East	337	89,66		Average	900-8100	3: North-East	265	110,94		23,73
Average	900-8100	4: East-North	409	48,37		Average	900-8100	4: East-North	409	53,83		11,30
Average	900-8100	5: East-West	376	47,45		Average	900-8100	5: East-West	378	51,52		8,58
Average	900-8100	6: East-South	260	69,75		Average	900-8100	6: East-South	262	73,02		4,70
Average	900-8100	7: South-East	232	70,46		Average	900-8100	7: South-East	198	96,98		37,64
Average	900-8100	8: South-North	930	66,63		Average	900-8100	8: South-North	799	95,77		43,74
Average	900-8100	9: South-West	188	75,67		Average	900-8100	9: South-West	159	100,35		32,62
Average	900-8100	10: West-South	294	47,39		Average	900-8100	10: West-South	294	51,38		8,43
Average	900-8100	11: West-East	348	47,06		Average	900-8100	11: West-East	348	53,85		14,42
Average	900-8100	12: West-North	148	69,64		Average	900-8100	12: West-North	148	72,20		3,68
Average	900-8100	13: Cycle North-West	110	102,40		Average	900-8100	13: Cycle North-West	110	109,85		7,28
Average	900-8100	14: Cycle North-South	264	109,43		Average	900-8100	14: Cycle North-South	262	110,31		0,81
Average	900-8100	15: Cycle North-East	113	144,56		Average	900-8100	15: Cycle North-East	113	142,32		-1,56
Average	900-8100	16: Cycle East-North	134	100,73		Average	900-8100	16: Cycle East-North	134	105,27		4,51
Average	900-8100	17: Cycle East-West	129	102,00		Average	900-8100	17: Cycle East-West	129	105,13		3,07
Average	900-8100	18: Cycle East-South	154	125,87		Average	900-8100	18: Cycle East-South	152	128,81		2,33
Average	900-8100	19: Cycle South-East	79	111,12		Average	900-8100	19: Cycle South-East	79	120,27		8,23
Average	900-8100	20: Cycle South-North	308	125,61		Average	900-8100	20: Cycle South-North	307	127,95		1,86
Average	900-8100	21: Cycle South-West	63	154,42		Average	900-8100	21: Cycle South-West	63	160,90		4,20
Average	900-8100	22: Cycle West-South	98	103,22		Average	900-8100	22: Cycle West-South	99	104,04		0,80
Average	900-8100	23: Cycle West-East	114	107,77		Average	900-8100	23: Cycle West-East	113	108,04		0,25
Average	900-8100	24: Cycle West-North	49	133,76		Average	900-8100	24: Cycle West-North	49	137,02		2,44

Time	Prio...	Type	ID	Message text
Simulation run 1				
05.06.2023 1...	War...	Parking L...	3	194 vehicles could not leave parking lot 3.
05.06.2023 1...	War...	Parking L...	6	269 vehicles could not leave parking lot 6.
Simulation run 2				
05.06.2023 1...	War...	Parking L...	3	248 vehicles could not leave parking lot 3.
05.06.2023 1...	War...	Parking L...	6	371 vehicles could not leave parking lot 6.
Simulation run 3				
05.06.2023 1...	War...	Parking L...	3	189 vehicles could not leave parking lot 3.
05.06.2023 1...	War...	Parking L...	6	335 vehicles could not leave parking lot 6.
Simulation run 4				
05.06.2023 1...	War...	Parking L...	3	164 vehicles could not leave parking lot 3.
05.06.2023 1...	War...	Parking L...	6	375 vehicles could not leave parking lot 6.
Simulation run 5				
05.06.2023 1...	War...	Parking L...	3	159 vehicles could not leave parking lot 3.
05.06.2023 1...	War...	Parking L...	6	310 vehicles could not leave parking lot 6.

Turbo-roundabout

Normal trucks:						High trucks:						
SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		Increase (%)
Average	900-8100	1: North-West	334	30,25		Average	900-8100	1: North-West	332	47,19		56,01
Average	900-8100	2: North-South	784	30,71		Average	900-8100	2: North-South	777	47,19		53,69
Average	900-8100	3: North-East	341	31,07		Average	900-8100	3: North-East	338	46,05		48,21
Average	900-8100	4: East-North	408	39,47		Average	900-8100	4: East-North	399	81,54		106,58
Average	900-8100	5: East-West	375	46,25		Average	900-8100	5: East-West	372	91,05		96,85
Average	900-8100	6: East-South	259	48,14		Average	900-8100	6: East-South	257	94,68		96,67
Average	900-8100	7: South-East	234	29,96		Average	900-8100	7: South-East	233	49,96		66,72
Average	900-8100	8: South-North	934	31,95		Average	900-8100	8: South-North	930	52,00		62,72
Average	900-8100	9: South-West	189	30,59		Average	900-8100	9: South-West	189	48,71		59,22
Average	900-8100	10: West-South	294	31,49		Average	900-8100	10: West-South	293	45,22		43,63
Average	900-8100	11: West-East	347	37,57		Average	900-8100	11: West-East	346	61,19		62,84
Average	900-8100	12: West-North	148	40,45		Average	900-8100	12: West-North	148	67,38		66,59
Average	900-8100	13: Cycle North-West	109	90,82		Average	900-8100	13: Cycle North-West	109	94,09		3,60
Average	900-8100	14: Cycle North-South	263	83,25		Average	900-8100	14: Cycle North-South	264	88,85		6,72
Average	900-8100	15: Cycle North-East	112	88,01		Average	900-8100	15: Cycle North-East	112	99,39		12,94
Average	900-8100	16: Cycle East-North	135	79,17		Average	900-8100	16: Cycle East-North	135	80,19		1,29
Average	900-8100	17: Cycle East-West	129	86,98		Average	900-8100	17: Cycle East-West	129	92,50		6,35
Average	900-8100	18: Cycle East-South	153	91,37		Average	900-8100	18: Cycle East-South	154	102,46		12,14
Average	900-8100	19: Cycle South-East	80	78,43		Average	900-8100	19: Cycle South-East	80	78,68		0,32
Average	900-8100	20: Cycle South-North	308	84,70		Average	900-8100	20: Cycle South-North	308	91,18		7,65
Average	900-8100	21: Cycle South-West	63	91,87		Average	900-8100	21: Cycle South-West	63	102,23		11,28
Average	900-8100	22: Cycle West-South	99	78,26		Average	900-8100	22: Cycle West-South	99	78,16		-0,12
Average	900-8100	23: Cycle West-East	114	84,09		Average	900-8100	23: Cycle West-East	114	90,06		7,10
Average	900-8100	24: Cycle West-North	48	89,56		Average	900-8100	24: Cycle West-North	49	103,01		15,02

Time	Prio...	Type	ID	Message text
Simulation run 2				
05.06.2023 1...	War...	Parking L...	1	3 vehicles could not leave parking lot 1.
05.06.2023 1...	War...	Parking L...	6	4 vehicles could not leave parking lot 6.
Simulation run 3				
05.06.2023 1...	War...	Parking L...	6	30 vehicles could not leave parking lot 6.
Simulation run 4				
05.06.2023 1...	War...	Parking L...	6	9 vehicles could not leave parking lot 6.
Simulation run 5				
05.06.2023 1...	War...	Parking L...	1	17 vehicles could not leave parking lot 1.

Roundabout

Normal trucks:						High trucks:						
SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		SimRun	TimeInt	VehicleTravelTimeMeasurement	Vehs (All)	TravTm (All)		Increase (%)
Average	900-8100	1: North-West	310	94,03		Average	900-8100	1: North-West	225	115,04		22,34
Average	900-8100	2: North-South	738	96,67		Average	900-8100	2: North-South	519	115,92		19,91
Average	900-8100	3: North-East	318	98,06		Average	900-8100	3: North-East	226	116,42		18,72
Average	900-8100	4: East-North	359	151,61		Average	900-8100	4: East-North	374	112,14		-26,03
Average	900-8100	5: East-West	333	150,68		Average	900-8100	5: East-West	350	112,57		-25,29
Average	900-8100	6: East-South	235	157,44		Average	900-8100	6: East-South	248	114,74		-27,12
Average	900-8100	7: South-East	198	125,32		Average	900-8100	7: South-East	149	128,85		2,81
Average	900-8100	8: South-North	807	127,78		Average	900-8100	8: South-North	613	132,58		3,75
Average	900-8100	9: South-West	160	128,62		Average	900-8100	9: South-West	122	131,50		2,24
Average	900-8100	10: West-South	291	104,57		Average	900-8100	10: West-South	296	60,16		-42,47
Average	900-8100	11: West-East	343	105,24		Average	900-8100	11: West-East	350	61,04		-41,99
Average	900-8100	12: West-North	146	103,41		Average	900-8100	12: West-North	149	60,99		-41,02
Average	900-8100	13: Cycle North-West	110	93,99		Average	900-8100	13: Cycle North-West	110	91,84		-2,29
Average	900-8100	14: Cycle North-South	264	80,14		Average	900-8100	14: Cycle North-South	264	79,88		-0,33
Average	900-8100	15: Cycle North-East	112	87,30		Average	900-8100	15: Cycle North-East	112	89,11		2,08
Average	900-8100	16: Cycle East-North	135	77,34		Average	900-8100	16: Cycle East-North	135	77,32		-0,02
Average	900-8100	17: Cycle East-West	129	86,69		Average	900-8100	17: Cycle East-West	129	88,73		2,36
Average	900-8100	18: Cycle East-South	154	87,02		Average	900-8100	18: Cycle East-South	154	88,50		1,70
Average	900-8100	19: Cycle South-East	80	92,36		Average	900-8100	19: Cycle South-East	79	92,81		0,49
Average	900-8100	20: Cycle South-North	308	83,74		Average	900-8100	20: Cycle South-North	308	93,86		12,09
Average	900-8100	21: Cycle South-West	63	93,06		Average	900-8100	21: Cycle South-West	63	104,58		12,38
Average	900-8100	22: Cycle West-South	99	77,24		Average	900-8100	22: Cycle West-South	99	77,23		-0,01
Average	900-8100	23: Cycle West-East	114	85,64		Average	900-8100	23: Cycle West-East	114	86,89		1,46
Average	900-8100	24: Cycle West-North	49	90,07		Average	900-8100	24: Cycle West-North	49	98,44		9,30

Simulation run 1				
05.06.2023 14:56:12	Warning	Parking Lot	1	63 vehicles could not leave parking lot 1.
05.06.2023 14:56:12	Warning	Parking Lot	3	473 vehicles could not leave parking lot 3.
05.06.2023 14:56:12	Warning	Parking Lot	6	484 vehicles could not leave parking lot 6.
Simulation run 2				
05.06.2023 14:58:08	Warning	Parking Lot	1	46 vehicles could not leave parking lot 1.
05.06.2023 14:58:08	Warning	Parking Lot	3	539 vehicles could not leave parking lot 3.
05.06.2023 14:58:08	Warning	Parking Lot	6	485 vehicles could not leave parking lot 6.
05.06.2023 14:58:08	Warning			When the archive file "C:\Users\teunb\OneDrive\Documents\Thesis opdracht\VISSIM\Original situatic
05.06.2023 14:58:08	Warning			When the archive file "C:\Users\teunb\OneDrive\Documents\Thesis opdracht\VISSIM\Original situatic
Simulation run 3				
05.06.2023 14:59:54	Warning	Parking Lot	1	56 vehicles could not leave parking lot 1.
05.06.2023 14:59:54	Warning	Parking Lot	3	464 vehicles could not leave parking lot 3.
05.06.2023 14:59:54	Warning	Parking Lot	6	540 vehicles could not leave parking lot 6.
05.06.2023 14:59:54	Warning			When the archive file "C:\Users\teunb\OneDrive\Documents\Thesis opdracht\VISSIM\Original situatic
05.06.2023 14:59:54	Warning			When the archive file "C:\Users\teunb\OneDrive\Documents\Thesis opdracht\VISSIM\Original situatic
Simulation run 4				
05.06.2023 15:01:45	Warning	Parking Lot	1	40 vehicles could not leave parking lot 1.
05.06.2023 15:01:45	Warning	Parking Lot	3	466 vehicles could not leave parking lot 3.
05.06.2023 15:01:45	Warning	Parking Lot	6	506 vehicles could not leave parking lot 6.
05.06.2023 15:01:45	Warning			When the archive file "C:\Users\teunb\OneDrive\Documents\Thesis opdracht\VISSIM\Original situatic
05.06.2023 15:01:45	Warning			When the archive file "C:\Users\teunb\OneDrive\Documents\Thesis opdracht\VISSIM\Original situatic
Simulation run 5				
05.06.2023 15:03:39	Warning	Parking Lot	1	71 vehicles could not leave parking lot 1.
05.06.2023 15:03:39	Warning	Parking Lot	3	479 vehicles could not leave parking lot 3.
05.06.2023 15:03:39	Warning	Parking Lot	6	483 vehicles could not leave parking lot 6.
05.06.2023 15:03:39	Warning			When the archive file "C:\Users\teunb\OneDrive\Documents\Thesis opdracht\VISSIM\Original situatic
05.06.2023 15:03:39	Warning			When the archive file "C:\Users\teunb\OneDrive\Documents\Thesis opdracht\VISSIM\Original situatic

Appendix 2: Calculations number of runs

	North-West	North-South	North-East	East-North	East-West	East-South	South-East	South-North	South-West	West-South	West-East	West-North
	67,27	63,72	75,36	43,25	46,93	65,42	75,62	71,35	80,88	40,31	47,75	62,34
	61,25	60,69	71,90	43,42	48,99	62,35	63,17	60,50	72,45	41,26	47,50	61,77
	64,98	66,29	74,22	45,21	47,87	60,52	69,94	66,73	70,08	41,69	45,51	67,41
	64,14	61,46	68,94	44,52	47,39	60,08	65,70	65,49	71,39	43,11	47,74	60,17
	75,61	73,13	82,75	43,45	47,76	62,37	68,28	65,89	76,44	42,82	46,19	65,44
Mean	66,65	65,06	74,63	43,97	47,79	62,15	68,54	65,99	74,25	41,84	46,94	63,42
St dev	5,45	5,01	5,16	0,86	0,77	2,10	4,72	3,86	4,40	1,15	1,02	2,93
N-runs	21	18	15	1	1	4	15	11	11	2	1	7

Cycle North-West	Cycle North-South	Cycle North-East	Cycle East-North	Cycle East-West	Cycle East-South	Cycle South-East	Cycle South-North	Cycle South-West	Cycle West-South	Cycle West-East	Cycle West-North
86,95	106,36	126,25	87,65	97,73	115,02	82,10	107,84	134,10	79,63	100,65	124,05
91,20	105,53	138,55	88,74	101,28	121,80	92,22	110,01	127,09	91,49	100,92	121,62
89,72	102,45	130,05	95,20	95,77	117,51	103,05	113,31	136,21	94,72	98,52	117,17
87,10	105,55	130,15	80,17	101,72	118,42	86,76	111,24	136,68	94,57	97,43	122,92
89,63	101,32	138,92	90,28	95,66	120,21	98,56	111,48	147,14	104,81	98,16	127,10
88,94	104,24	132,78	88,48	98,43	118,59	92,65	110,78	136,24	93,27	99,14	122,57
1,84	2,22	5,66	5,44	2,92	2,59	8,50	2,02	7,20	9,03	1,56	3,64
1	1	6	12	3	1	26	1	9	29	1	3