A cost-effective interchange design with emphasis on traffic safety

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Research Report

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1. Introduction

1.1 Background information

Host organization/ Company

Witteveen+Bos

Witteveen+Bos is a consultancy and engineering company established in Deventer - the Netherlands in 1946. The company was named after its founders Willem Gerrit Witteveen and Prof. Goosen Siger Bos and has over 1100 employees. Additionally, apart from its activities in the Netherlands, Witteveen+Bos is active internationally with offices in Europe, Central/Southeast Asia, the Middle East, and Africa. The company is mainly developing complex, multi-disciplinary projects for governments and private businesses. (In further parts of this report Witteveen+Bos will be referred to as W+B)

- Organization Structure

Witteveen+Bos is a public limited company consisting of four group companies:

Witteveen + Bos Raadgever Ingenieurs BV
Witteveen + Bos International BV
Witteveen + Bos Deelnemen BV
Witteveen + Bos Vastgoed BV

The organization of W+B is working with a PMC model which uses relatively independent organizational units with their own assignments and products for different markets within W+B, called Product-Market Combinations (PMCs). There are more than 30 PMCs in W+B with a size of 20 to 50 employees per PMC. The PMCs are grouped into four main business lines: Built Environment; Deltas, Coasts and Rivers; Energy, Water and Environment; and Infrastructure and Mobility. This Research Report is being conducted for the Infrastructure and Mobility business line.

- Management

The management system of W+B is based on the Supervisory Board as of April 5, 2016. The Supervisory Board is responsible for the day-to-day management and represents the interests of shareholders, employees, and stakeholders, for the benefit of the company. Additionally, all shareholders of the company are its employees, which makes W+B opt for the large company regime:

The Supervisory Board safeguards the continuity of the company by performing external supervision but cannot nominate new directors (Witteveen+Bos,2021). The board consists of three supervisory directors:

- Wouter Bijman
- Eveline Buter
- Stephan van der Biezen

City of Rotterdam

Rotterdam is an important cultural and economic region for the Netherlands as it is the second-largest city and municipality in the Netherlands while also having the biggest port in Europe – The Port of Rotterdam. The city is a part of the Zuid-Holland (South-Holland) province which is the most densely populated province in the Netherlands with over 3.5 million residents of which 580 000 are living in Rotterdam.

Additionally, Rotterdam is in close proximity to the North Sea as it is situated at the mouth of the Nieuwe Maas channel which is connected to the Rhine-Meuse-Scheldt delta at the North Sea. The city itself is having a well-equipped port infrastructure, multi-modal accessibility, and considerable volumes of goods and passengers. Adding on, Rotterdam is a part of the so-called “Randstad area”, or the economic center of The Netherlands. All of these factors explain why the Port of Rotterdam is one of the biggest ports in the world and is referred to as the ‘Gateway’ of Europe.

Blankenburg connection Project (A24)

The Blankenburg connection (A24) is a new motorway project which aims to connect the already existing A20 and A15 motorways. According to Rijkswaterstaat the Blankenburg connection is being constructed in order to guarantee accessibility, quality of life, and economic activities of the region of Rotterdam. In addition to the largest port complex in Europe and Greenport Westland, the Rotterdam region offers space for many business services and creative activities. Therefore, making the Rotterdam region as accessible as possible is crucial to keep up with its fast economic growth and the Blankenburg connection makes the desired situation possible. The Blankenburg connection connects the A20 motorway west of Vlaardingen with the A15 motorway on the east side of Rozenburg.

- A20 Motorway

The A20 motorway is a motorway entirely located in the province of ''Zuid-Holland'' (South Holland) - the Netherlands. It is approximately 39 kilometers in length and connects various important motorways such as A4 towards Den Haag/Amsterdam and A16 towards Dordrecht/Breda. On its western side, it links to the N213 road from the Westland municipality. On its east side, it attaches to the existing A12 motorway at the interchange ''Gouwe''. On a national/international level, the importance of A20 is significant due to its connection to the A12 motorway which is leading to numerous other motorways and international European highways.

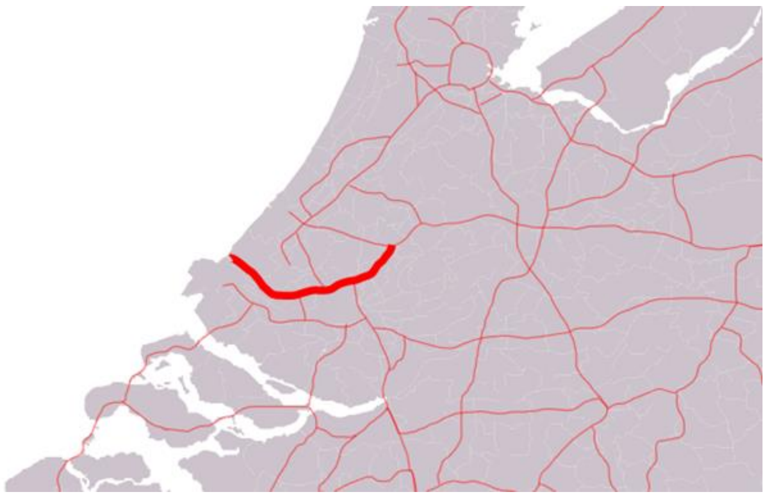


Figure 1 A20 motorway (bold red)

- A15 Motorway

The A15 motorway is a motorway that connects the Europort at Maasvlakte and Ressen. The A15 provides important access to the port terminals in The Port of Rotterdam from the northern side and the other way around. The westernmost part of the road, between the Maasvlakte and exit 8 is officially not a motorway (despite the fact that it has many characteristics of such), and is

Figure 2 A15 motorway (bold red)

therefore known as the N15. As of exit 8, the road becomes an official motorway, called A15. Together with the Betuweroute, which runs parallel on several stretches, the A15 is the main transport corridor from the Port of Rotterdam to the eastern parts of Europe, the Middle East, and Asia.

- A24 Motorway

The A24 is a motorway that is currently in construction. The motorway dives underneath the Aalkeetpolder through a land tunnel and then connects to a deeper tunnel that is under the river Het Scheur. On the north side, the A24 connects to the A20 via a recessed junction. On the south side, the new road connects to the A15 in a junction with a number of new fly-overs. The project's main goal is to further develop the economic structure, the attractive living environment and to provide good internal and external accessibility towards the city and port of Rotterdam and its surrounding areas. This will result in great economic benefits for the Rotterdam region since the new connection will not only allow a better traffic flow but also not disturb the natural appearance of the area while taking the importance of the environment into great consideration.

Figure 3 A24 Motorway (bold red)

Hollandtunnel (A24)

The Hollandtunnel (A24) is a land tunnel that will be a part of the Blankenburg connection between A15 and A20.

Figure 4 Hollandtunnel

Figure 4 shows that the Hollandtunnel will be located closely after the Maasdeltatunnel which will be under the Het Scheur River. The main purpose that the Hollandtunnel will be serving is providing a sufficient connection between A15 and A20 regarding accessibility without disturbing the present environment of Aalkeetpolder by creating additional noise in the surrounding area and also avoid interrupting the current metro line.

1.2 Problem statement

The accessibility of the Rotterdam region and port is important for the economy of not only the region itself but for the Netherlands as a whole. This is because, in addition to the largest port complex in Europe and Greenport Westland, the Rotterdam region also offers space for various business services and creative activities.
Even though the Dutch government had previous investments in roads and public transport before 2020 it appears that the accessibility of the Rotterdam region by road infrastructure still has room for improvements and growth. Rotterdam Vooruit Masterplan is a plan and vision for infrastructure improvements in the Rotterdam region for the 20-year period between 2020 and 2040 and the Blankenburg connection Project – A24 is a part of it. This connection will, on the north side connect

to the A20 via a recessed junction in both directions, and on the south side, the new road connects to the A15 in a junction with several flyovers.
This Research Report is focused on the north side of the new A24 connection, or the junction between A24 and A20. In this current connection, there are three dive-unders that aim to provide an effective connection to the A20.

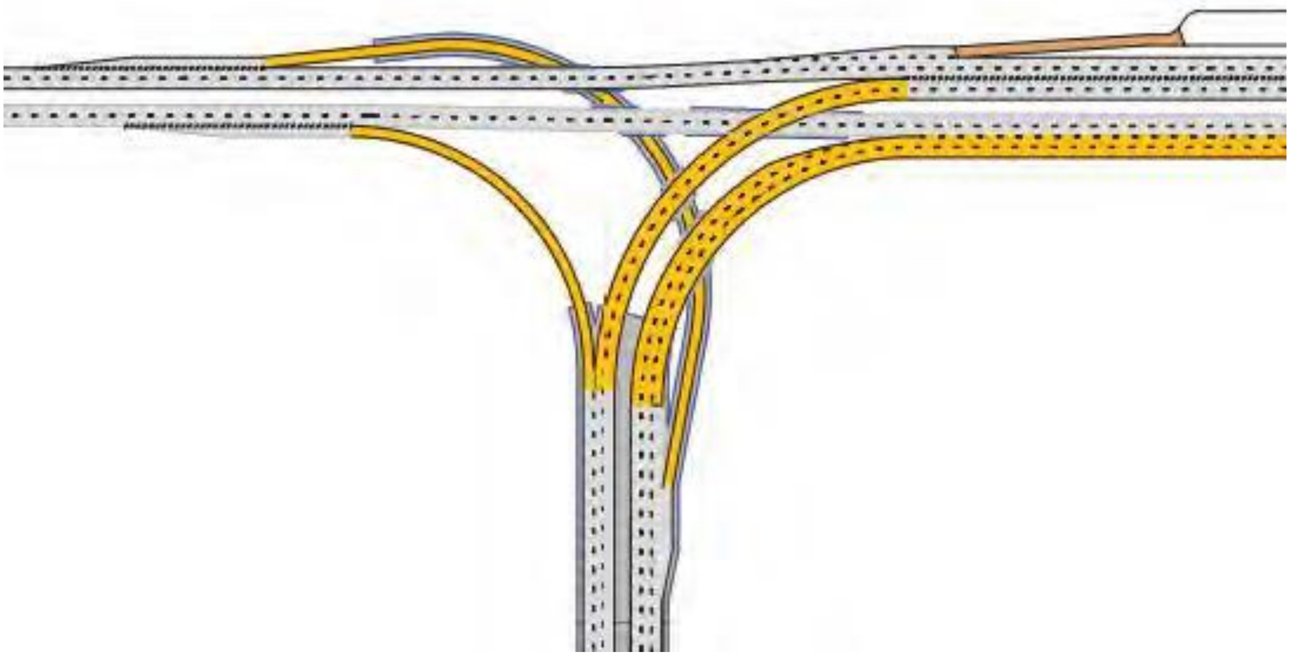


Figure 5 The new connection between A24(vertical) and A20(horizontal)

In Figure 5, the new connection has a design with 3 dive-unders in order to sufficiently connect to the existing A24 (horizontal). Despite providing the needed solution to this project, this connection is unnecessarily complex which will require more recourses, such as time and budget, in the design and construction phase, in order for it to completely fulfill its function. Therefore, this report aims to analyze this connection with a deeper perspective and additionally explore different interchange design alternatives in order to propose an interchange design that is more economical while still providing sufficient traffic safety and meeting all the existing stakeholder requirements.

1.3 Research questions

Main research question

What is the best alternative design to the current design developed by W+B for the interchange between the new A24 motorway and the already existing A20, that is more cost-effective while still providing the required traffic safety?

Sub-questions

- **What is the current situation of the connection between A24 and A20?**

  a) What are the problems that are present in the current connection project?
  b) What is the current solution for this connection trying to achieve?
  c) Why does the current connection need improvements?

- **What are the stakeholders involved in this project and how are they going to be affected by the outcome of the project?**

  a) What are the stakeholders in this project?
  b) What impact is the project going to have on these parties?
  c) How are these parties classified in terms of power?
  d) How are these parties classified in terms of interest?
  e) Which stakeholders should be paid more attention to and which less?

- **What are the existing limitations that can impact the project?**

  a) Which factors influence the choice of a potential solution to the current problems?
  b) What are the social factors that influence a potential solution?
  c) What are the construction limitations that influence the choice of a potential solution?
  d) What are the environmental limitations that influence the choice of a potential solution?

- **What are the requirements that have to be met by the outcome of this project?**

  a) What are the functional requirements?

b) What are the technical requirements?
c) What are the requirements set by the stakeholders?
d) What are the requirements for traffic safety?

- **What are potential alternatives to the current connection project?**

a) How are all the requirements going to be met by each alternative?
b) How are the alternatives going to be compared and evaluated?
c) What are the advantages and disadvantages of each alternative?
d) What is the best alternative solution to the current connection?

- **What methods are going to be used in order to find the best alternative?**

a) How are qualitative and quantitative research techniques going to be implemented within the research?
b) What will be the main research strategy to achieve the research goals of this research?
c) What must be done to achieve the desired result?

1.4 Goals and Objectives

Main Goal

The goal of each research is the overarching purpose of its conductance. The goal of the research aims to provide clarity as to what this study is all about. This is usually done from a broad perspective.

The main goal of this research report is to investigate and analyze the current design for the new connection between A24 (currently in construction) and A20 and provide an alternative that does not limit the traffic safety and is more cost-effective.

Objectives:

On the contrary, objectives are aiming to provide more specific information on how the main goal will be achieved. This is done with a list of objectives that will explain the short-term actions that are to be taken to reach the aim of this research report.

The objectives of this research report are:

- Determine what are the advantages and disadvantages of the current design for the needed connection and where there is a need for improvement.

- Determine, the goals that are set to be reached for cost-efficiency and traffic safety.

- Investigate what parties are involved in this current project and what parties will be affected by it.

- Find what are the requirements and limitations connected to this project and its construction process and how are these limitations going to impact the development of possible solutions.

- Develop different alternatives/variants which will not overstep the previously set requirements and limitations while also achieving the goals for traffic safety, effectiveness, and cost.

- Compare and determine which variant is the most suitable as a solution for the optimization of the current design.

2. Theoretical framework

2.1 Current situation

The existing connection design between the new A24 and the present A20 highway is developed by Witteveen+Bos and consists of a total number of 3 dive-unders.

Figure 6 A24 to A20 connection design

This design takes into account all the requirements set by the project stakeholders and involved parties that will be affected by the project. Additionally, the design allows the connection between A20 and A24 to keep the natural appearance of the project area while providing a sufficient traffic flow between the new build and the already existing highway.
Although it covers all the set requirements for the interchange, there are areas in which the W+B interchange design between A20 and A24 has downfalls that are highly connected to its complexity. These areas are cost-effectiveness and sustainability.

Sustainability

Sustainability always plays a significant role in civil engineering projects all around the world. The Dutch government also pays a lot of attention to the sustainability of the government projects and are aiming to be as sustainable as possible.
The sustainability problems that the current interchange design is having are directly connected to the complexity of the connection itself. The current W+B connection design uses many complex structures such as the 3 dive-unders it has and requires the existing A20 to be moved below ground level in order to spare the appearance of the project area. This approach is demanding in terms of construction resources and time before and during the construction phase which greatly influences the overall sustainability of the interchange.

Cost

The cost denotes the amount of money that the client – Rijkswaterstaat invests in the connection between A20 and A24. In most of the projects in the infrastructure industry, the cost is the main criteria and decision driver that has to be respected the most.
The whole Blankenburg connection project has an estimated cost of approximately 1 billion euros. Seeing the total budget of this project and how high it is rises a lot of questions such as why is the sum so high and is there a way to be more economic and cost-effective?
It is important to note that this budget of 1 billion euros is for the whole Blankenburg connection project and not the A24 to A20 connection.
Focusing on the connection between A24 and A20, it is noticeable that even though the current design meets all the requirements it is still complex and hard to construct. This of course means that such design will need more recourses to build and execute which will then lead to higher overall costs.

2.1 Stakeholder analysis

Introduction

Everybody who is influencing a project or will be influenced by the project and outcome is called a stakeholder. Stakeholders can be individuals, communities, social groups, or organizations. The stakeholder analysis aims to distinguish the different stakeholders included in the project, by their interests, and ideas about the outcome of the project, which makes the stakeholder analysis a mandatory part of every building project. It also helps to choose the stakeholders that will be needed the most and the ones that need less attention.

Identifying

Most of the stakeholders are usually companies or large groups of people. To make communication easier and better they will be separated by using their power and interests as a factor (Table 1). The ones with the highest power and interest will be considered the most important ones, and in opposite the ones with the lowest power and interest will be considered unimportant.

Table 1 Stakeholder Power-Interest

Stakeholders	Power level (1-10) 1 being the lowest and 10 the highest	Interest level (1-10) 1 being the lowest and 10 the highest
Port of Rotterdam	**7**	**10**
Rijskwaterstaat (Ministry of infrastructure and water management)	**10**	**10**
Regional Waterboard	**7**	**7**
Transportation companies	**2**	**6**
Residents	**5**	**8**
Northern (to the project location) Municipalities	**5**	**8**
Southern (to the project location) Municipalities	**2**	**3**
Rotterdam Municipality	**7**	**8**
“Veiligheidsregio” (Safety organizations)	**6**	**4**
Environmentalists/environmental agencies	**4**	**9**
Tourists	**2**	**2**
Terminal owners	**5**	**6**
Other users	**2**	**4**
Contractor	**6**	**5**

As every stakeholder is now characterized by their power level and level of interest, they are going to be also categorized with the Stakeholder Map, which shows the importance of every stakeholder. However, before using the Stakeholder Map, a comparison between the stakeholders has to be made to provide a more accurate view of each stakeholder and their demands.

Stakeholder's comparison

In this part of the analysis, all the stakeholders will be compared to further analyze their demands and how exactly the project will eventually affect them. This will show what each stakeholder demands from this project.

- Port of Rotterdam

The port of Rotterdam is the largest port in Europe and any kind of disruption in its function and working schedule is having an impact on the overall recorded performance of the port itself. Based on this fact, the demand that this stakeholder is having is the possible disruptions caused by the Blankenburg connection project be as limited as possible. In other words, this means that there should not be any notable reduction in the accessibility of the port itself. To achieve this, the contractors have a certain schedule and method of work that allows ships to use the canal for transportation even when construction takes place.
On the other hand, the outcome of the project is going to have a positive impact on this institution, since the new connection will significantly improve the infrastructure situation in the region and port of Rotterdam.

- Rijskwaterstaat

As the client for the Blankenburg connection project, Rijkswaterstaat has all the power and interest in this project's development and outcome. Since Rijkswaterstaat is the client for this project, there are demands and requirements that have to be met in order to satisfy this stakeholder. They are:

a) Provide sufficient and safe connection between A20 and A24 which will improve the accessibility of the port and region of Rotterdam.
b) Provide a cost-effective variant for the A20 and A24 in both the construction and design phases.
c) Provide a variant that will keep the recreational prospects of the project zone and will not disturb the current environment in the Zuidbuurt area.

The final demand has significant importance for the clients. ''The connecting arcs are located on or below the adjacent ground level, thus the highest point of the new node does not become substantially higher than the "ground level" of the current A20. This concealed solution has been chosen to spare the vulnerable open landscape of Midden Delfland as much as possible.'' (Inpassingsplan, 2016).

- Regional Waterboard

The regional Waterboard is charged with managing water barriers, waterways, water levels, water quality, and sewage treatment in their respective regions. The fact that the north side of the Blankenburg connection project is having a number of water bodies that will be affected during construction increases the interest and power of the Waterboard as they will be managing these bodies after the project is completed. The water bodies that are present in the construction site are mainly small rivers/canals and lakes, with the lake Surfplas being the most notable example. The demands that the Waterboard will be having are of course connected to the overall state of the water bodies that will likely be disturbed during construction. Possible negative effects on these water bodies are water pollution, decrease/increase in size, decrease in the overall quality of the water.

- Transportation companies

Transportation companies will be undoubtedly affected by this project as it is interfering with both land and water transport, which are the two most commonly used transport methods in the port area. These types of companies are highly interested in the Blankenburg connection. The project itself, however, will be positively impacting these stakeholders after its construction because the infrastructure situation of the region will be improved. Additionally, there will not be many transport restrictions during construction which indicates that the connection will only be positively impacting this stakeholder group.

- Residents

Every construction project that is executed in a residential area has to take into account the opinions and needs of the people living in the surrounding areas. The Blankenburg connection project is being built in several residential areas. In this part, only the residents living close to the A24 to A20 connection will be analyzed as this research report is focusing on this exact area. The main demands of the residents of the surrounding area are connected to the construction phase of the project since there will noise occurring during that time. Adding on, the current appearance of the polders and water bodies in the project area is also of significant importance for many of the residents. Nevertheless, the project schedule is made in a way in which there will be as little noise as possible during the times in which residents are expected to be affected. Additionally, whenever noise is expected all the residents that may be affected are going to be notified. (Vlaardingen, 2020)

- Municipalities

The surrounding (towards the project) municipalities are all the municipalities that will be affected by the project. In the initial parts of this analysis, they are divided into Northern (Maassluis, Vlaardingen), Southern (Rozenburg), and the municipality of Rotterdam. Since this research report is focusing on the A24 to A20 the southern municipalities of less importance. On the contrary, the northern municipalities will need to be taken into account since the A24 to A20 connection will interfere with their lands and residents. Finally, the municipality of Rotterdam is the main municipality to be paid attention to since the core of the Blankenburg connection project is improving the accessibility of the region and port of Rotterdam. The demands of the municipalities are similar to the ones of the residents and Rijkswaterstaat.

- Environmentalists/ environmental agencies

These are people or organizations that will be closely monitoring the project execution and construction phase to understand how it can affect the surrounding environment in means of flora and fauna. Logically, their biggest demand from this stakeholder towards the A24 to A20 connection is to limit and minimize the possibility of any negativity occurring in the surrounding environment which will mainly cover the area of Zuidbuurt.

- Tourists

Tourists are an inseparable part of the city of Rotterdam. The current A24 to A20 connection project, however, will not have a significant impact on the tourist situation around the area, because of its location (distant from the center), and its low overall impact on traffic during construction (no disruptions). After its completion, the A24 to A20 connection will allow a better traffic flow to and from the city of Rotterdam.

- Terminal owners

These are the companies that own lands and terminals at the Port of Rotterdam. Some of these companies are Vopac, Cotac, Kamer Group, BP. The main demands that such companies will be having an overlap with the demands of the Port of Rotterdam since they are connected – As few transportation delays as possible.

- Other users

Other users are considered all the people/parties that are potentially going to be using the new infrastructure connection once it is constructed. This stakeholder group is having interest in the project, however, their power level is low

- Contractor – Ballast Nedam

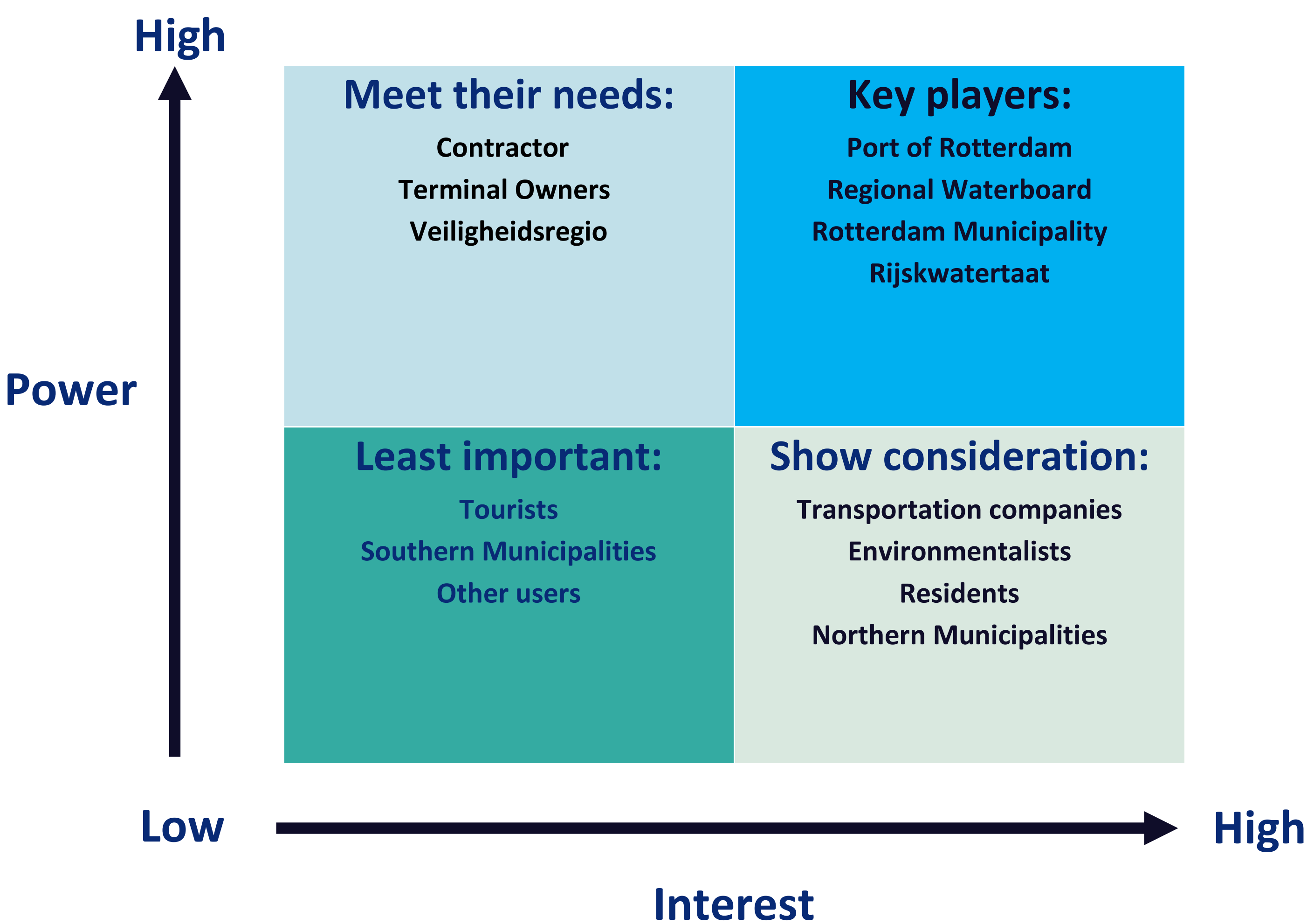
The contractor for the Blankenburg connection is also an important stakeholder. This is the company that will be responsible for the construction of the new highway – A24 and making sure that this stakeholder's needs are understood is crucial for the outcome of the project. The demands of the contractor are based on the complexity of the connection design. The more complex and complicated the design the harder it will be to construct. Additionally, a more complicated design will eventually need more time and resources to be constructed. Therefore, a design that is also practical for construction is needed in order to meet the demands of the contractor.

- Veiligheidsregio (Safety organizations)

These are organizations that are responsible for the overall safety of the population of the Netherlands. Examples can be fire services, disaster and crisis management, public safety, medical assistance, etc. These organizations have an impact on the connection design. Their demands towards any possible solution should be taken into account because if a design is not meeting all the fire safety requirements, for instance, it will not be accepted by the government.

Stakeholder Map

After understanding where all the stakeholders must be categorized, in the next table, every stakeholder is placed in different categories, using their power and interest level. Any interest and power level above the score of 6 from Table 1 will be considered as High for the following categorization.



Strategy per category

Key players

The stakeholders which are placed in the upper right corner are called KEY PLAYERS. The most important people and organizations for the project- the key players have to be informed about every detail connected with the development of the project and they should be involved in every decision about the project, because they can always help with their financial opportunities, knowledge and power.

Meet their needs group

Placed in the upper left corner the stakeholders with high power and low interest can cause harm to the project because of their high influence and low interest, so it is always better to make sure the project meets their interests to be sure that they will disrupt the project from moving forward.

Show consideration

It is important to show the stakeholders in this category consideration by conducting interviews, questionnaires, and keeping close contact with them and make slight modifications to the project according to their needs.

Least important

The stakeholders in this group must not be forgotten. They may not have a great impact on the project, but they should also be informed of what will happen with the project and how that will make a difference for them.

2.2 Boundary conditions and Limitations

Boundary conditions and limitations is the part of the report which describes what are the factors that will limit or restrict the conducted research in any possible way. The boundary conditions are the boundaries set by the author of the research paper, whereas the limitations are describing the outside factors that will influence the research in one way or another.

Boundary conditions

- **Design criteria**

This research report is aiming to investigate different possible alternatives in comparison to the current A20 to A24 connection design. During this thesis project, all the design criteria of the current connection design such as the number of lanes and lane width will be considered for all other variants as well.

- **Specific design of the winning variant**

After conducting a multi-criteria analysis, a winning variant will be present. This variant will be considered as the most suitable alternative for the current connection design (if applicable). For the further phases of this thesis project, only one part of the winning variant will be considered for a more specific and deeper design including calculations and model. This part will be the road alignment including horizontal and vertical alignment of one of the road connections to or from the A20.

Limitations

The following limitations are known prior to the research start. The limitations are to ensure transparency and clarify what factors limit this research and to what extent is the research limited. The following limitations have been set:

- Time period of this thesis is 6 months

The time for completion of this thesis project is set to 1 semester/6 months which will limit the final product. Due to the limited time period, just a portion of the final variant of this research will be detailed and designed.

- The data used in this research is to be limited to a desk research

Given the fact that this thesis project is being executed during the Covid 19 pandemic, the data used will be limited to desk research due to the governmental measures in regards to Covid 19.

- Language limitations

The location in which the project will be carried out is in the Netherlands, which means nearly all written papers and documents will be in the local language. This may limit the available information that can be efficiently used.

- The data used in this research is obtained from open sources.

The data that will be obtained during the desk research is limited to open sources found in available research papers and books.

2.3 Schedule of requirements

In this part of the second chapter of this research report, the requirements towards the viewed connection between A20 and A24 will be listed. These requirements are separated into three types – Functional, Technical, and Stakeholder requirements.

Functional requirements

- The connection is accessible for all types of vehicles that are allowed on the two highways.
- The connection allows the traffic to flow efficiently from and towards the A20 without creating any unwanted traffic delays.
- The capacity of the connection is sufficient enough to handle the expected traffic flow on the connection from both directions.
- The connection provides adequate driving space for all the different types of vehicles that will be using it.
- Acceleration and deceleration lanes must be present in the places where vehicles are expected to change directions.
- The used pavement in the connection lanes is in sufficient condition to make traffic flow safely.
- All safety features for the connection are present (signs, guard rails, emergency lanes, traffic lines, etc.).

Technical requirements

- All lanes present on the connection must fall within the minimal lane width criteria for the Netherlands which is: 3.10m for emergency lane 3.25m for normal lanes in accordance with the present speed limit.
- Maximum allowed speed on the interchange.
- The construction phase must use as few materials and recourses as possible in order to reach the sustainability goals of the connection.
- Slopes present in the interchange must fall within the minimal required slope degree for water drainage – 2.5%.
- Cants preset on horizontal arcs must fall within the minimal required cant percentage for the given design criteria – 5%.
- All calculations regarding curve radii must be done using the SSD value.

- The radius of the curves of the interchange design must fall within the minimally required radius for traffic safety on the interchange.

Stakeholder requirements

- The connection must be constructed as close to ground level as possible, in order to keep the visual aspects of the project area.
- The connection must be as safe as possible in terms of traffic safety and accident occurrence.
- The connection must sufficiently improve the accessibility of the Rotterdam Region.
- Noise mitigation is maximized during and after the construction phase.
- The decrease of accessibility towards and from the Port and City of Rotterdam during construction is as limited as possible.
- The environmental impact that the project is going to have is minimized as much as possible.
- The connection is sustainable and cost-effective.
- The connection project does not negatively impact the surrounding water bodies.
- The connection design is not unnecessarily complex and complicated to build and construct.

These requirements are representing the demands that the stakeholders with a power level above 6 are having. These demands are considered as requirements that have to be met in one way or another because of the high power level of these stakeholders and the way they can impact this current connection project.

2.4 Alternative interchange designs

After a deeper investigation on possible three-way interchanges, there are 4 different alternatives that are going to be compared in the following multi-criteria analysis. To make a sufficient comparison to the current situation on the A24 to A20, the current design will also be put into the Multi-Criteria analysis and compared to the other 4 alternatives. This way it will be seen how well the current design is performing within the set criteria. The 4 alternatives that are going to be compared are:

- Trumpet interchange
- Half-clover interchange
- Three-way roundabout interchange
- Directional T interchange

An important aspect to be paid attention to in the alternative designs is to see if the proposed alternative designs can in fact fit into the landscape of the project area. This aspect is especially important due to the fact that the area that that is available for construction is limited because of the naturally and culturally significant objects in the near surroundings. As mention in the previous chapter, a stakeholder requirement is that the project area is disturbed as little as possible.

Therefore, alternatives that do not accurately fit into the available construction area cannot be considered as possible solutions.

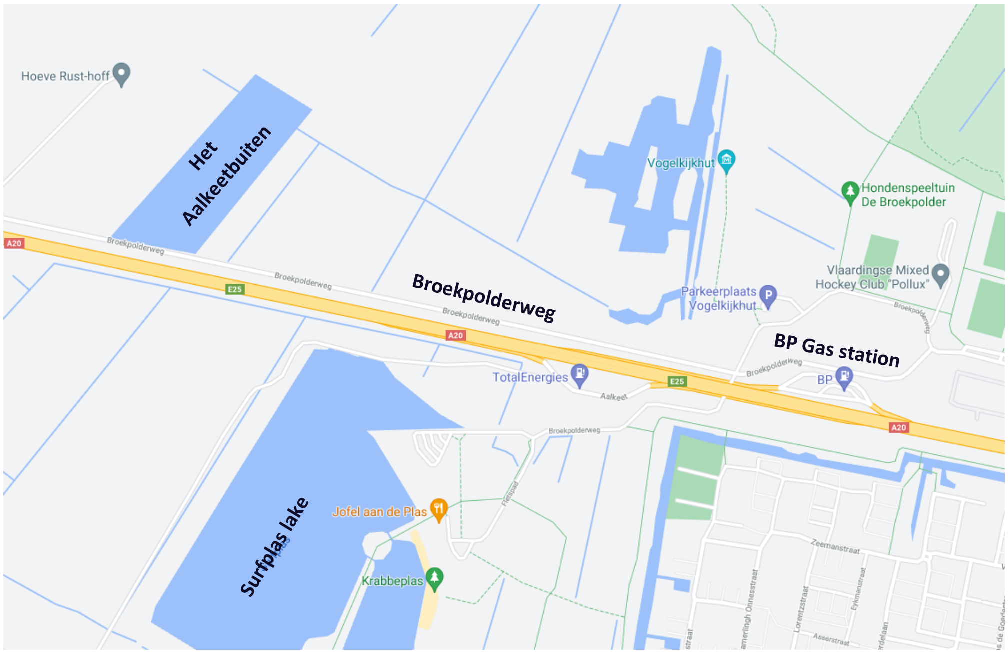


Figure 7 Project surroundings

Figure 7 shows the project surroundings and indicates the area available for construction in which the potential solution has to fit in. The main restricting obstacles that each alternative has to avoid disturbing are the BP Gas station, Surfplas lake, the duck shed at Het Aalkeetbuiten, and Broekpolderweg.

The current interchange design does not interfere with the important surroundings significantly, the only part that is disturbed is the top-left part of the Surfplas lake.

Figure 8 Current Interchange design

In order to see if each alternative can fit into the area that is available for construction in the Zuidbuurt and Midden Delfan area, every design will be scaled and shown into a map of the project area.

Alternative 1 – "Trumpet" interchange

The trumpet interchange is a widely used type of interchange when it comes to connecting two perpendicular highways where one terminates into the other. This type of interchanges (in most cases) uses one flyover or tunnel to connect the traffic that either leaves or enters the highway. The high popularity of this exact interchange is due to its low construction costs and fully free-flow traffic.

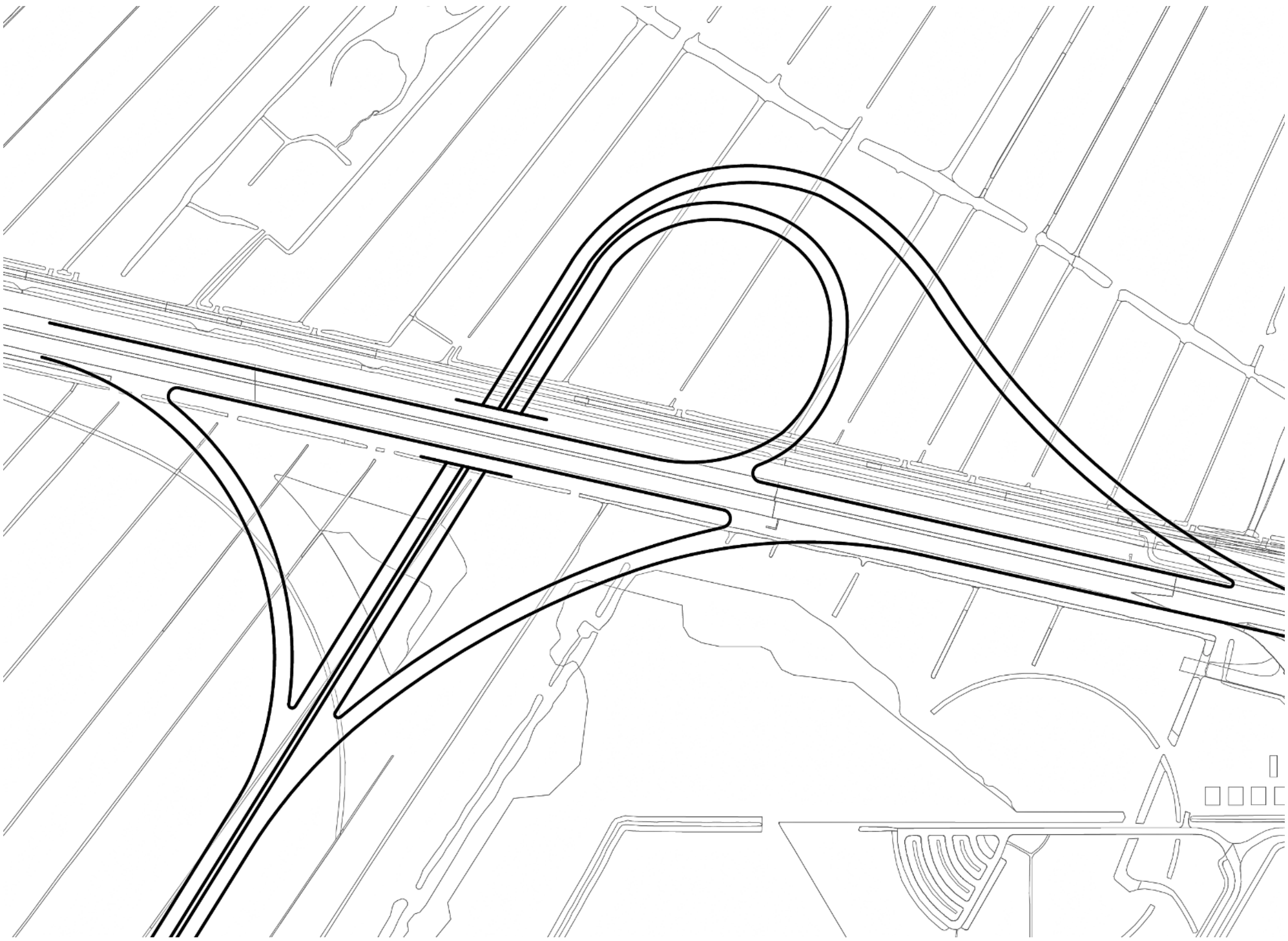


Figure 9 Trumpet Interchange fit into the Project landscape

As Figure 9 shows, the trumpet interchange and its current design avoid and do not disturb the important objects in the surrounding area. Similar to the W+B design, part of the interchange comes close to the Surfplas lake. Additionally, this alternative requires the Broekpolder street to be moved and reconstructed in a different place since it would interfere with the new highway. Apart from that, the trumpet interchange uses only space that is available for construction.

Alternative 2 – Half-clover interchange

Originating from the cloverleaf interchange, this interchange type is constructed to connect in just three directions instead of four (which is the case for the original cloverleaf interchange). The half-clover interchange is rarely used due to the traffic weaving that it causes and the large area that it requires. However, this type of interchange is used in areas where a possible upgrade to a full cloverleaf interchange may be needed.

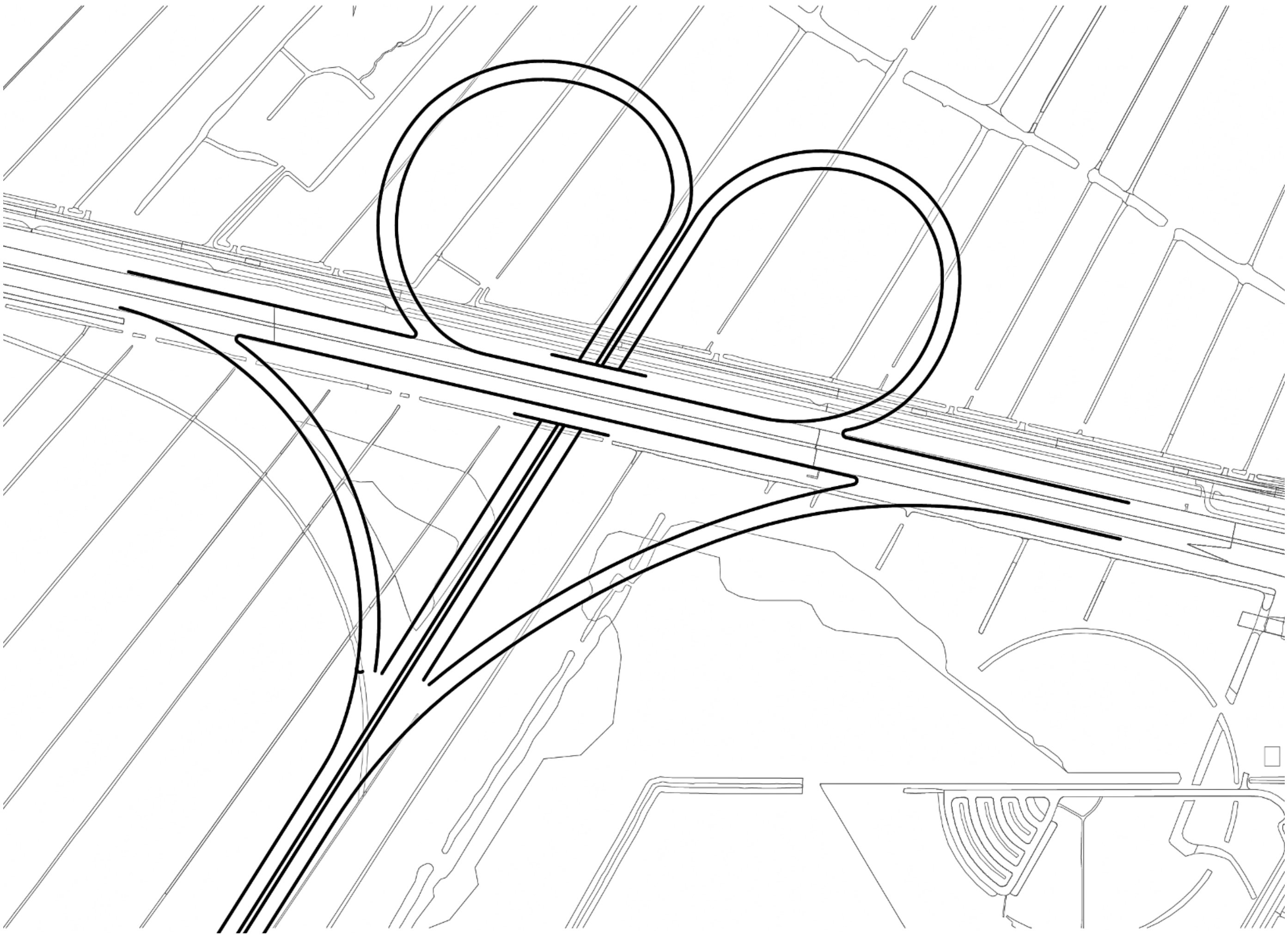


Figure 10 Half-clover interchange fit into the Project landscape

This interchange design uses a lot of space in the connecting parts for both directions. Figure 9 indicates that this alternative is difficult to fit into the available construction space since it comes close to both the Surfplas lake and the duck shed at Het Aalkeetbuiten. Adding on, this alternative also requires the street of Broekpoder to be moved.

Alternative 3 – Three-way roundabout interchange

The three-way roundabout interchange is another rarely used type of connection for three directional situations. This design's uniqueness is due to its roundabout that gives all the users the ability to safely change directions. However, this comes with the cost of slow traffic flow, and the high amount of area required for construction.

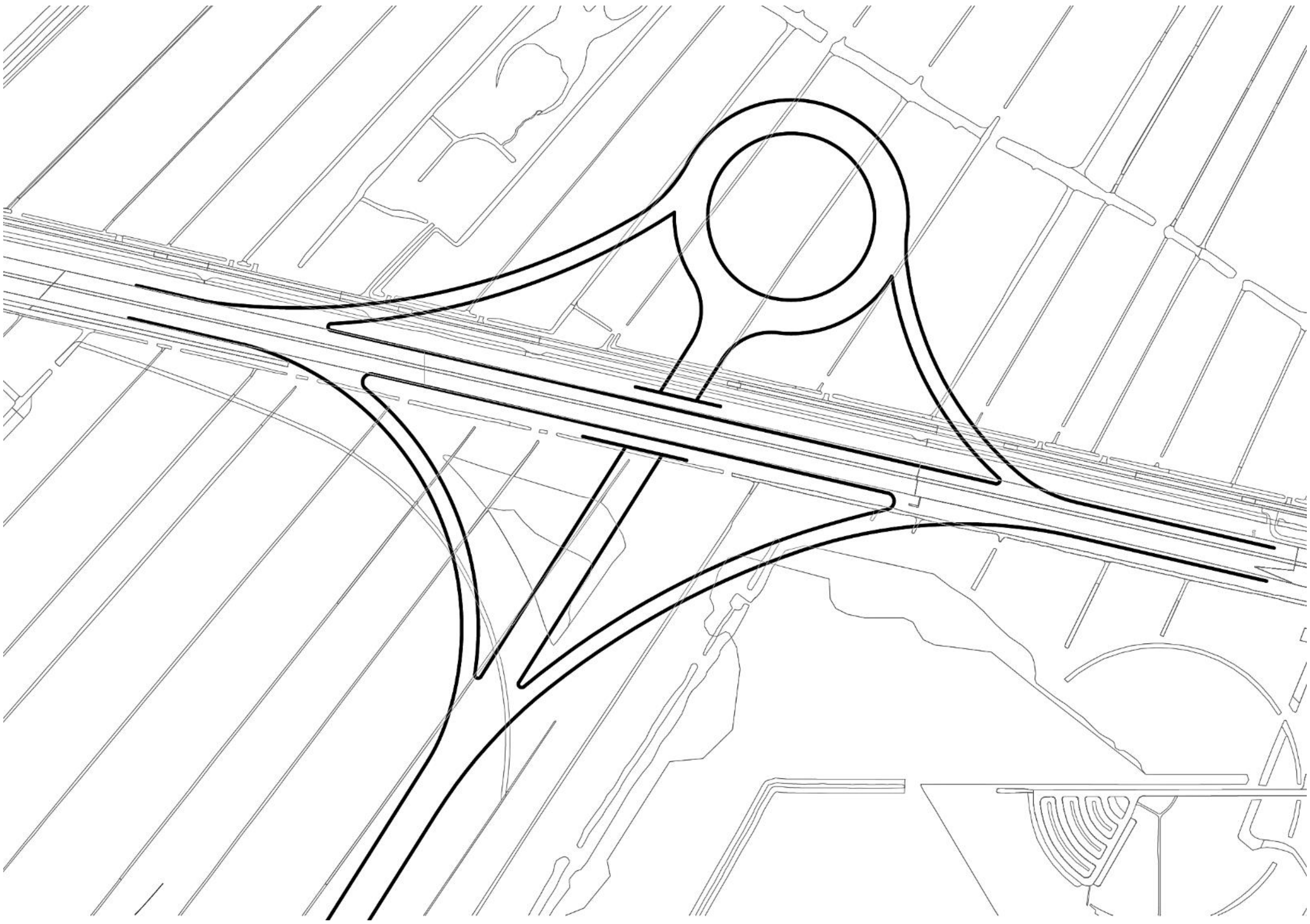


Figure 11 Three-way roundabout interchange fit into the Project landscape

The situation for the three-way roundabout interchange is more or less identical to the half-clover interchange design. It comes close to the Surfplas lake and Het Aalkeetbuiten, and also requires the movement of Broekpolder street to a different route.

Alternative 4 – Directional T interchange

The directional T interchange is a three-way interchange where two highways are to connect perpendicularly. This design uses three flyovers/dive-unders in order to sufficiently connect for all directions, which is similar to the current W+B design and also has the cost and complexity downsides. On the other hand, this type of interchange uses a minimal amount of space compared to the other alternatives.

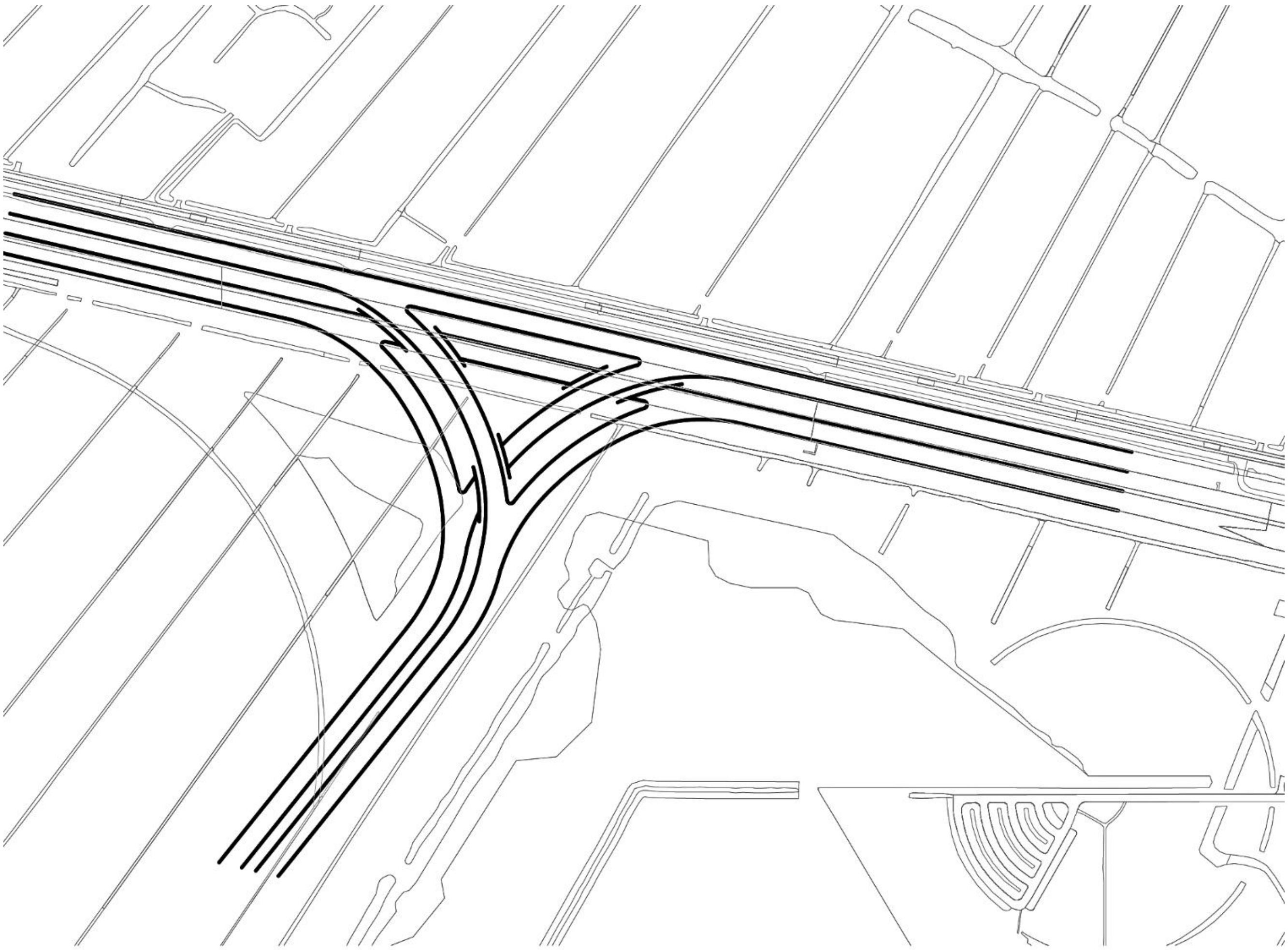


Figure 12 T interchange fit into the Project landscape

In Figure 12, it is noticeable that the T interchange by far fits in the best out of the 4 alternatives. This is because it uses three flyovers/dive-unders which eliminates the need for space on the Northside of the A20 highway. This results in much more flexibility in the positioning of the interchange design with regards to the important surrounding objects which optimizes the use of available construction space allowing the interchange to be placed in a way that it does not disturb any of the naturally and culturally important objects in the surroundings.

3. Methodology

3.1 Research Strategies

The following part of the Methodology chapter will describe the activities taken to answer the already set-up (sub) research questions and the products to be acquired, in order to find the optimal solution that the main research question is asking for.

Table 2 Research strategies

Research question	Activity	Product
What is the current situation of the connection between A24 and A20?	Obtaining further information from W+B on the current connection design and its specifications and sorting out the data that is useful for this research.	Chapter: Theoretical framework 2.1 -Current situation
What are the stakeholders involved in this project and how are they going to be affected by the outcome of the project?	Investigating how the current connection will impact the organizations connected to it, with the help of desk research and additional information provided by W+B.	Chapter: Theoretical framework 2.2 – Stakeholder analysis
What are the existing limitations that can impact the project?	Understanding what limitations and boundaries are expected to limit the results of this current research report and define them.	Chapter: Theoretical framework 2.3- Boundary conditions and limitations
What are the requirements that have to be met by each alternative variant?	Research and find what are the functional and technical requirements that each alternative has to meet in order to be considered as a potential solution.	Chapter: Theoretical framework 2.4 – Functional and technical requirements
What are potential alternatives to the current connection design?	Research and further analyze different connection interchanges that complete the set requirements and can be considered as a potential solutions.	Chapter: Theoretical framework 2.5 - Alternatives
What methods are going to be used in order to find the best alternative?	Define and describe how each alternative will be evaluated in order to find which one is the most suitable as a potential solution.	Chapter: Methodology 3.3 Multi-Criteria Analysis

3.2 Methods

To gather all the information needed to make this research report, the main research methods that are going to be used are qualitative and quantitative research. By implementing these two methods into this final thesis assignment enough information will be acquired in order to make the Multi-Criteria Analysis and give reasonable yet effective scores in order to find what the best alternative will be. The data will be entirely collected through desk research.

For the final part of this thesis assignment, after completing this research report, a 3D model of the horizontal and vertical alignment of one of the connecting lanes of the winning variant will be developed. The aim of this 3D model will be to visualize and show the horizontal and vertical alignment of the road surface.

- Calculations

Before starting with the development of the 3D model, calculations have to be made in order to understand and determine the optimal values in the horizontal and vertical alignment for: minimal curve radius, minimal sight distance, minimal curve length, transition curve radius, minimum and maximum slope, minimal vertical radius, and others. All the formulas and equations that will be used to calculate the needed for the 3D model values will be taken from the provided materials from HZ University of Applied Sciences, and the Dutch Ministry of Infrastructure and Water Management – Rijkswaterstaat.

- Modeling and visualizing

To develop the 3D model, a graphical programming software – Dynamo will be used.
The calculations that will determine the optimal values that are needed for the 3D model design can be either done manually or with the help of Dynamo. The advantage that Dynamo provides compared to the traditional way of calculation is that the formulas can be inserted into the software where different options can be modeled automatically. This provides flexibility in the choice of different design values because, when a value is changed this automatically changes the end result of the formula, which also saves time.
After calculating all the required values in Dynamo a graphical image and a lightweight visualization of how the vertical and horizontal alignment looks like will be made. This is done with the insertion of different points in the coordinate system of Dynamo, where each point is then adjusted according to the position it has to take (which is determined by the values that were previously calculated).

4. Results

4.1 Multi-criteria Analysis

Introduction

The Multi-criteria analysis aims to compare different designs or solutions for a specific problem mainly in projects, following a variety of criteria. This method is based on the evaluation of designs (in this case) or actions by means of a weighted average.

The variants that are to be compared receive a score that is estimated for each criterion and further information will be provided on how these estimations were made and what influenced the scores.

Criteria

For this MCA, eight criteria have been formulated to compare all of the variants. These criteria best reflect the important aspects set by (client and other stakeholders) which were required to achieve the goal and objectives of this research report. Each of the chosen criteria is connected to a certain demand from one or more stakeholders the ones with higher weight are of course the demands of the clients. The criteria that were picked for the evaluation are:

- Cost
- Sustainability
- Traffic Safety
- Design Speed
- Required space
- Construction time
- Design complexity
- Environmental impact and Visual pollution

Weight of criteria

The main goal of giving weight to each criterion is to show and understand which one(s) is(are) more valuable for the final outcome of the project and the involved stakeholders. This means that some criteria will be more 'significant' than others.

For this current MCA, the weight of each criterion will be entirely based on the demands of all of the important stakeholders. An ''important'' stakeholder will be considered every stakeholder that has a power or interest score of more than 6 in the stakeholder analysis in chapter 2 – Theoretical Framework.

The following table will show the weight of the chosen criteria in % with a cumulative value of 100%.

Table 3 Weight of each criteria

Criteria:	**Weight:**
Cost	20 %
Sustainability	10 %
Traffic Safety	20 %
Capacity	5 %
Required space	10 %
Construction time	10 %
Design complexity	5 %
Environmental impact and Visual pollution	20%

Variants to be compared

The variants that will be compared in the further parts of this Multi-Criteria Analysis will be the listed alternatives in the Theoretical Framework chapter. In addition, the current design will also be in the analysis.

To make sure this MCA achieves the most accurate results for the scoring of the variants a pre-assessment will be made. The aim of this pre-assessment is to see if there is enough available information and data for a certain criteria score to be evaluated. By executing such pre-assessment, the variants that prove to be insufficient (meaning there is not enough data available to give a specific score) will be directly ruled out of the later parts of this Multi-Criteria Analysis. Each variant will receive a mark per criteria which will indicate if the available information is sufficient, fair, poor, or insufficient.

Table 4 Pre-Assesment

Criteria	Variant 1 Trumpet	Variant 2 Half-clover	Variant 3 Current design	Variant 4 Roundabout	Variant 5 Directional T
	Mark:	Mark:	Mark:	Mark:	Mark:
Cost	Fair	Poor	Sufficient	Poor	Fair
Sustainability	Fair	Fair	Sufficient	Fair	Fair
Traffic Safety	Sufficient	Insufficient	Fair	Insufficient	Fair
Capacity	Sufficient	Sufficient	Sufficient	Fair	Sufficient
Construction time	Fair	Poor	Sufficient	Poor	Fair
Design complexity	Fair	Fair	Sufficient	Fair	Fair
Required space	Sufficient	Sufficient	Sufficient	Sufficient	Sufficient
Environmental Impact and Visual pollution	Fair	Fair	Sufficient	Fair	Fair

From the information that table four provides, it is seen that the available information for Variant 2 and Variant 4 is less compared to others. This is based on the fact that interchange designs such as Half-clover and Three-way Roundabout are used for rare situations that are specific and require a unique solution and design. Therefore, these two variants will not be compared in the later parts of this MCA.

Scoring

The variants that are to be compared will receive a score that is estimated for every criterion and there will be further information on how these estimations were made and what influenced the scores.

The variant with the highest overall score will be considered as the best possible solution to the problem that this research report is investigating. For every criterion the scale that will be used for evaluating will be from -2 to +2 where -2 will be considered as the most undesirable result and in the opposite +2 will be considered and the most desirable result for each criterion. The score of 0 will be considered neutral, which means that the criterion which has a score of 0 will not be affected by the outcome of the project.

Table 5 Scoring of each variant

Criteria	**Weight**	Variant 1 Trumpet	Variant 3 Current design	Variant 5 Directional T
		Score:	Score:	Score:
Cost	20 %	+2	+1	+1
Sustainability	10 %	+1	-1	-1
Traffic Safety	20 %	+1	-1	-2
Capacity	10 %	-1	+2	+2
Required space	5 %	-1	+2	+2
Construction time	10 %	+2	-1	-1
Design simplicity	5 %	+1	-1	-1
Visual pollution and Environmental impact	20%	-1	+2	+2

Score Reasoning

This part of the MCA is going to provide further information on the reasoning behind each score that the variants received per criteria.

- Cost

Trumpet interchanges in general are a high-budget solution for a three-way connection. However, compared to directional interchanges which represent the other two variants the trumpet is more economical. This is due to the fact that in directional interchanges there are more complex structures such as flyovers/dive-unders which, of course, means that there would be more time and materials needed to fully execute such a variant.

A study, that was focused on 34 underpasses built in Greece between 1997 and 2009 all of which used reinforced concrete for construction, (which is also the case for the interchange between A24 and A20) found that the average cost of an underpass structure is around 1271€/m2 (Antoniou et al., 2018). This means that an underpass of 800m2 would cost more than 1 million euros to be built. Logically, more underpasses require higher budge, more machinery, and more time to be built. Therefore, the trumpet interchange design costs more than 2 million euros less (assuming that all dive-unders are having an area of 800m2) at minimum, because of the fact it has fewer dive-uders.

Adding on, according to Nicholas J. Garber (1999) directional interchanges have the highest costs from all interchange types due to the large structures involved, and they are preferred only when high speeds and high capacity are required.

- Sustainability

By definition sustainability the degree to which a process or enterprise is able to be maintained or continued while avoiding the long-term depletion of natural resources. For the case of interchange design sustainability, a design that is easier to maintain/build and avoids the unnecessary usage of natural resources will logically be considered more sustainable.

The simplicity of the trumpet interchange design gives more room for sustainability. Compared to the other variants the trumpet interchange has fewer complex structures which means that it requires less time to build, needs fewer resources, and is easier to maintain.

The study used in the cost section of this score reasoning chapter also investigates the amount of materials needed to construct an underpass. The results show that a dive-under of 800m2 requires about 3000m3 of concrete and 400 tons of steel (Antoniou et al., 2018). The conclusion is that the trumpet interchange (1 dive-under) requires 6000m3 of concrete and 800 tons of steel less than the other 2 variants (3 dive-unders).

This all results in the trumpet being a more sustainable variant since fewer resources are going to be used for it.

In addition, the current design, compared to variant 3 is more complex due to the extended road connection on the west side which extends the length of the road and requires a longer dive-under.

- Traffic safety

The information that is present regarding traffic safety on different interchanges is limited. However, the importance of this criterion remains high. In order to evaluate the scores for each variant, the following approach was taken.

To make sure there is a base for comparison, for each interchange (variant) there are 3 locations assigned. These locations have the same interchange type and share a similar background. With the help of data sets provided by PDOK, the number of traffic accidents is given for each location for the period of 2008 to 2017. Thus giving the opportunity to see at which interchange type the most accidents are occurring. The accuracy of this approach, of course, is limited due to the low sample size and the fact that the A24 to A20 interchange is located in a port area, where more trucks are expected.

Variant 1 – Trumpet

Locations:

Langeweg

Roosendaal

Het Hazeleger

Number of accidents on these locations: Langeweg – 72 accidents; Roosendaal – 58 accidents; Het Hazeleger– 56 accidents.

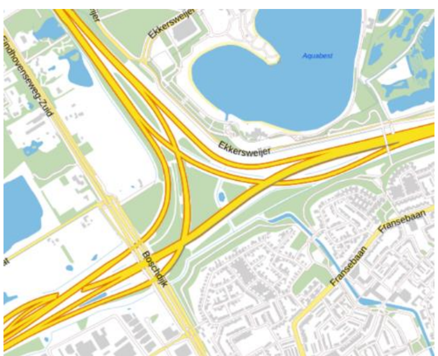
Total: 186 accidents

Variant 2 – Current design

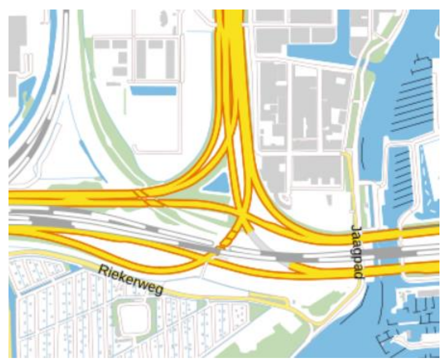
Locations:

’s-Hertogenbosch

Woensel (Northen connection)



Amsterdam Zuid



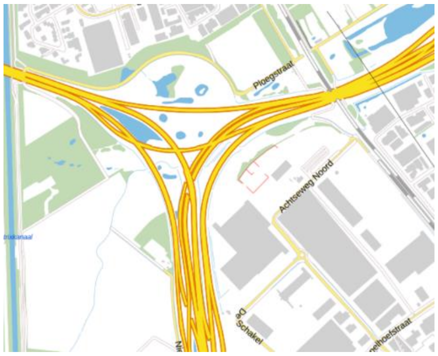
Number of accidents on these locations: ‘s-Hertogenbosch – 88 accidents; Woensel – 92 accidents; Amsterdam Zuid – 89 accidents

Total: 269 accidents

Variant 3 – T directional

Locations:

Woensel (West) | Breda | Eindhoven



Number of accidents on these locations: Woensel (West) - 98 accidents; Eindhoven – 110 accidents; Breda – 95 accidents

Total: 303 accidents

From this comparison, it is clear that trumpet interchanges are safer directional interchanges, since fewer accidents are occurring in this interchange type. This assumption, however, is lacking preciseness and accuracy because other outside factors also do have an influence on traffic accidents, such as interchange capacity, design speed, intensity, and types of vehicles that are most common on the interchange. Due to the potential inaccuracy of this assumption, the weight of this criteria was reduced from 25% to 20% and more weight was transferred to other criteria such as cost and sustainability.

- Capacity

The capacity of each interchange plays a crucial role in the decision-making when it comes to picking a specific design. The capacity is strongly dependent on the curves that the intersection has and the maximum design speed it allows. Directional interchanges offer the highest capacity and can move traffic at the highest speeds (Nicholas J. Garber, 1999). Knowing this, it is understandable that directional intersections such as Variant 3 and 5 are to be preferred if there are high demands in terms of capacity. On the other hand, trumpet interchanges offer less capacity since the curves present are sharper and the design speed is lower.

- Required Space

The trumpet interchange requires more space than the directional interchange types and this is purely based on design rather than any other interchange factor. Variants 3 and 5 are both very similar in regards to required space for construction, the difference that is seen in the road connection in the west direction is neglectable.

- Construction time

As mentioned previously, it is assumed that the simpler and less complex design that the trumpet interchange provides, results in faster construction time compared to Variant 3 and 5, because of the fact that there are fewer complex structures involved.

- Design simplicity

The trumpet interchange is much easier to design and construct, again due to the fact that it has less specific components such as underpasses or flyovers. Trumpet interchange has 1 where the other two variants have a minimum of 3 underpasses.

- Visual pollution and environmental impact

One of the main client requirements is to keep the appealing appearance of the area that surrounds the project and minimize the environmental impact. In order to do that the winning variant will be constructed under ground level wherever it is needed. This results in minimal visual pollution and minimization of the impact on the surrounding flora and fauna. All of the variants have the possibility to be constructed in these set conditions, however, the trumpet interchange uses more space and comes in close proximity to the duck shed at Het Aalkeetbuiten. On the other hand, variants 3 and 5 require much less space, thus their impact on the surrounding appearance, and flora and fauna is low.

4.2 Final/Winning variant

In this part, the winning variant will be shown based on the scores and weight given in the Multi-Criteria Analysis in Table 6. The final Variant is the one that has the highest overall score and will be considered as the best alternative to the current design of W+B.

Table 6 Overall Scores

Variant	1	3	5
Overall score	0.60	0.45	0.25

After the final score calculation, it is seen that with the highest score of 0.6 Variant 1 – Trumpet interchange is the winning variant of this Multi-Criteria Analysis and will be considered the best alternative to the current A24 to A20 design.

When it comes to three-way interchanges, the trumpet interchange design is one of the simplest and most commonly used ones not only in the Netherlands but in the world as well. This design provides traffic safety, cost-effectiveness, and sustainability due to its simplicity while also not significantly limiting the capacity of the allowed traffic. This design can also be built with a fly-over or dive-under depending on what is needed more in the specific situation. In the case of this alternative, a dive-under is preferred since it is minimizing the visual impact of the project area.

Despite the fact that the Trumpet interchange is the winning variant, there are still situations in which the W+B design is a better solution. The main advantages of the current design are that it has the ability to accommodate higher traffic capacity and can allow higher intensity and traffic speed. This, of course, is hard to predict accurately because of the fact that it is uncertain if the new motorway will be preferred over the already existing infrastructure. This prediction is highly dependent on the choice of the users of the current infrastructure systems in the area.

Therefore, the main trade-off between the trumpet interchange and the current design are:

Trumpet interchange is more cost-effective and simple to design and construct, which leads to higher sustainability but has a lower capacity.

The current design requires a higher budget and is more complex to design and build, which leads to lower sustainability, but has a higher capacity and offers higher traffic speeds.

4.3 Road Design

The following part of the Results chapter will describe the processes undergone and calculations done to make a traffic safe road design of the longest connection road of the trumpet interchange design. All of the calculations were done following the rules and regulations of the "Richtlijn Ontwerp Autosnelwegen 2017" furtherly referred to as 'ROA 2017' (in English: Motorway Design Directive 2017) provided by Rijkswaterstaat (Ministry of Infrastructure and Water Management). This road design is made with regards towards only the surface of the road in the connecting interchange. There are design values that were indirectly used for the different calculations of design are based on estimations. The Road Surface Design consists of these sections:

Cross-section

The cross-section does play a significant role when it comes to the surface of the road and there are values and parameters such as lane width and total cross-section length that have to be set and known in order to successfully design the alignment of the road. These parameters are all directly taken from the ROA 2017 and are estimates.

Number of lanes – 2 lanes + 1 emergency lane (by design from W+B)

Lane width– According to the ROA 2017 for the lane width applied to the main lanes of Dutch motorways and city motorways to obtain a constant and recognizable road image and to create clarity in order to minimize errors in the design, the gross width of 3.50 m per lane is prescribed for all main carriageways of motorways.

Lane width of emergency lane – In the Netherlands, it is stated that the emergency lane must offer the possibility of carrying out work on the emergency lane at a distance of 1.10 m from the lane (inside edge line), whereby a standard vehicle with a width of 2.60 m can stand on the emergency lane. The reason for this is that in the event of maintenance or breakdowns, the lane next to the emergency lane does not have to be crossed. This brings the total width of 3.50 m excluding an edge line of 0.20 m.

Total carriageway width - 11.00m including emergency lane

table 5.25 Minimum carriageway width

design speed	single-lane carriageway *	multi-lane carriageway
120 km / h	6.70 m	11.00 m
90 km / h		
70 km / h		
50 km / h		

Visibility parameters

A driver must always have a view of the course of the road to be able to control the transverse position of the vehicle and to respond safely and comfortably to events in the longitudinal direction of the road. There are two types of visibility parameters in road design – Visibility for Safety and Visibility for Comfort.

Safety visibility refers to the time identification of unexpected events, such as stationary vehicles and objects on the road in which the driver can safely take action – brake or accelerate.

Comfort refers to a view of the course of the road that is needed by the driver to be able to perform the necessary maneuvers in time - comfortably. For this, the longitudinal marking of the carriageway must be visible over a sufficient distance and, changes in the alignment, such as curves or lane ends, must be identifiable in time.

When it comes to calculations with visibility parameters there are 3 types of views that are used for designing different sections of the road such as horizontal and vertical arcs. They are:

- View of the road elements informative for the performance of the driving task - Anticipation view
- View of the course of the road in continuous situations - Road course view
- View of stationary traffic downstream - Stop view

Minimum sight length

The minimum sight length or stop sight distance is based on the stop view mentioned above. It is the minimum distance that the drive needs to see, in order to react on time and bring their vehicle to a full stop safely. The following formula is used to calculate the minimum stop sight length for Dutch Motorways:

$$Stop\ distance = \left[prt * \frac{v_o}{3,6}\right] + \left[\left(\frac{v_o}{3,6}\right)^2 * \frac{1}{2g * \left(f_{lg} + \frac{P}{100\%}\right)}\right]$$

Where:

- PRT - perception-reaction time is the period of time required for successively making an observation, processing the observation, and determining any necessary action. The prt is highly dependent on how the driver performs his driving task at a particular time. The higher the vehicle speed, the longer the PRT. **For the calculations made in this report a value of 1.75 seconds is used for a design speed of 70km/hr.**
- V_0 – This value represents the design speed for which the stop sight distance is calculated. **The whole road section has a consistent design speed of 70km/hr**
- flg - average coefficient of friction in the longitudinal direction, based on 86% sliding on the road surface and wet road surface. **Values that are used for flg differ per design speed in this case the value of 0,44 is used for a design speed of 70km/hr.**
- g – gravitational acceleration – **9.81 m/s2**
- P – slope percentage of **5%** for both design speeds (based on regulations set by ROA 2017)

Results

To calculate the stop sight distance, a Dynamo script was used (see Appendix C) where the formula was computed and it gave the following results:

For design speed of 70km/hr – Stop sight distance = 73.35 meters

The value for the stop sight distance is later used for the calculation of the minimum arc radii of the horizontal and vertical alignment.

Horizontal Alignment

The horizontal alignment is the horizontal course of the road axis. The horizontal alignment is made up of the following elements:

- horizontal straight(red)
- horizontal (circle) arc (green)
- transition curve (blue)

The following figure will show the final horizontal alignment and its components

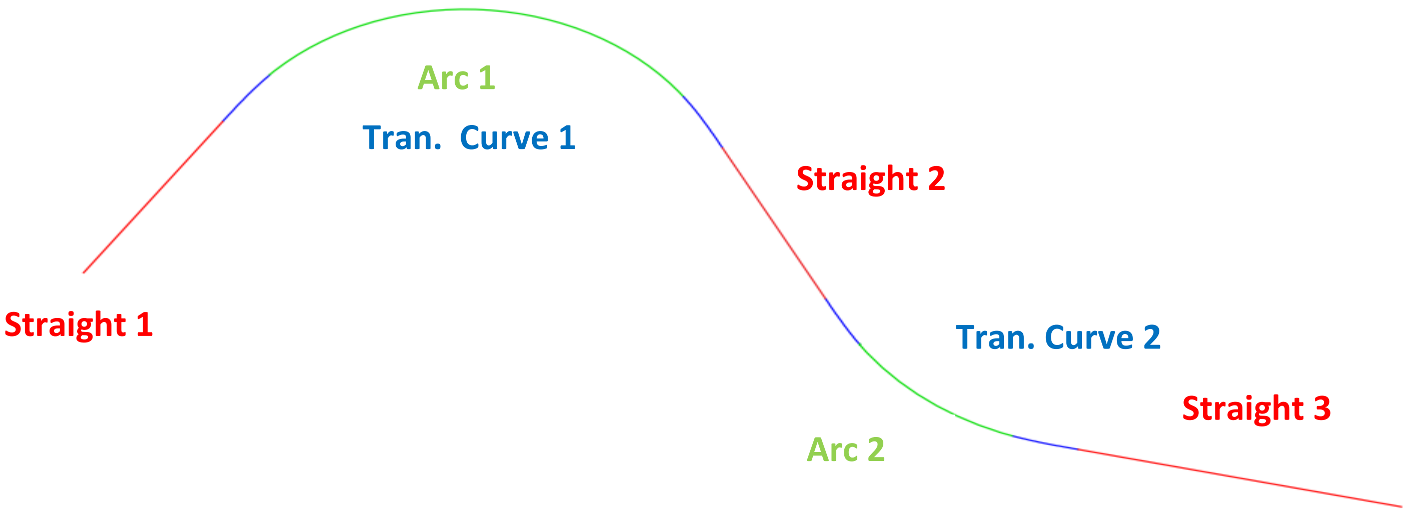


Figure 13 Horizontal alignment (simplified)

As Figure 13 shows, the horizontal alignment design for this thesis project consists of 7 parts in total. There are 3 straight horizontal lines, 2 arcs, and 2 transition curves for each arc respectively. The characteristics of each section apart from the horizontal straights were calculated by formulas provided by the ROV 2017.

Horizontal arcs

The horizontal arc is a circular arc with a specified radius in the horizontal alignment. Its functions are:

- facilitating a change in horizontal direction
- connecting roads with different directions
- offering an inconsistent road image to increase concentration on the driving task
- improve visibility of downstream traffic

When applying a horizontal arc, requirements are set for the radius of the arc and the length of the arc.

Minimum arc length

The minimum arc length varies in different situations which are based on road image and design speed. For a design speed of 70km/hr a minimum arc length of 60m is sufficient (Rijkswaterstaat, 2017a).
In comparison to the set minimum arc length, the arc lengths of the curves present in this horizontal alignment are: **Arc 1 – 315m; Arc 2 – 130m.**
The horizontal arc lengths that are present are safe to use as they are exceeding the minimum set value.

Minimum arc radius

When choosing a radius of curvature, the visibility requirements must be met. Furthermore, arc detection must also be taken into account, as well as estimation of curves, and consistency of the road image. For the requirements concerning arc radii, a distinction is made between arcs in main roads and arcs in non-main roads. The road that is calculated for this thesis project is a connecting road, therefore, it is considered as non-main.

To calculate the minimum arc radius for both arcs, the following formula was used:

$$Minimum\ curve\ radius = \frac{(L_z)^2}{2 * \left(\sqrt{d_z + d_w} + \sqrt{d_z + d_c}\right)^2}$$

Where:

- Lz – Sight distance. According to the regulations set in ROA 2017, the value for Lz that needs to be used in this formula must be the stop sight distance that was previously calculated in the vision paragraph. Therefore, Lz = 73.35m for a design speed of 70km/hr (see part - minimum sight length)

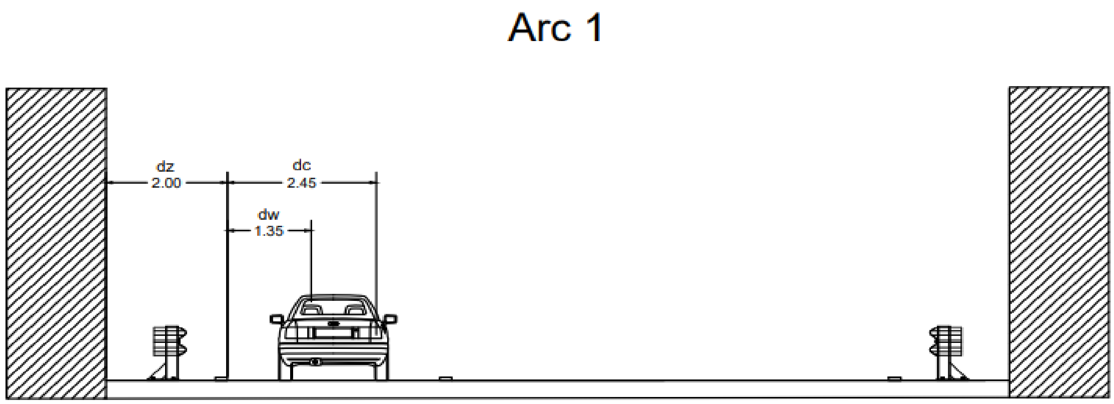
The values for dz,dw, and dc are fully based on the position of the vehicle on the road and its surroundings. Figure 14 will show how each of these values is acquired.

Figure 14 Definition of the dz,dw, and dc values

Figure 14 shows that:

- dz = distance between inside edge line and obstructing object (m)
- dw = distance between inside edge line and driver's observation point (m)
- dc = distance between inside edge line and control object (m)

Figure 15 will show the estimated values for dz,dw, and dc for arc 1 and arc 2 of the road that is being calculated in this thesis assignment.



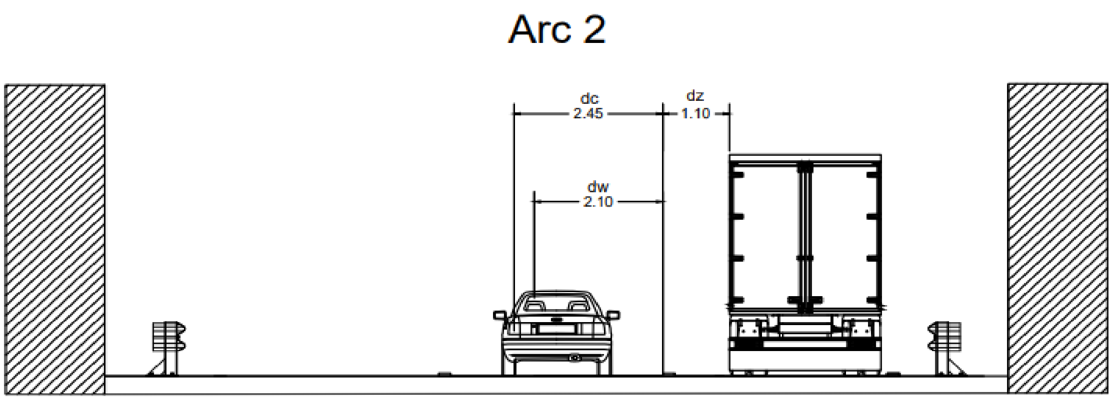


Figure 15 Estimated values for dz,dw, and dc for horizontal arc 1 and 2

For horizontal arc 1 the values for dc and dw are equal to the guideline values present in the ROA 2017, on the contrary, the value for dz, which is having a significant weight over the minimum arc radius result is based on a worst-case scenario due to the uncertainties around the surroundings of the connecting road.

For horizontal arc 2, where the vehicles are taking a right turn the values for dc,dw and dz are different from the ones in arc 1. In this case, the value for dc does not change, however, the value for dw and dz are equal to 2.1 m and 1.1 m respectively. For the value of dz, again a worst-case scenario is represented, this scenario is when a truck is using the emergency lane (stationary) and is obstructing the sight view of the driver.

Results:

- Arc 1 Minimum radius -**174m (see appendix c)**
- Arc 2 Minimum radius – **199m (see appendix c)**

Used radii: Both radii used are bigger than the minimum required.

- Arc 1 – **180m**
- Arc 2 – **200m**

For both arcs, the radii that are being used are very close to the minimum allowed radius of each arc respectively. This is done, because of the limited space in the project area and its surroundings. (see Figure 7 and Figure 23). If larger radii were to be used, this would result in a higher overall length of the connecting road, which will interfere with the duck shed at Het Aalkeetbuiten and the BP gas. (see Figure 7)

Transition curves

The transition curve is used and needed for a gradual transition between a horizontal straight and a horizontal arc or between two horizontal arcs. Its functions are:

- providing gradual steering turn
- smoothly connect horizontal curves with horizontal straights and/or horizontal arcs
- keeping lateral vehicle forces manageable for the driver
- smooth design of the motorway in curves, so that drivers have better access to the curves and so that any kinks in the road image are prevented
- providing the needed space for cant transition

When designing a transition curve the clothoid is used as a base. The clothoid is a spiral with a radius of curvature R which is inversely proportional to the length calculated from point 0 where R = infinity. By using the clothoid as a base of the transition curve a smooth transition between two design elements is secured. The clothoid is characterized by the clothoid parameter A. This is represented by the following formula:

$$A^2 = R_x * L_x$$

Where:

- R_x – Radius used
- L_x – Length of transition curve

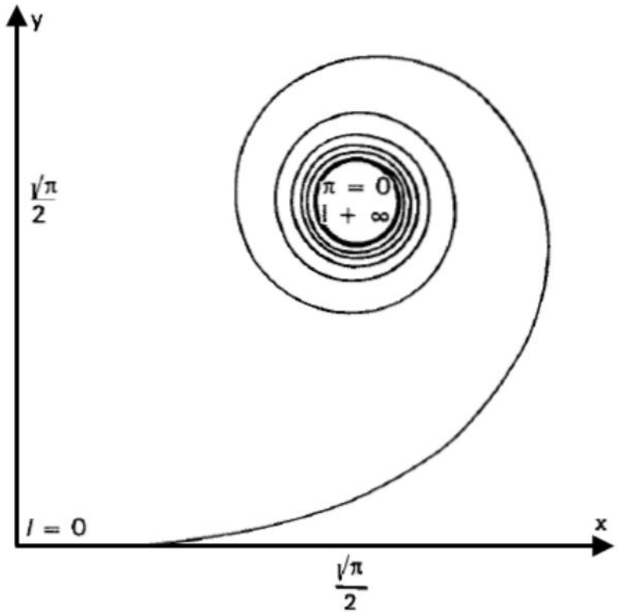


Figure 16 Standard Clothoid

Transition curve length

In principle, the clothoid parameter A has to be as small as possible because this results in better arc recognition. In order to find the minimum clothoid parameter A that needs to be used, the following formula is applied:

$$A_{min} = 0,146\sqrt{\frac{v_0^{\,3}}{C_{toelaatbaar}}}$$

Where:

- V_0 – Design speed – **70km/hr**
- C - factor for the permissible change of acceleration in the lateral direction (m /s3) – value used: **0.8 m/s3** (provided by ROA 2017).

This formula is based fully on comfort parameters, if the minimum visibility parameters are to be used then the minimum clothoid parameter would be equal to 1/3 * R, where R is the radius of the arc. For the road design of this thesis project, the parameters for comfort are used, as they result in a smoother and safer transition, and provide more space for cant transition.

Results:

- **A min = 95**

By finding the minimum clothoid parameter, the total length of each transition curve is calculated with the following formula:

$$A^2 = R_x * L_x$$

Results:

- Length of transition curve 1 = **50m**
- Length of transition curve 2 = **45m**

Horizontal straights

A horizontal straight line is a straight line in the horizontal alignment. The horizontal straight has the function of connecting two horizontal curves. In the alignment, horizontal straight lines are mainly applied at junctions and connections, or when bundling with other infrastructures such as railways or canals. Whenever horizontal straight lines are used, the aim should be a limited length. As a guideline, a length in meters of twice the design speed in km / h can be used (Rijkswaterstaat, 2017a). On the other hand, the horizontal straight must not be too short, so that it is recognized as an independent element and no errors (kinks) occur in the road image.
Design speed in the connecting road is 70km/hr, therefore the minimum length of the horizontal straight lines is 140m.

Length of:

- Straight 1 = **180m** - length needed to bridge the height difference in the vertical alignment (see section Vertical Alignment)
- Straight 2 = **170m** - distance between the two horizontal arcs
- Straight 3 = **210m –** length of deceleration lane

Vertical Alignment

The vertical alignment determines the way in which height differences are overcome in different sections of the road. Similar to the horizontal alignment the vertical alignments also consist of straights and arcs that are applied in the vertical alignment. The general properties of the vertical straight lines and arcs are shown in Figure 17.

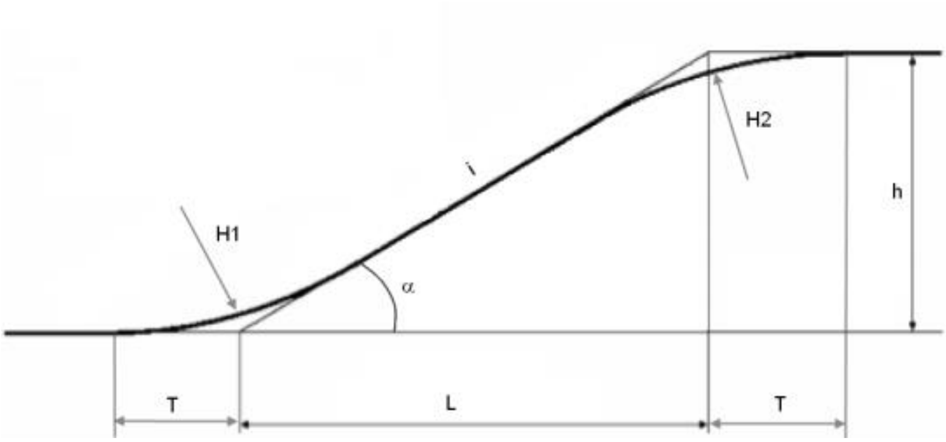


Figure 17 Typical vertical alignment and its properties and values

Where:

- H – Arc radius
- i – Slope %
- h – High difference
- T – Tangent length

The following figure will describe the current situation on-site with average heights with regards to NAP:

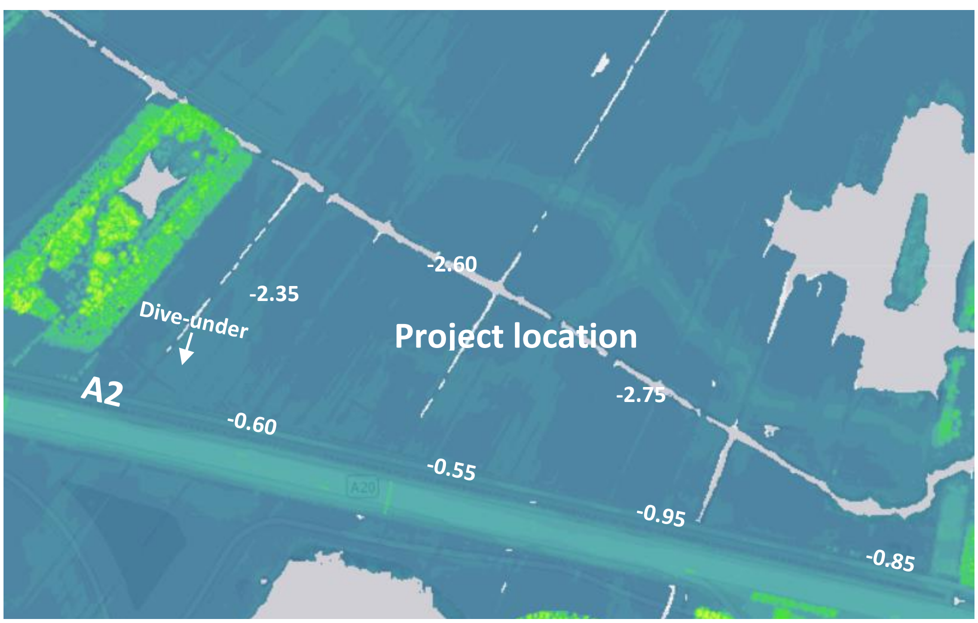


Figure 18 AHN Viewer map

With the information gathered from the AHN Viewer Map (Actueel Hoogtebestand Nederland, 2021), an average height will be set for the A20 and the location from which the connecting road will go through. **The average height of the project location is -2.56 NAP and the one of A20 is - 0.74 NAP**. This gives a general idea of the heights that are already present.

Given the fact that by design the connecting road that is being calculated for this thesis will be going underneath the A20 via dive-under the initial height at the beginning needs to be estimated.
In order to estimate at what depth the connecting road will start, two values need to be found: the height of the dive-under and the height of the roof of the dive-under which is placed to support the A20.

Dive-under height

As mentioned in the initial chapters of this report, prior to the A20 to A24 connection there are two tunnels that are going to be built (Maasdelta Tunnel and Holland Tunnel). Therefore, for the height in the dive-under, the (usable) height of the Maasdelta tunnel will be used because the same vehicles are going to pass through both tunnels and the dive-under in the trumpet interchange. The design height of the Maasdelta tunnel is **4.70m** (Toelichting, 2017).

The height of the roof of the dive-under is a value that requires specific calculations in order to be found. These calculations are connected to reinforced concrete slabs and are far from what the main focus of this final thesis assignment is. Therefore, an estimated value of **1.30m** will be used. This value is based on the roof height of the Maasdelta tunnel which is 1.35m.

By knowing the total depth of the dive-under and the average height of the A20, **the height difference (h) to be bridged is equal to 6 meters in total**, which sets the starting point of the road surface at -6.74m NAP. This means that the connecting road will have to be elevated by around 1.80m in the areas below the A20 to achieve coherent vertical alignment and smooth connection (vertically) to the A20.

To sum up, there are height differences only on the section of the connecting road which is located only on (horizontal) Straight 1. For all the other sections of the horizontal alignment, the vertical position of the road is consistently on – 0.74m NAP. Therefore, a vertical alignment design with arcs and straights (vertical) will only be made for this section of the road.

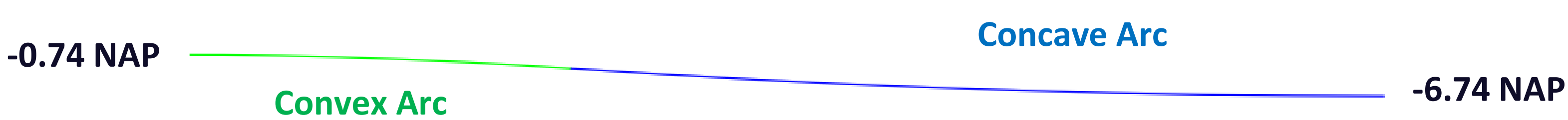


Figure 19 Vertical alignment

Convex Arc

The Convex arc represents the arc that is on the highest part of the vertical alignment. For the design criteria of a convex arc, the parameters for visibility rather than comfort apply. This means that the stop sight distance that was calculated previously will be used to calculate the minimum radius of the convex arc for this vertical alignment. The minimum radius is calculated with the following formula:
Where:

$$R_{bol,min} = \frac{L_z^{\ 2}}{2(\sqrt{h_o} + \sqrt{h_h})^2}$$

- $R_{bol,min}$ - Minimum radius of convex arc
- L_z - Sight distance – 73.35m (see part – minimum sight length)
- h_o - Observation height – 1.10m (Rijkswaterstaat, 2017a)
- h_h – Height of observation object – 0.50m (Rijkswaterstaat, 2017a)

Result:

Minimum radius of convex arc = Used radius = 865m

Concave arc

The Concave arc is the circular bottom rounding in the vertical alignment. The decisive criterion for the dimensioning of concave arcs is the clarity of the road image so that the impression of counter-arches or kinks is avoided. For this, it is generally sufficient to assume a radius of curvature of R concave = 2 * R convex (Rijkswaterstaat, 2017a).

This results in the minimum radius of the concave arc being 1730m.

For both concave and convex arcs, the used radius is also the minimum one. This is done, due to the fact that the available construction space on the project area is limited, and if bigger radii were to be used, the interchange would not fit into this available space. For instance, if radii of 900 for convex and 1800 for concave arc were used, this would result in the total length of horizontal straight 1 being around 200m. This would then lead to a longer overall interchange which would not fit into the available constructions space between the BP gas station and the duck shed at Het Aalkeetbuiten.

The vertical alignment discussed above consists of two arcs with different radii. There is no vertical straight line applied because the height difference is low. For the design of a vertical alignment for a main track, height differences are preferably bridged by connecting a concave arc directly to a convex arc, so without the intervention of a vertical straight line. This promotes a smooth course of the road and reduces the risk of errors in the road image (Rijkswaterstaat, 2017a).

In this situation, the maximum slope allowed on the vertical alignment is calculated with the following formula:

$$p = \frac{2 * \Delta H}{\sqrt{2 * \Delta H * (R_{v,bolleboog} + R_{v,holleboog})}} * 100\%$$

Where:

- ΔH - Height difference – 6m
- $R_{v,\ bolleboog}$ - Radius of Convex Arc – 865m
- $R_{v,\ holleboog}$ - Radius of Concave Arc – 1730m

Results:

- **Maximum slope % allowed = 6.8%**
- **Total length of Vertical alignment (horizontal straight 1) = 175m**

Slopes and cants

To complete the road design of the connecting road the final step is to establish what slopes and cants will be present in the road image

Slopes present on the horizontal straight lines

The slope in pavements is the transverse slope of the surface of the pavement or road verge that is responsible for water drainage mainly in horizontal straight lines. A slope of at least 2.5% is required for good water drainage (Rijkswaterstaat, 2017a). The slope of the roadside is standard 5%, regardless of the cross slope of the pavement. The verge should logically never drain towards the road.

As explained in the horizontal alignment part of this chapter the connecting road that is calculated has three horizontal straight lines. For the slope of straight lines 2 and 3, the minimum slope of **2.5%** will be used which must provide sufficient water drainage. For straight 1 however, there will be no slope present as this segment already water drainage functions due to its vertical alignment situation.

Cants present on the horizontal arcs

The cant in pavements is the transverse slope of the surface of the pavement that is used to limit the sliding-off movement of vehicles due to centrifugal force in horizontal curves/arcs. On horizontal arcs, the cant to be applied falls under a certain limit value that is highly dependent on the arc radius. In general, in cases where a smaller arc radius must be used, a higher cant % is applied in order to support the road user in performing their driving task. In addition, the cant is also improving the visibility inside the arc.

Cants are applied when the horizontal radius of curvature is small enough and compensation in centrifugal force on moving vehicles is required. In the case where a design speed of 70km/hr is used, cant is required for radii below 800m (Rijkswaterstaat, 2017a).

In horizontal arcs, the cant is also responsible for water drainage, which means the minimum value is 2.5%. On the other side, the maximum allowed cant in arcs is 7% on non-main tracks which is the case for the connecting road that is calculated in this thesis.
After understanding the lower and upper limit values for the cant that has to be used a decision has to be made as to what cant percentage is optimal for this connecting road. This decision is highly influenced by the regulations set by ROA 2017 where it is stated that for radii of less than 300m the minimal cant % must never be less than 5%. This improves the recognisability of the curves for the road users and improves the overall safety situation on the road itself. Therefore, as both radii of the connecting road are below 300m, the cant that is going to be used is 5%.

Cant/Slope transition

There are two types of cant/slope transitions – rectified, when only a decrease/increase in slope is present without change of direction of drainage, and revolving, where a change of drainage direction also takes place.
Given the fact that there are different cants and slopes throughout the whole road alignment, in order to have a safe and secure road image a gradual transition between each cant/slope has to be made. This transition has an upper and lower limit value for length. The main goal of these limits is to minimize the water drainage problems that might occur during the transition when the certain cant/slope % falls below the value of +/- 2%.
In the case of this connecting road, there will be both rectified and revolving transitions present.

Rectified cant/slope transitions

Rectified cant/slope transitions takes place when the road is entering a horizontal arc. Since there are two arcs present in the horizontal alignment of this connecting road, a total number of four rectified transitions are expected, before and after each arc respectively. These transitions must take place in the transition arc, however, if the lower length limit is bigger than the transition arc length the slope/cant transition must start before the transition arc. In order to calculate the upper and lower limits for the length of the transition, the following formulas are going to be used.

$$L_{v\_max} = 2 * \frac{i_e - i_b}{\Delta S_{min}} * B$$

$$L_{v\_min} = 2 * \frac{i_e - i_b}{\Delta S_{max}} * a$$

Where:

- $L_{v\_min/max}$ - Upper and lower limit of transition length
- I_e – cant/slope at the end of the transition
- I_b – cant/slope at the beginning of transition
- $\Delta S_{min/max}$ – Lower and upper limit for relative slope (0.9% min/2.5% max, values provided in ROA2017)
- A - distance between the axis of rotation and the farthest edge line (axis of rotation – midpoint) – 5.5m
- B - carriageway width between the edge lines – 11m

Results:

Since both horizontal arcs present in the road alignment have the same parameters (same slope before and after arc, and same cant inside arc, same carriageway width, same design speed) they will have the same lower and upper limit values for the length of slope/cant transition.

- L_{v_min} – 11.00m
- L_{v_max} – 61.11m

An exception is made for the slope after Arc 1, where the road is going into a dive-under, therefore, instead of the slope after Arc 1 being 2.5% it is 0% when entering the vertical alignment of the dive under, which is happening 5 meters after the end of the transition curve of Arc 1.

Calculation results for cant transition at the end of Arc 1: Slope 5% to slope 0%

- L_{v_min} – 122.22m
- L_{v_max} – 20.00m

As the transition arc values for both curves fall within all the upper and lower limits calculate limits, to assure a better road image the cant/slope transition length will be the same as the lengths of the transition curves 1 and 2 resulting in:

- **Cant/slope transition length for Arc 1 in both ends – 50m**
- **Cant/slope transition length for Arc 2 in both ends– 45m**

Revolving cant/slope transition

As previously said, revolving cant/slope transition is a transition not only between two different slopes but also between drainage directions. This type of transition usually takes place between two oppositely oriented horizontal arcs. Given the fact that this connecting road has such arcs, a need for revolving transition is present. These transitions will take place in the middle of horizontal Straight 2 (meaning that the point of slope % of 0 is exactly in the middle of the straight). The formulas used for upper and lower length values are the same, therefore, the results will be shown directly.

Results:

- L_{v_min} – 20.00m
- L_{v_max} – 122.22m

The total length of horizontal Straight 2 is 170m, this means that there is enough room for the transition to occur. However, when the overall slope of the road surface falls below +/-2% drainage problems are expected. Logically, if the Lv maximum value is used for the transition length, there will be a bigger area with drainage problems. On the contrary, if the Lv minimum value is used, the transition becomes too sharp and can create problems for the road users. Therefore, an optimal value must be set which should be closer to the minimum in order to minimize drainage problems while still being comfortable for the road users.

- **Total revolving transition length: 60m**

Deceleration lane

A deceleration lane is needed when there is a change in direction happening on a motorway and the change in design speed of the two sections is not happening gradually. This is also the case for the connecting road of this calculation sheet, where the difference in design speeds is 50km/hr (120km/hr to 70km/hr). The main design parameter for the deceleration lane is its length.
The deceleration length is the distance required to reduce the speed of a vehicle to an extend where road section immediately downstream can be used safely. Deceleration must take place on the exit lane and the curving carriageway after leaving the traffic lane.

The required deceleration length depends on the following factors:

- design speed of the carriageway
- design speed of the curving roadway
- deceleration of the decelerating vehicle
- average gradient of the curving roadway

Sufficient deceleration length must be available for the following two scenarios:

Scenario 1
When the vehicle enters the deceleration lane in time and makes this at the first part of the diverting lane for a comfortable deceleration – L_d.

Scenario 2
When the vehicle enters the deceleration lane at the last possible moment, just before the point section, and does not use the exit lane for deceleration but decelerates with a considerable delay on the first part of the curving carriageway - $L_{d'}$. (Rijkswaterstaat, 2017a).

To calculate the deceleration lane length, the following formula was used:

$$L_d = \frac{v_0^2 - v_a^2}{256 * \left(\frac{d}{g} + \frac{p}{100}\right)}$$

Where:

- L_d – Deceleration length
- V_0 – Design speed on highway – 120km/hr
- V_a – Design speed on connection road – 70km/hr
- d - Deceleration of the vehicle (comfortable -1.5 m / s2, resulting in L_d, last moment (hard): 2.5 m /s2, resulting in $L_{d'}$)
- g – Gravitational acceleration – 9.81 m/s2
- p – Average slope percentage of the road – 2.5%

Results:

The deceleration lane is represented as Straight 3 in the horizontal alignment part.

- L_d = 208,6m
- $L_{d'}$ = 132.6m

The used deceleration length is L_d because it offers a comfortable vehicle deceleration length and is be rounded to 210m.

After calculation, an image of the trumpet interchange is drawn to get a comparison with the current W+B design. The two following figures will show the trumpet interchange and the W+B design scaled and put into the map of the surroundings.

Figure 20 Trumpet interchange

Figure 21 W+B interchange design

5. Conclusion and Recommendations

This final thesis assignment was mainly focused on providing different interchange designs and finding the best alternative to the W+B interchange design that is more cost-effective while still being traffic safe and meeting all stakeholder requirements. A Multi-Criteria Analysis was used to sieve through all the proposed alternatives and to find the most suitable one. The results of the MCA indicate that a trumpet interchange design is by far the best possible alternative to the current interchange design while also meeting all the stakeholder requirements.

In the final stages of this thesis assignment, a detailed design of the road surface of the longest connecting road (see Appendix A) was developed to prove the statement that a trumpet interchange design is not only a more sustainable and cost-effective alternative, but also fits the surrounding environment in a nature-sparing manner which was a very important requirement. This design included horizontal and vertical alignment with all slopes and a 3D model developed in Dynamo.

However, this generalized result was limited by different factors such as lack of data, low sample size, and language and time limitations. For some of the proposed alternatives there was little to no usable and concrete information regarding many different aspects and criteria, this lead to a pre-assessment of the available data, and score assumptions that were made based on limited data. For instance, the scores given in the MCA for traffic safety, which was one of the highest-weight criteria, were lacking accuracy due to the fact that the data was unspecific and there was a low sample size. Additionally, due to the limited time period of this final thesis assignment, a detailed up-to-scale design of the road surface could be made only for one connecting road of the winning alternative. In contrast, if such a design was made for the whole trumpet interchange a better understanding of the situation could be achieved.

Further research is needed to establish in which situations a trumpet interchange is to be preferred over a directional interchange (such as the W+B design) for a three-way connection as there are many different decision influencing factors that can impact the interchange type choice. These factors such as capacity, traffic safety, and expected intensity are of course bound to the exact situation that is present in a particular project. Nevertheless, a more direct and general idea on which interchange design is better for a certain situation can be developed if such information is available.

Regardless of the limitations that were present during this final thesis assignment, based on the findings, the trumpet interchange design is a suitable option for an alternative to the current W+B interchange design. Despite having its downfalls in the appearance and capacity departments, the trumpet interchange offers a more sustainable and cost-effective design while not compromising all the important stakeholder requirements.

6. References

Actueel Hoogtebestand Nederland. (2021). AHN Viewer | AHN. In *Ahn.Nl*. https://www.ahn.nl/ahn-viewer

Ann M. Johnson, P. E. (2005). *Best Practices Handbook on asphalt pavement maintenance*.

Antoniou, F., Konstantinidis, D., Aretoulis, G., & Xenidis, Y. (2018). Preliminary construction cost estimates for motorway underpass bridges. *International Journal of Construction Management*, *18*(4), 321–330. https://doi.org/10.1080/15623599.2017.1358076

Brennan, M. J., & Knapton, J. (1997). *Colm A Flaherty-Highways_ the location, design, construction & maintenance of road pavements-Butterworth-Heinemann (2001).pdf*.

Broniewicz, E., & Ogrodnik, K. (2020). Multi-criteria analysis of transport infrastructure projects. *Transportation Research Part D: Transport and Environment*, *83*(April), 102351. https://doi.org/10.1016/j.trd.2020.102351

Farah, H., Van Beinum, A., & Daamen, W. (2017). Empirical speed behavior on horizontal ramp curves in interchanges in the Netherlands. *Transportation Research Record*, *2618*, 38–47. https://doi.org/10.3141/2618-04

Inpassingsplan, T. V.-. (2016). *Tracébesluit / MER Blankenburgverbinding Blankenburgverbinding*.

Nicholas J. Garber. (1999). *Guidelines fro preliminary selection of the optimim interchange type for a specific location*.

PDOK. (2020). *PDOK viewer*. https://www.pdok.nl/viewer/%0Ahttp://pdokviewer.pdok.nl/

Rijkswaterstaat. (2017a). *Richtlijn Ontwerp Autosnelwegen*. *november*, 166. https://staticresources.rijkswaterstaat.nl/binaries/Richtlijn Ontwerp Autosnelwegen 2014_tcm21-76103.pdf

Rijkswaterstaat. (2017b). *Zicht vanaf Zuidbuurt Zicht vanaf fietspad spoorzone ‘Schuur’ in polderlandschap*.

Toelichting, D. I. I. I. (2017). *Tracébesluit / MER Blankenburgverbinding*.

Van, W., & Blankenburgverbinding, T. (2017). *Tracébesluit Blankenburgverbinding (2017)*.

Vlaardingen, K. (2020). *Inhoudsopgave*. 1–9.

Appendix A – Supporting Drawings

Figure 22 - Horizontal Alignment of the calculated connecting road (Scaled)

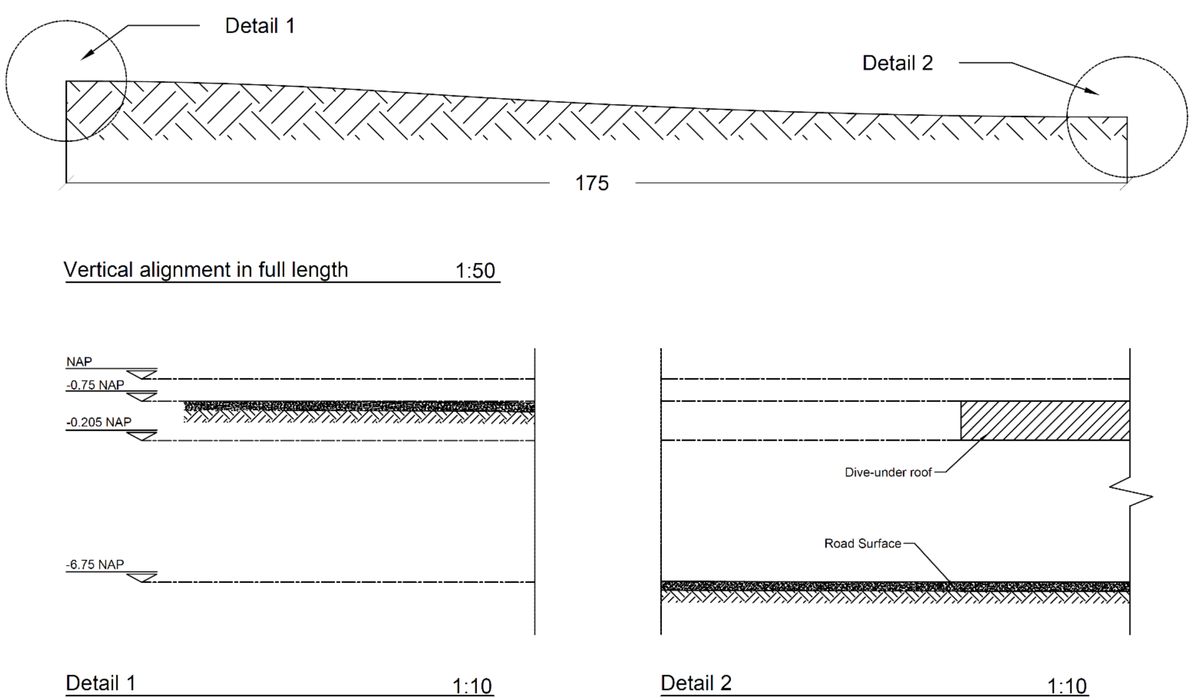


Figure 23 - Vertical alignment at full length and showing NAP levels

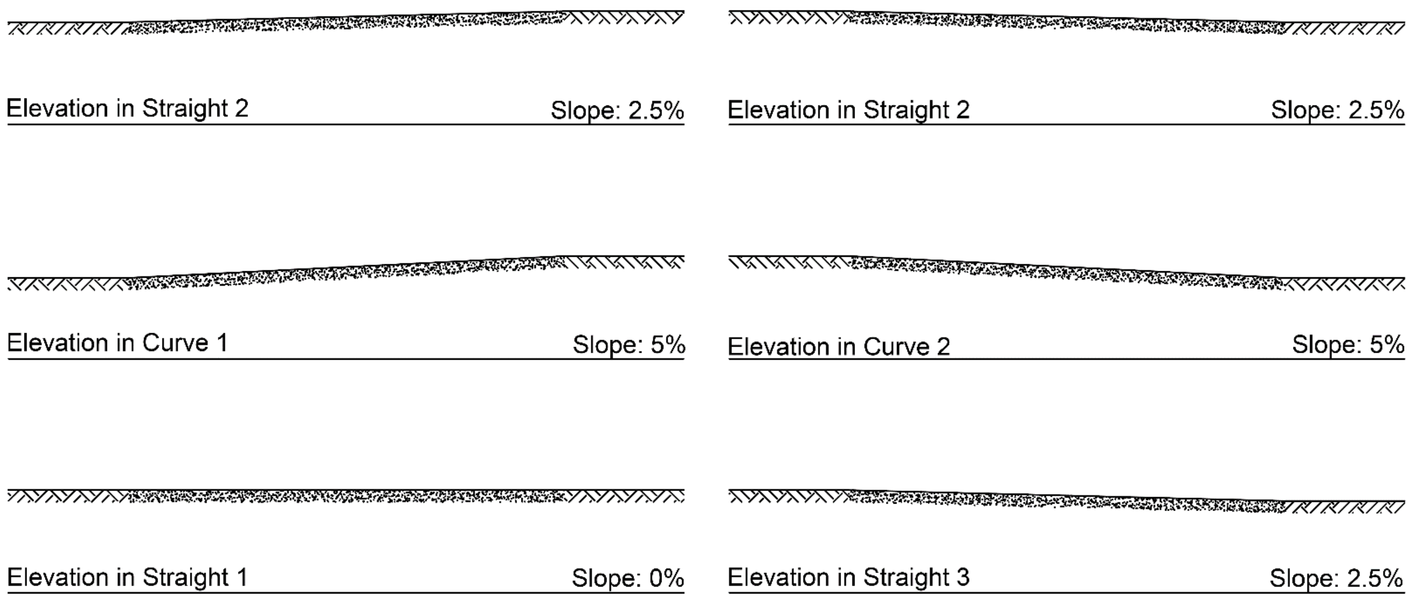


Figure 22 - Slopes in different segments of the connection road

Appendix B – 3D Model in Dynamo

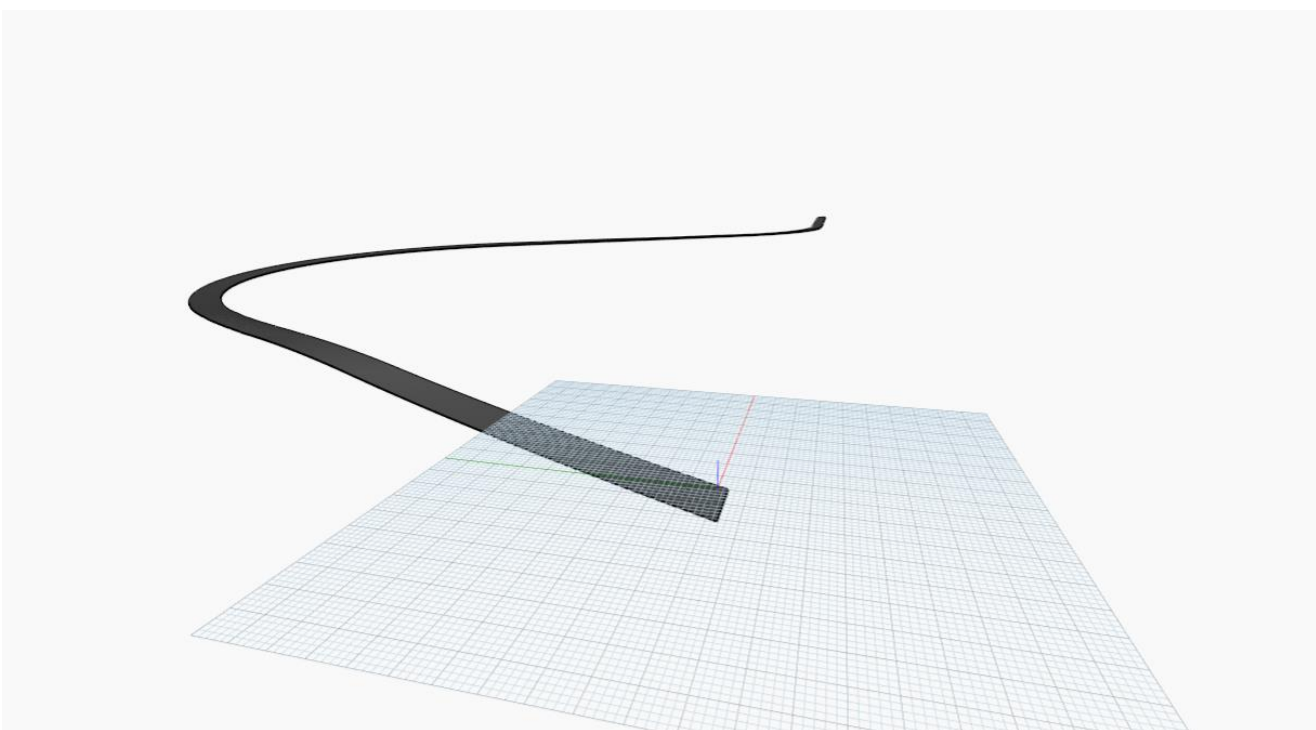


Figure 23 3D Model

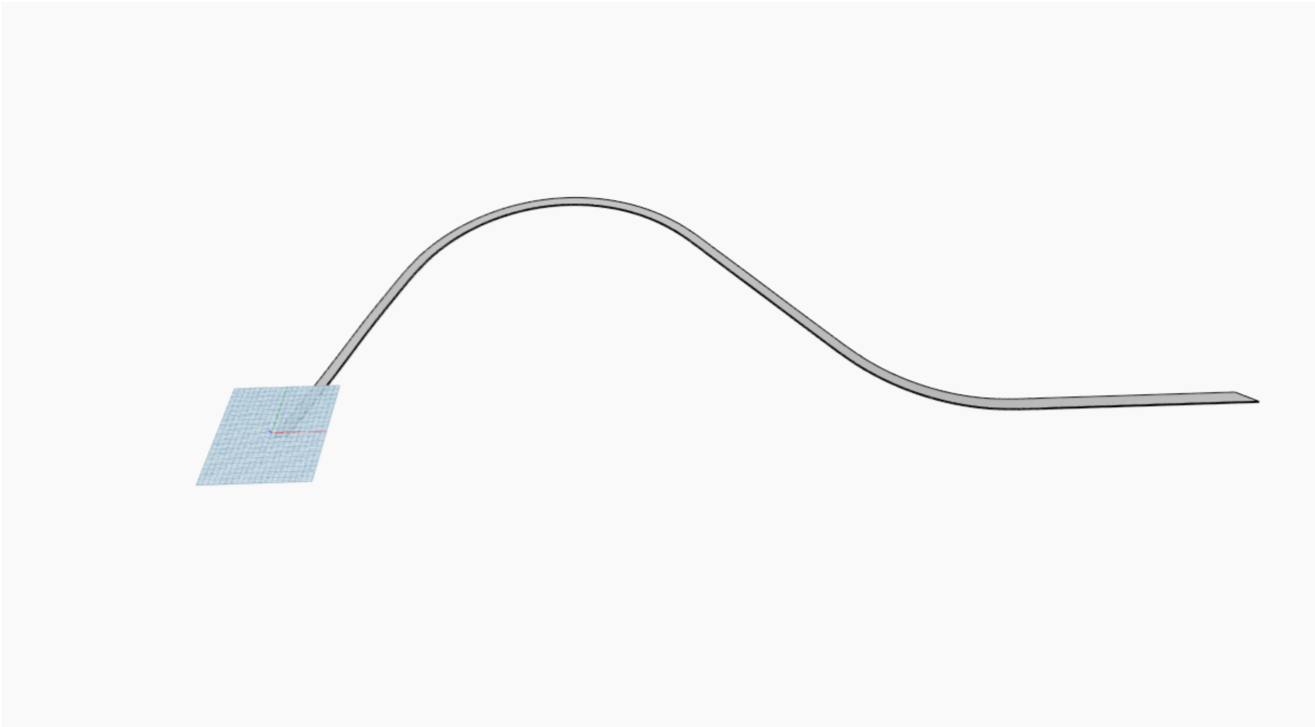


Figure 24 3D Model

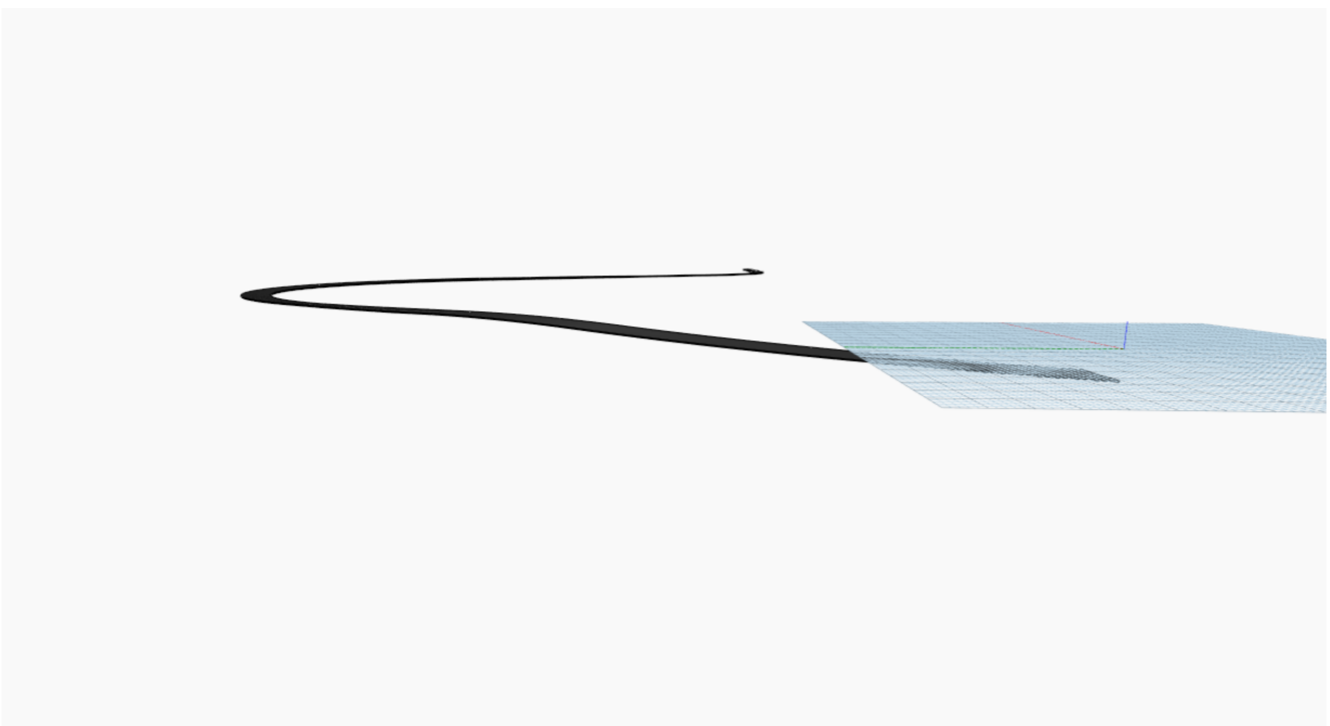


Figure 25 3D Model

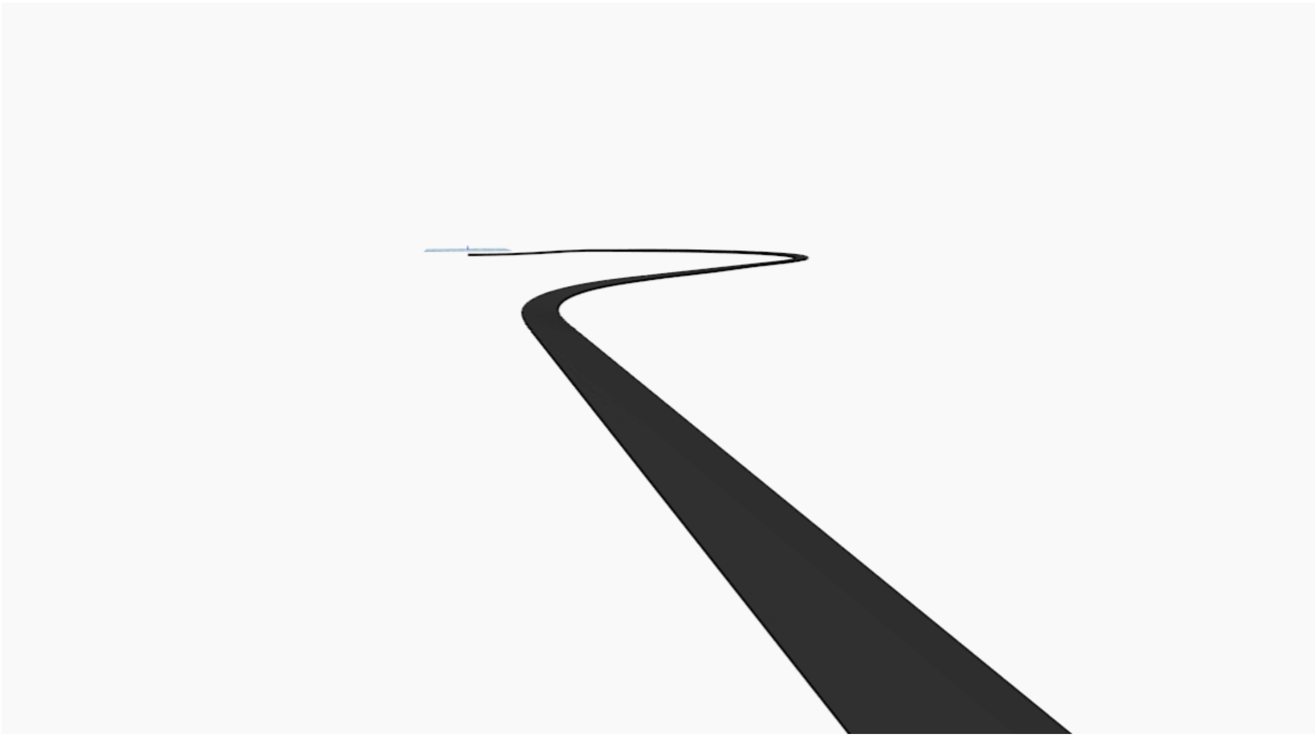


Figure 26 3D Model

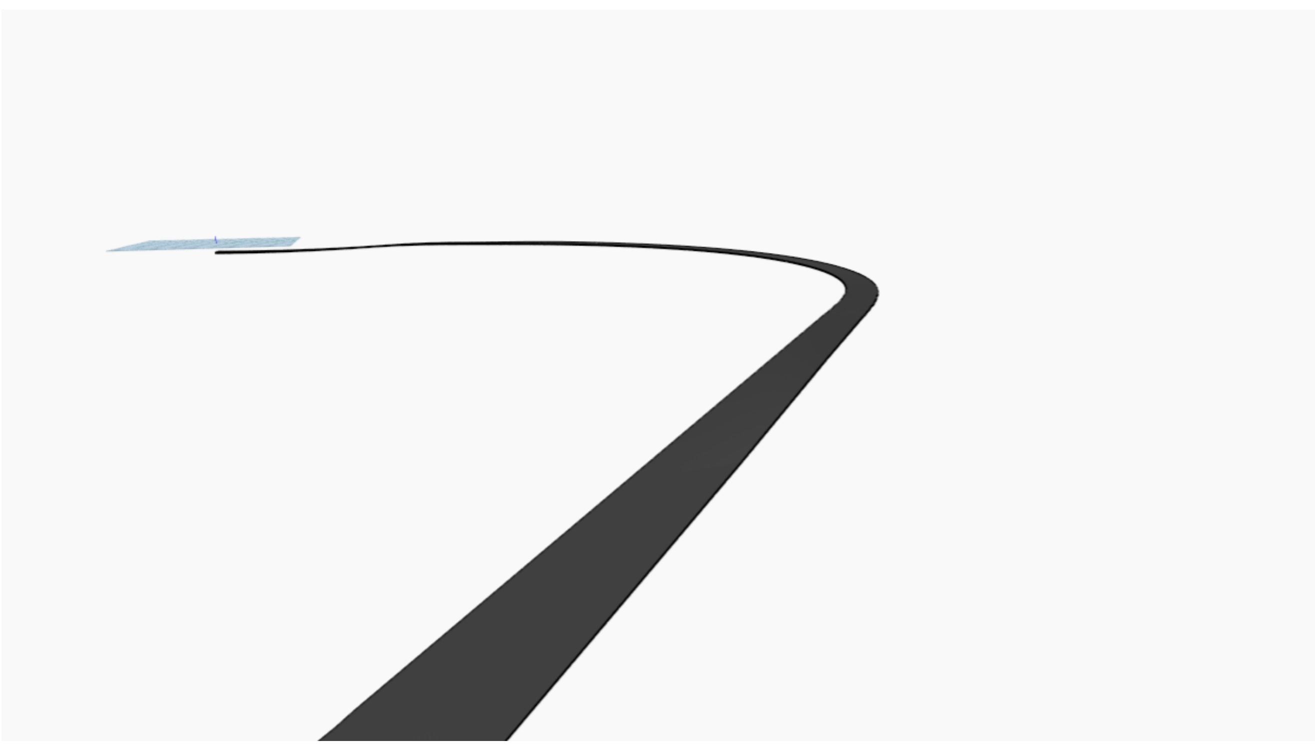


Figure 27 3D Model

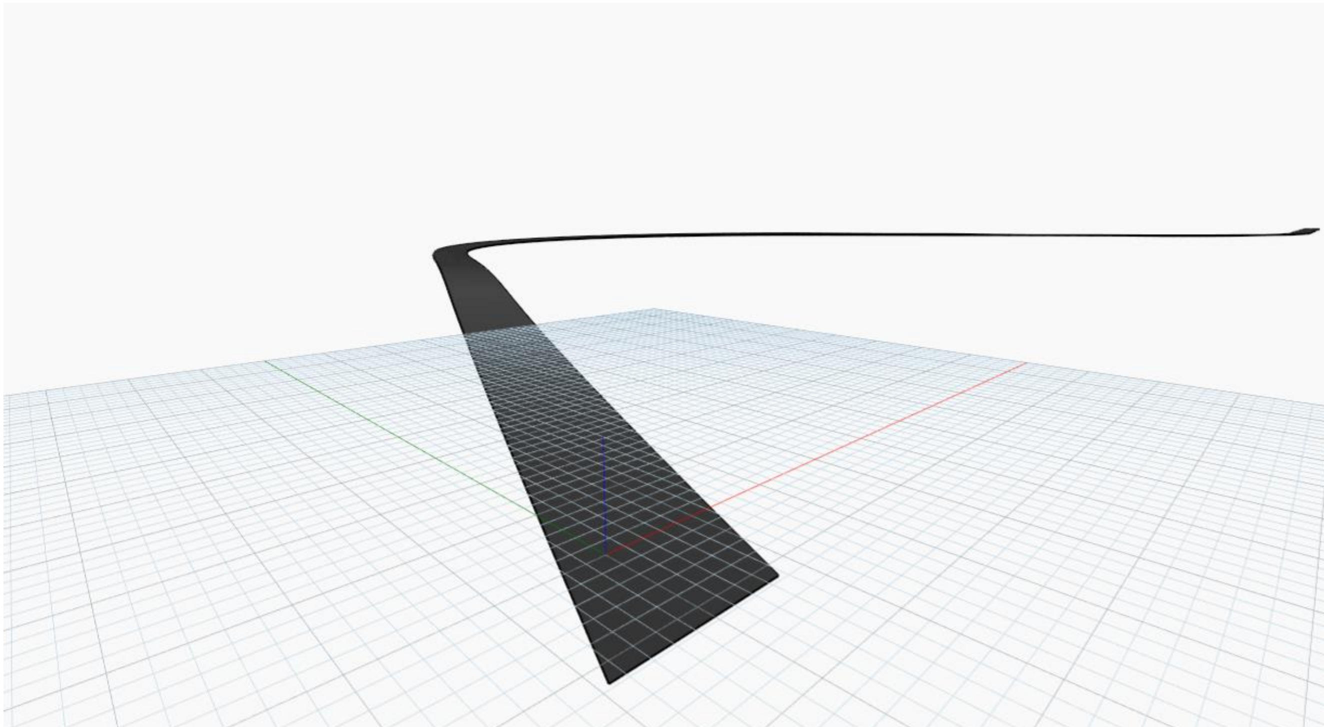


Figure 28 3D Model

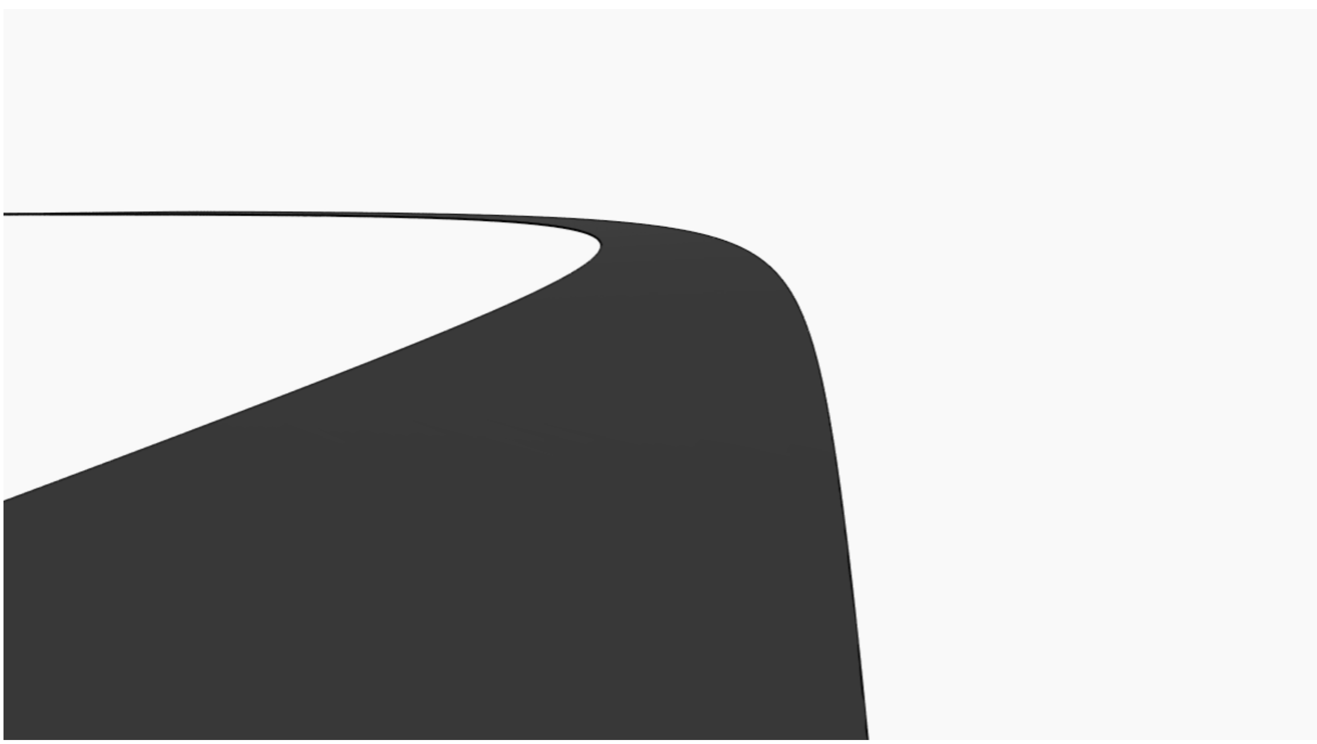


Figure 29 3D Model

Appendix C – Dynamo Scripts

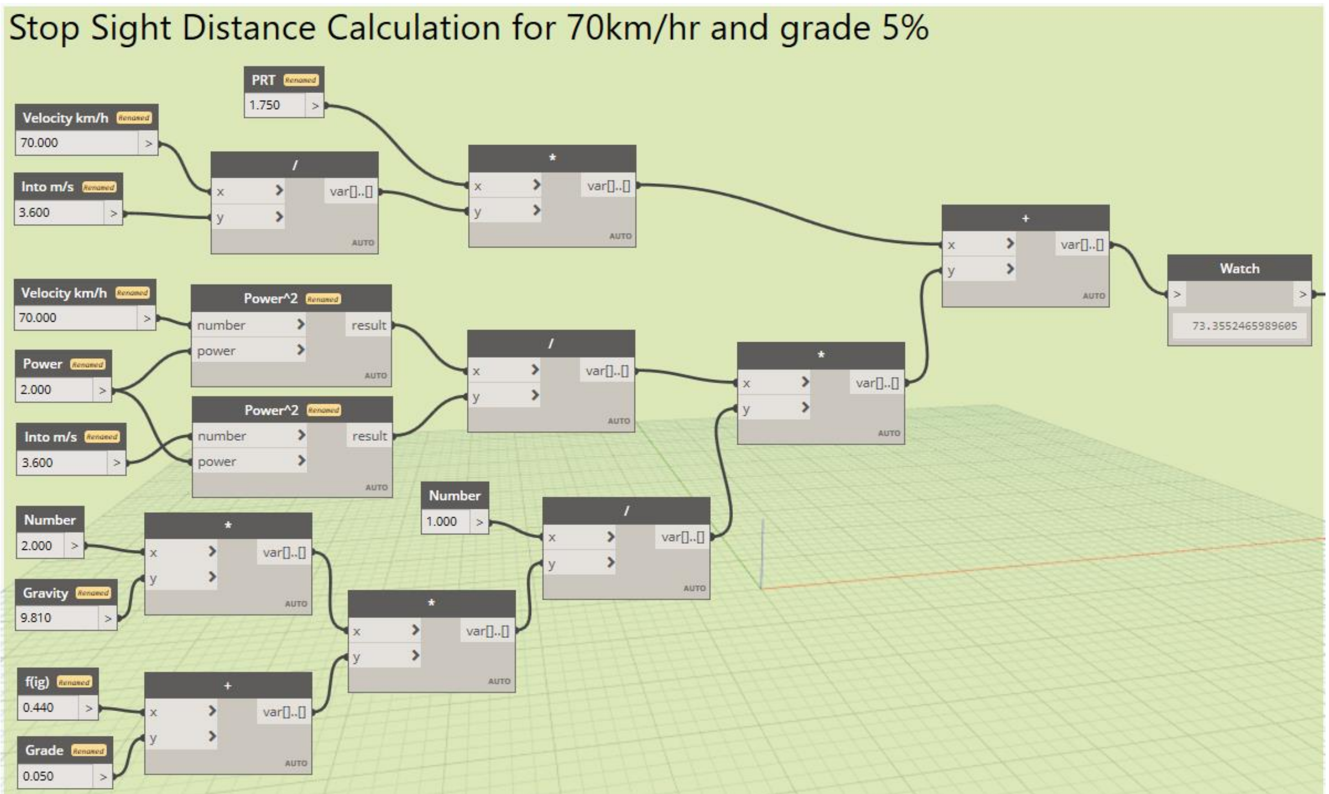


Figure 30 Stop View Calculation Dynamo Script

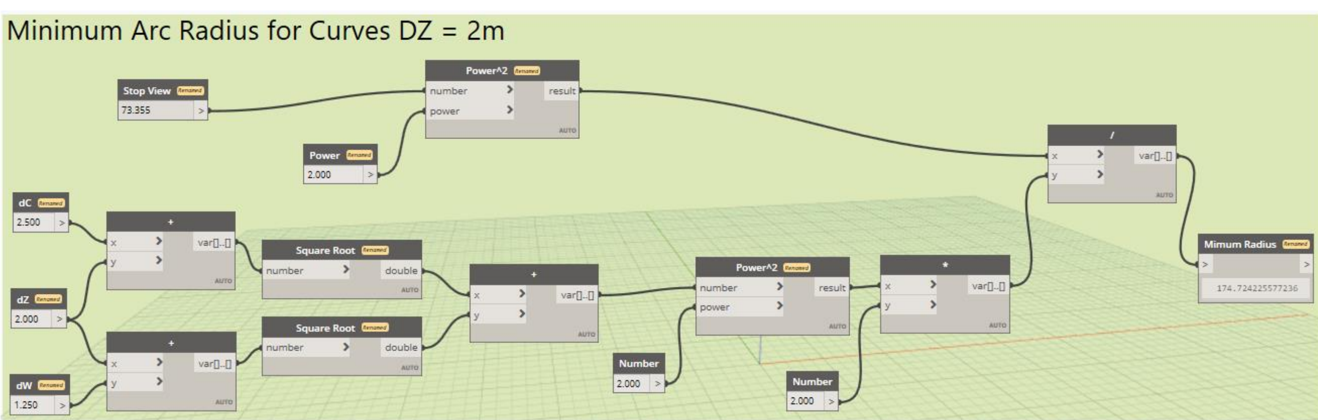


Figure 31 Minimum Arc Radius Calculation for Arc 1 Dynamo Script (dZ=2m)

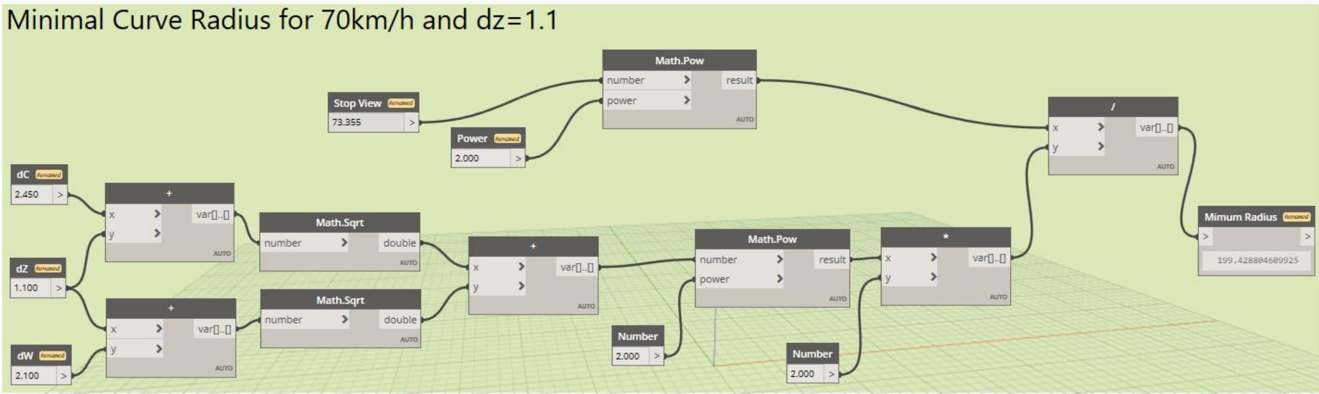


Figure 32 Minimum Arc Radius Calculation for Arc 2 Dynamo Script (dZ=1.1m)