‘Bridge over troubled water’

Design of logistic route after Paddepoelsterbrug broke down

Faculty of Natural Sciences
IE&M Bachelor Thesis
June 2019

Integration Project PTL 47
Ruben Kuik S2929805
Group number 9
dr. ir. J. (Jeroen) Vos (with Karin Ree) &
dr. A.J. Bosch

Table of contents

Disclaimer: *This report has been produced in the framework of an educational program at the University of Groningen, Netherlands, Faculty of Science and Engineering, Industrial Engineering and Management (IEM) Curriculum. No rights may be claimed based on this report. Citations are only allowed with explicit reference to the status of the report as a product of a student project.*

Abstract

The bridge ‘’Paddepoelsterbrug’’ across the canal ‘’Van Starkenborghkanaal’’ connects the city of Groningen to the Reitdiep countryside. The bridge was part of a popular walking and cycling route mainly due to its location in a rural environment. But it was also a direct route to school, work and daily groceries. In 2018 the bridge was crashed, resulting in an ongoing debate between residents and governments about repair, substitution or complete removal of the bridge. This report presents a design of a new logistic route for former users of the Paddepoelsterbrug. This could be replacement of the former bridge, a newly designed bridge or the improvement of current cycle paths for example.

1. Introduction: collapse of the Paddepoelsterbrug

On the 26th of September 2018, a large cargo ship named “Andamento” crashed against the Paddepoelsterbrug. It is not completely clear what exactly happened, because the bridge started to close right at the point where the ship was passing through. These type of cargo ships have a braking distance of about one kilometer, so a collision could not be avoided. However, it is not of interest if there is anyone guilty of this accident because after the collision a new situation has occurred. So either if there would be someone to blame or not, the replacement of the bridge is considered in both scenarios. After the accident, the bridge was directly removed to the side to guarantee the transit of ships. Rijkswaterstaat is not willing to repair and replace the bridge and, from that moment on, the former users of the bridge cannot cross the Van Starkenborghkanaal at the point where the Paddepoelsterbrug used to be.

Currently, Rijkswaterstaat and the provinces of Friesland and Groningen are working on the improvement of the waterway between Lemmer and Delfzijl to make the Northern Netherlands accessible for four-layer container shipping. The replacement of the Paddepoelsterbrug was part of phase 2 of the waterway improvement program. A decision about the future of the bridge was scheduled. This would result in the substitution or the removal of the bridge between 2023 and 2025 because the bridge does not meet all current requirements of Rijkswaterstaat. (Rijkswaterstaat, 2017) However, the collision shifted this decision forward while research has not taken place yet.

At this moment, civil organization ‘Brug terug’ has become rather active since its start in the beginning of 2019. In the meantime, three meetings of Rijkswaterstaat and affected people have taken place. There is much uncertainty about the final solution which could take up to three years according to Rijkswaterstaat. On the other hand, these meetings are meant for discussion about a short-term solution.

Figure 1 provides an overview of the current situation. The former Paddepoelsterbrug is indicated as well as the two adjacent bridges; Dorkwerdbrug and Walfridusbrug.

Figure 1: mapping of current situation

2. **Problem definition: no proper (alternative) route present**

2.1 Detour scenarios

The former users of the Paddepoelsterbrug have to take a detour of minimum 1 and maximum 3 kilometers which requires more time and energy. Approximately 500 to 600 people made use of the bridge on a daily basis. (Pers nieuwsbericht Rijkswaterstaat, 2019) The distance of the detour is dependent on the exact starting point and destination. Three realistic scenarios will be considered to define the problem; a student from Garnwerd who goes to school at Reitdiep College Kamerlingh Onnes, a resident of Adorp who works at Zernike and a tourist who walks the Pieterpad route from Groningen to Winsum.

A student from Garnwerd can be taken as an example because Winsum only offers class 1 to 3 for havo and vwo. This means that every student of this education level in villages like Ezinge, Feerwerd, Garnwerd, Sauwerd and Adorp has to go to Groningen. This can be either Reidiep College Kamerlingh Onnes or any other secondary school, but also Hanzehogeschool Groningen or the University of Groningen. The Paddepoelsterbrug was part of all of their former routes. In total, it can be assumed that approximately 250 students made use of this route based on citizen data (www.allecijfers.nl, 2019). The same story can be applied to a resident of Adorp working at Zernike or any other company located in the north of Groningen. However, it is very hard to say how many people working here are originated in the villages mentioned. The Pieterpad route is annually walked by approximately 30,000 people and it consists of 26 stages. Very generally speaking, one could assume that approximately 1200 people walk the stage Groningen - Winsum annually. Besides these Pieterpad tourist, regular recreationists also made use of the Paddepoelsterbrug.

Figure 2 visualizes scenario 1: a student from Garnwerd who goes to school at Reitdiep College Kamerlingh Onnes. Instead of a traveling distance of 10,1 kilometer which takes 28 minutes, the detour is 11,5 kilometer and takes 34 minutes. The blue line indicates the current route and the red line indicates the former route via the Paddepoelsterbrug.

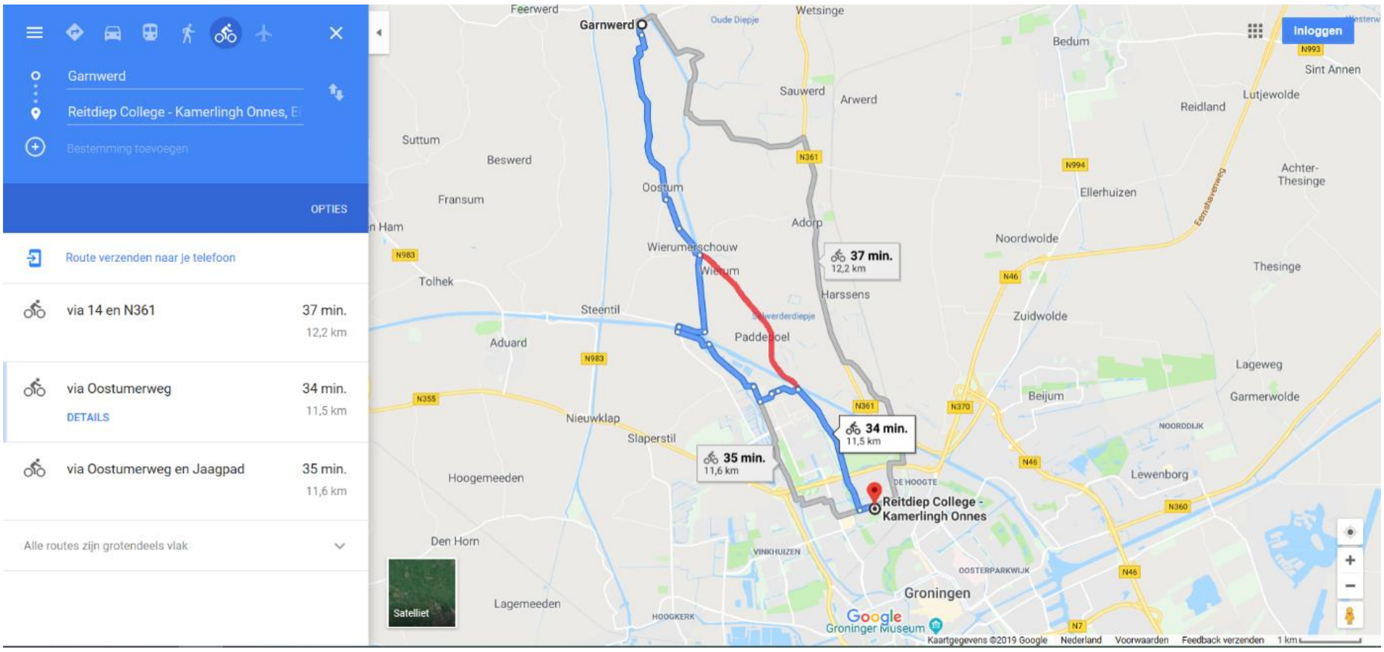

Figure 2: detour Garnwerd – Reitdiep College Kamerlingh Onnes

Figure 3 visualizes scenario 2: a resident of Adorp who works at Zernike. Instead of a traveling distance of 5,7 kilometer which takes 16 minutes, the detour is 7 kilometer and takes 21 minutes. The blue line indicates the current route and the red line indicates the former route via the Paddepoelsterbrug.

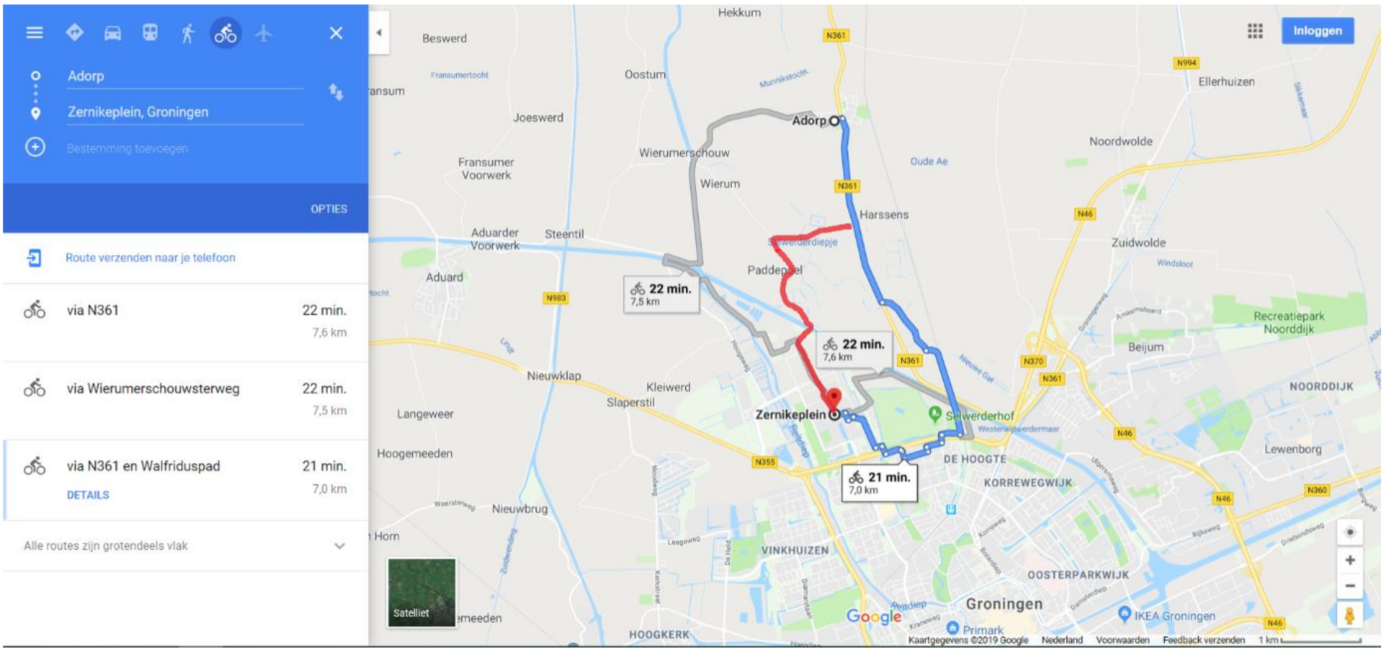

Figure 3: detour Adorp - Zernikeplein

Figure 4 visualizes scenario 3: a tourist who walks the Pieterpad route from Groningen to Winsum. The traveling distance is increased by approximately 0,9 kilometer (Pieterpad, 2018) and requires around 10 minutes extra time. The red line indicates the original route and the green line indicates the detour in figure 4 below.

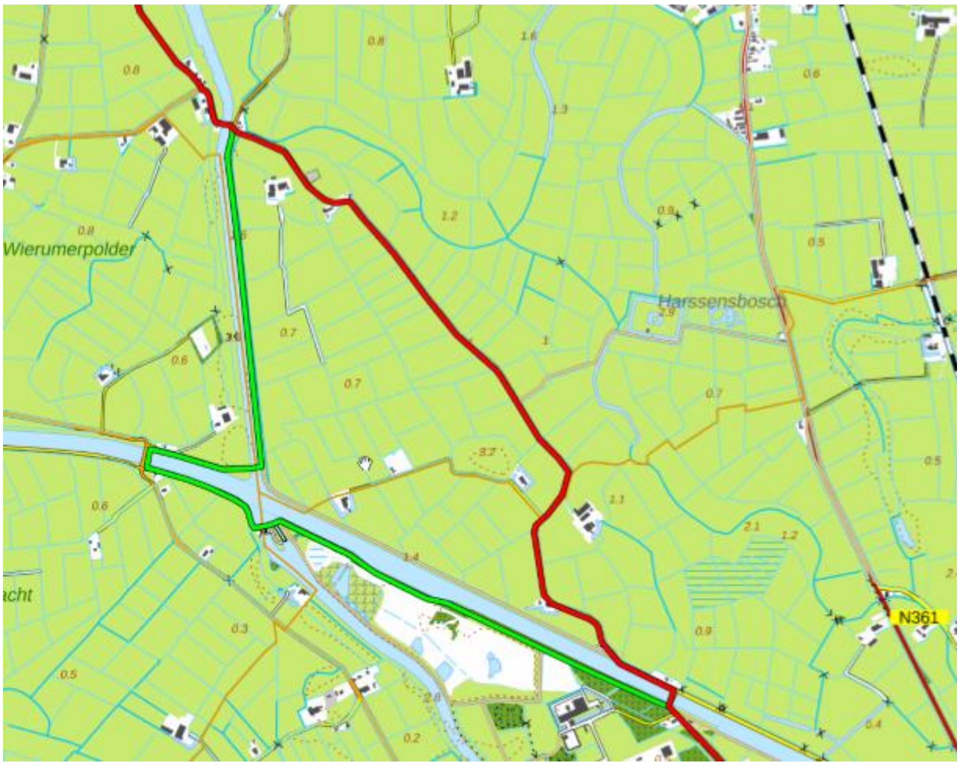

Figure 4: detour Pieterpad Groningen - Winsum

2.2 Detour disadvantages

Besides the required extra time and energy, people mention the fact that the detour would be dangerous and unattractive. Arguments are; the fact that cycle paths are narrow or unpaved, there are no street lights everywhere or there is no bicycle path present at all causing cyclists to cycle on the normal road. As an example of unattractiveness one can look at figure 4 where the detour is just one straight path parallel to a canal instead of the historical route along old farms. Additionally, users of the detour experience a dangerous crossing of the Tjardaweg and Winsumerweg N361, which is a rather busy road, especially during rush hour. On top of that, this crossing is located in a bending of the road. This particularly worries parents with children who have to take this route to school.

Summarized disadvantages of detour:

- Cycle paths are narrow or unpaved
- No street lights
- Some parts no bicycle path present at all
- Dangerous crossing Tjardaweg and Winsumerweg
- Unattractive route

In conclusion, the problem is defined as:

“Former users of the Paddepoelsterbrug do not have a proper (alternative) route since it broke down.’’

3. **Stakeholder analysis**

3.1 Problem owner

The problem owner is **civil organization 'Brug terug'**, which started last January. This organization represents a group of people who are affected by the collapse of the bridge. Until this moment, they have received about 900 emails of people who are directly or indirectly involved. Everyone is free to email, so probably not all of these people have the same interest. It can be stated that most of them are former users of the Paddepoelsterbrug. In addition, organizations like the 'Fietsersbond' (Fietsersbond, 2019) and 'stichting Groninger landschap' (GIC, 2019) support 'Brug terug'.

As mentioned above, the civil organization 'Brug terug' consists of different subgroups, which are all affected in a different way. Some may be more affected than others but all of them more or less have the same interest. Therefore, they are considered as one problem owner and thus stakeholder. There are roughly four subgroups considered and even the members of the supporting organizations can be subdivided. An overview of the subgroups and their particular interest can be seen in table 1 below.

Civil organization 'Brug terug'		
Subgroup	**Description**	**Interest**
Local residents	Residents of villages such as Ezinge, Feerwerd, Garnwerd, Sauwerd and Adorp. Daily use of bridge; mainly used for commuting to work and study in direction towards city of Groningen. Especially the distance to Zernike has become much greater.	This subgroup is most affected and has the highest interest of a proper route to city of Groningen. However, they have a strong preference for replacing the bridge instead of improving an alternative route.
Local recreationists	Nature lovers from the city of Groningen who enjoy area of Reitdiepdal, described as varied and culturally and historically attractive, by bike or on foot.	This group lost direct access to the Reitdiep area.
Tourists	Paddepoelsterbrug was part of the Pieterpad, a touristic route from Maastricht up to Pieterburen. The Pieterpad attracts around 30,000 tourists annually.	A few extra kilometers will probably not be a big issue for active tourists of the Pieterpad. However, their interest in this case is the fact that the Pieterpad route shifted to a more dangerous and unattractive route.
Small economy	Tourists are related to small touristic stays, such as Bed & Breakfasts or small camping sites near the bridge.	They already experience a decrease in bookings because tourists will not take the same road since the route of the Pieterpad has shifted.

Table 1: overview of civil organization 'Brug terug'

3.2 Role of Rijkswaterstaat and Municipality of Groningen

The second stakeholder is **Rijkswaterstaat**. They are responsible for canals in the north of the Netherlands and it is in their interest that as many ships as possible can go through the Van Starkenborghkanaal as fast as possible while safety of bridges can be guaranteed. Because of an increase of bigger container ships the provinces of Friesland, Groningen and Rijkswaterstaat are working on improving the waterway between Lemmer and Delfzijl (Hoofdvaarweg Lemmer Delfzijl, sd). The aim is to ensure that these larger ships (class Va: ships of 110 meters long, 11,4 meters wide, a draft of 3 meters and a loading height of 9,1 meters) can sail smoothly and safely through this waterway. Since the old bridge does no longer meet all current requirements in terms of transit and safety, Rijkswaterstaat is not willing to replace the old bridge (Rijkswaterstaat, 2019). They mention the fact that the Paddepoelsterbrug in its former state forms a bottleneck in the Van Starkenborghkanaal with an increasing intensity of bigger Va-ships.

Current requirements which former Paddepoelsterbrug could not meet (Rijkswaterstaat, 2019):

- Firstly, a minimum width of 54 meters without center pillar is required in order to ensure a two-lane passage of large Va-ships. Currently, the passage is only 22 meters.
- Secondly, a moveable bridge must be at least 4 meters high while the former bridge was only 1 meter high.
- Finally, the Paddepoelsterbrug was too poorly visible and because it was a swing bridge the sailing route was not in the middle of the passage causing an asymmetrical underwater profile.

The third stakeholder is **Municipality of Groningen**. They are responsible for the accessibility and satisfaction of their residents. Therefore, 'Brug terug' expects the Municipality of Groningen to join their side. On the other hand, this stakeholder is responsible for the management of bridges and directly involved with a decision of Rijkswaterstaat. Where Rijkswaterstaat is responsible for the bridge itself, the Municipality is responsible for the road laying on top of the bridge. Also, they are both government parties which ensures some collaboration. This corresponds to their official statement:
"Rijkswaterstaat and the municipality of Groningen have decided to postpone the recovery by one year and to work directly on a structural solution" (Gemeente Groningen, 2019).

In conclusion, this stakeholder has a broad interest but limited power. Both the limited amount of power and level of involvement become clear in the letter of the Mayor and City Council Members of Groningen (Groningen, 2019). In this letter most answers rely on the decision of Rijkswaterstaat.

3.3 Interrelationships between stakeholders

Table 1 described the subgroups of civil organization ‘Brug terug’ and their interest. Table 2 below provides an overview of all considered stakeholders and their particular goal which is converted into a KPI (Key Performance Indicator).

Stakeholders´ goal and KPI		
Stakeholder	**Goal**	**KPI**
Civil organization ‘Brug terug’	Currently, their goal is the replacement of an equivalent bridge with respect to the former Paddepoelsterbrug. Obviously, if this cannot be realized, they are interested in the improvement of an alternative route.	- Time to cross Van Starkenborghkanaal - Safety of route - Attractiveness of route
Rijkswaterstaat	Ensure fast and safe transit of (large Va-) ships while safety of bridges can be guaranteed. Simultaneously, they have a limited budget in terms of costs.	- Costs - Transit of ships - Safety of waterway; both for ships and users of possible bridge
Municipality of Groningen	Ensure accessibility of city and citizen satisfaction while collaborating with Rijkswaterstaat	- Accessibility/citizen satisfaction: required time to city center and vice versa - Should fit into landscape - Solution should be in consultation with Rijkswaterstaat

Table 2: overview goals and KPI’s of stakeholders

Most notably, civil organization ‘Brug terug’ and Rijkswaterstaat are in an economic conflict due to different interest regarding costs. Currently, Rijkswaterstaat is not willing to replace the bridge because it is not safe and a similar bridge which could meet all requirements will be expensive.

Most people within ‘Brug terug’ can be described as pluralist participants in relation with Rijkswaterstaat. They share the same basic interests, which is a proper route, in terms of safety and travel time, to cross the Van Starkenborghkanaal. Although their values and beliefs differ, Rijkswaterstaat is more concerned with ships passing through the waterway while people united in ‘Brug terug’ are focused on their own personal disadvantage after the bridge has collapsed. In conclusion, space for discussion needs to be made and even a conflict could take place. If this is done, and all feel that they have been involved in the decision-making, compromises can be found. Soft system thinking approach is most appropriate in this situation (Jackson, 1984).

However, some people within the civil organization ‘Brug terug’ have more of a coercive relationship towards Rijkswaterstaat. This means they have few interests in common and would hold conflicting values and beliefs. For instance local residents whose only solution would be the replacement of the former bridge. Compromises will not be possible and, therefore, decisions are taken based on who has the most power (Jackson, 1984).

It should be mentioned that the term power is not completely suitable because Rijkswaterstaat is the decision-making key stakeholder. Nevertheless, they have a certain responsibility towards society which makes decision-making power on its own not sufficient. They should somehow substantiate why a certain decision has been made.

4. **Design scope**

The function of the design scope is to demarcate what is included and what is excluded in this design research. Short-term solution and indirect economic damage are out of scope of the project. This frames the system and the goal which will be set up afterwards.

4.1 Short-term solution excluded

Currently, a short-term solution is being discussed during the information meetings between Rijkswaterstaat and ‘Brug terug’ because the long-term solution can take up to three years. However, this short-term solution is out of scope because the focus is probably on a solution that is quickly achievable, which is not the goal of this project in particular. Obviously, input from these meetings about a short-term solution is included in the design since it may result in a structural solution.

4.2 Indirect economic damage excluded

As mentioned in the stakeholder analysis, small economy is also affected by the broken bridge. Small touristic stays such as Bed & Breakfasts or small camping sites near the bridge already experience a decrease in bookings because tourist must take a detour. This design project will only focus on the logistic point of view. The trade-off between all users and a few affected touristic stays is very hard to determine and would make this project too broad. Therefore, indirect economic damage is excluded. However, it should be mentioned that this subgroup is very small but it has a good negotiating position because they are directly affected in terms of revenue. They could not anticipate on the disappearance of the bridge due to the unforeseen event of the collapse. Therefore, in case the final design solution has proven that local economy is still affected negatively it may be reasonable that this group would be financially compensated to some extent.

5. **System defined as logistic route**

By a system approach of the problem it becomes clear what is inside and outside the boundaries of the system and which parameters are related. There is much information present at this point and the system definition should indicate and visualize the main aspects.

To start, a route is defined as ´´a way taken in getting from a starting point to a destination´´. By defining the system as a logistic route its performance related to its users can be measured. In this way logistic means the transport of people in general who make use of the route. So this can either be by car, by bicycle or by foot.

The system is defined as the logistic route across the Van Starkenborghkanaal near the point where former users of the Paddepoelsterbrug could cross the canal. It is defined as the logistic route because logistics is the field of interest and the performance of a route regarding its users can be analyzed. This route used to be the bridge but, because it broke down, a new situation has arisen. Therefore, the new logistic route could be a new bridge but also an alternative route, for instance the improvement of current cycle paths. The input are the former users of the Paddepoelsterbrug themselves, independent whether they travel by car, by bicycle or by foot. Generally, this input can be described as people who have to cross the Van Starkenborghkanaal because it is part of their route. All of them leave at a their own starting point and go through the system to end at their particular destination. Therefore, the output is defined as people arrived at their destination.

Because the system is the logistic route, there are some boundary conditions to the system. The design of a logistic route should at least be safe (both for ships and users of bridge) and a minimum transit of ships should be guaranteed. In other words, these requirements are unconditionally and should be met regardless of other design parameters. These design parameters are a result of the discussed KPIs and will eventually decide the optimal route while the boundary conditions are met. In conclusion, the system is bound in terms of safety and minimum transit of ships.

The described system is visualized in figure 5 below.

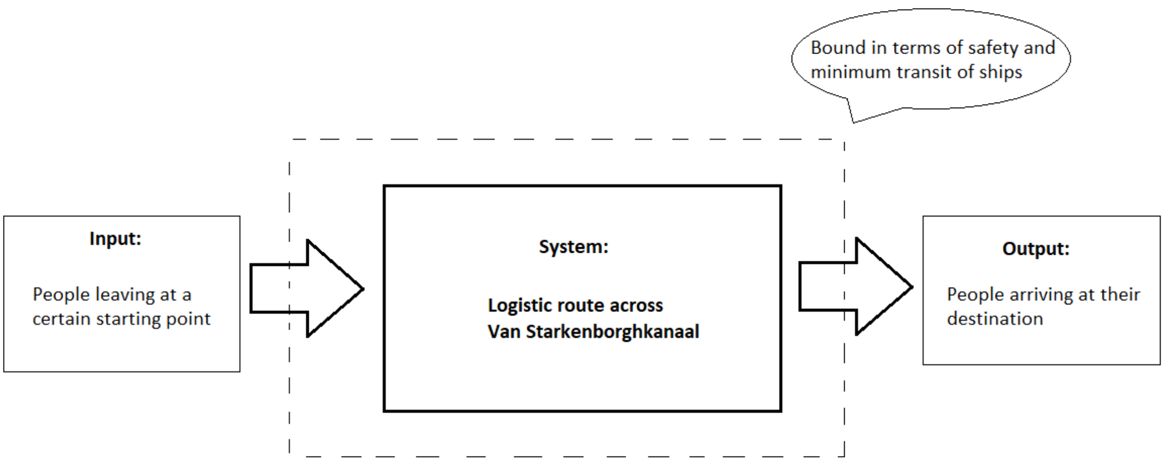

Figure 5: visualization of system

6. Goal: the design of a proper (alternative) route

To start, three cycles of Hevner can indicate the root of the problem whether it is located in the relevance, the design or the rigor cycle. The relevance cycle forms the connection between a problem and a need/demand from a real case. This is also where the Paddepoelsterbrug case is located. Whilst the problem became clear during the problem definition, stakeholder analysis and system definition, the problem is shifting towards the design cycle. The design cycle has an input of requirements which are arranged from the problem definition phase. Inside the design cycle, design questions will be identified and answered to end up with a design. Finally, this design should be brought back into the relevance cycle to undergo field testing. In this case field testing is the validation of the optimal route proposal. Validation consists of approval of Rijkswaterstaat and the Municipality of Groningen because the management of the route is their responsibility. On top of that, boundary conditions should be met and civil organization ‘Brug terug’ should understand why this is the optimal route to avoid further escalation. The validation will be elaborated on in chapter 11. The last cycle contains new research and will not be used in this project because it is assumed that all necessary research already has been done (Hevner, 2007).

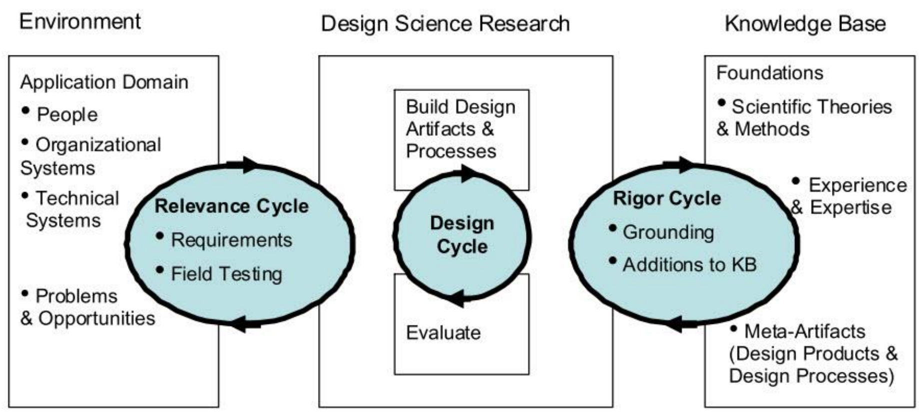

Figure 6: cycles of Hevner

The system boundaries, which are described in the last chapter, should be met unconditionally. However, there are more design parameters which are measurements of the system performance. For instance, travel time and attractiveness of the route. Here will be elaborated on in chapter 10.1. The best design solution will be the one with an optimized combination of design parameters after the boundary conditions have been met.

Therefore, the goal is defined as:
“To design a logistic route with optimized performance for former users of Paddepoelsterbrug, considering all relevant design parameters while boundary conditions (safety and transit of ships) are met.’’

This goal is SMART; specific, measurable, achievable, relevant and time bound. A period of one year is considered to be reasonable for the realization of a designed route. However, this will be assessed in 10.3 as a parameter: time for realization. The optimal solution should be validated, outsourced and finally be realized. The goal can be achieved by building a new bridge or creating an alternative route. After research has been done and a design has been made, all stakeholders should be satisfied in their personal interest in order to end the ongoing discussion regarding the Paddepoelsterbrug. Figure 7 below visualizes the root of the problem, the relationship between stakeholders, the location of this IP project and the goal.

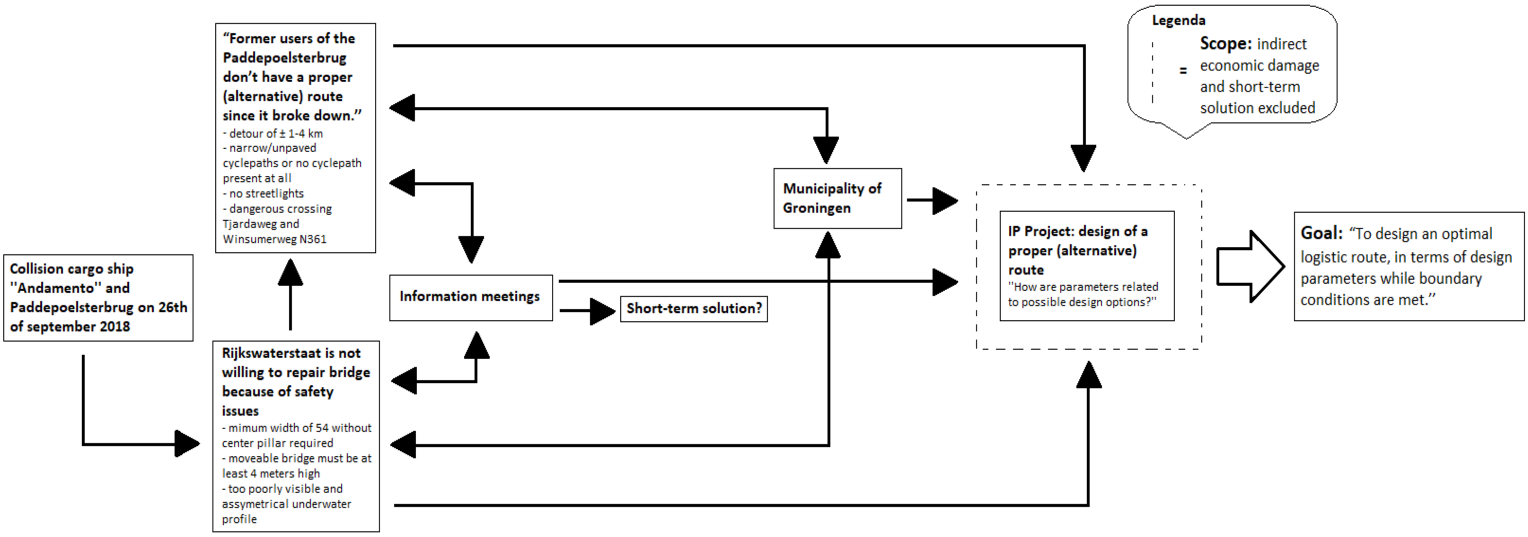

Figure 7: structure of project goal related to problem

7. Design questions: how are parameters related with respect to design options?

Where the goal statement is focusing on the final solution, the design questions are the start of working towards this solution. The following design questions are set up and divided into two parts which will later be referred to as design orientation and design selection.

Design questions 'design orientation':

- What are possible design options for a logistic route for former users of Paddepoelsterbrug?
- Which design options can meet boundary conditions of the system?

Design questions 'design selection':

- What are the different design parameters and their relative weight?
- What are the scores of the remaining possible design option on the design parameters relative to each other?

Two main aspects should become clear after answering the design questions. The first part of research concerns the set of possible design solutions and which can meet the boundary conditions. The second part of research concerns the importance of different design parameters and the performance of the remaining design option on these parameters. The scores for different design options will be calculated with the help of a method called AHP (Analytical Hierarchy Progress). In the end, this will result in an optimal design solution. More on this method in general will follow in chapter 8.4 and its application will follow in chapter 10.

8. Methods and tools to design a proper (alternative) route

8.1 Interviews

To start, background information is collected by doing interviews, problem definition, system definition and stakeholder analysis. It becomes clear where the exact problem is located and how stakeholders are involved. The conversation with stakeholders has mainly taken place via email, but also a few calls have been made. Each two weeks civil organization 'Brug terug' sends a newsletter via email which contains updates and documents received or sent by the organization. Some of these documents are formal and some are informal. Resulting in a large collection of (background) information. On the 26th of March 2019, a meeting between Rijkswaterstaat and people from civil organization 'Brug terug' was attended. Afterwards, several people have been spoken to and this emphasized how involved people, especially local residents, are. Unfortunately, members of 'Brug terug' did not want to contribute to a survey about the inconveniences of a detour.

8.2 Literature

In the first place literature will be used to collect information about parameters which have an influence on the performance of a route. Parameters will be distinguished in boundary conditions and design parameters according to their level of importance. Subsequently, literature will be used to weigh the different design parameters according to the interest of different stakeholders.

8.3 KPI (Key Perfomance Indicator)

Throughout the stakeholder analysis, different KPIs were described. By doing so, specific goals and interests became clear. In the system description boundary conditions are separated form design parameters. Afterwards, both boundary conditions and design parameters of influence were found and converted into a design question. This step of setting up a design question is important because it forms a bridge between the problem and the start of working on a design solution.

8.4 AHP (Analytical Hierarchy Process)

The optimal design solution is determined with AHP, Analytic Hierarchy Process. This method helps decision makers find one that best suits their goal and their understanding of the problem rather than prescribing a "correct'' decision. Firstly, the decision problem is decomposed into sub problems which can be analyzed independently. This is done with the help of KPIs which were described before. Afterwards different parameters can be seen as different sub problems. Once this is done, the different design parameters are compared to each other to determine their importance. AHP converts these evaluations to either numerical values that can be processed and compared over the entire range of the problem. In the end, an optimal design solution will be the result (Knickel). This method forms the basis of the calculation towards the relative weight of all design parameters. Afterwards, it will determine the optimal solution in table 6, chapter 10.3.

8.5 V-Model

The v-model is mainly used for software development, however, it can also be applied to the validation of a design. The purpose of this method in general is to show designing steps over time and the various engineering levels. It starts with configuration on modular level and ends with verification and validation of the complete system. In this project it will contribute to the validation of a design. Meaning that the optimal design will not only be assessed on the final requirements but on all phases in the project definition. Hereby, it should satisfy the goal statement in order to solve the problem defined (Sauser, 2010). This method is visualized in figure 8 below.

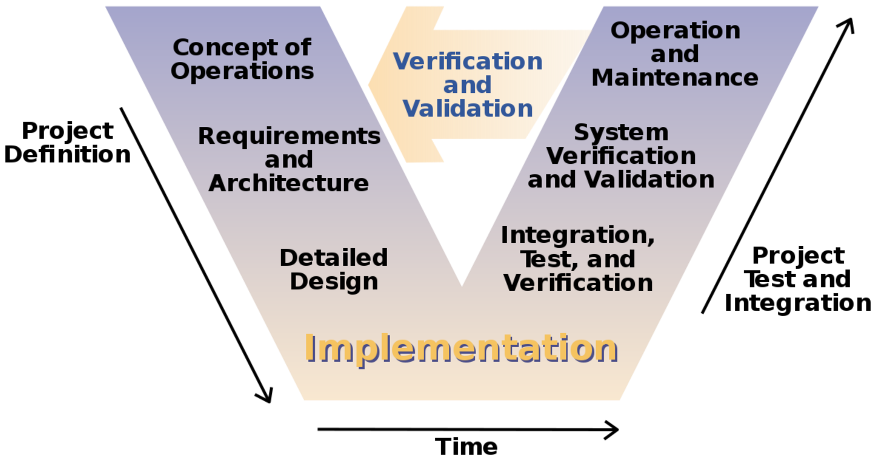

Figure 8: V-Model

9. Design orientation

9.1 Possible design solutions

In this design project not all possible design solutions will be determined because this has been done before. Besides the fact that possible design solutions are already available, the research of all possible design solutions from the start would make this project too broad.

In 2015 a plan study has been done by Rijkswaterstaat. The Paddepoelsterbrug is part of phase 2 of the improvement of the waterway between Lemmer and Delfzijl (MIRT, 2019). In the plan study 4 promising cases have been assessed:

1. Low swing bridge on current location
2. Low lift bridge on current location
3. Lift bridge with 4 meters clearance height west of current location
4. Table bridge with 4 meters clearance height east of current location

The possible design solutions above will be complemented with the latest alternative options submitted by Rijkswaterstaat and civil organization 'Brug terug':

5. Repair of former Paddepoelsterbrug
6. High bicycle bridge with 9,1 meters clearance height
7. Improvement of alternative route (cycle paths towards adjacent bridges)

In total seven possible design solutions will be assessed in this project. After the design scoring phase, it could well be that a new design is created based on particular scores of considered design solutions. In other words, an optimal design could be a combination of highest scoring design solutions.

9.2 Boundary conditions check

As discussed in chapter 5 the boundary conditions are the safety of the logistic route (both for users of route as well for ships using the canal) and a minimum transit of ships. If these conditions are not met for a specific design, then this design would never be optimal. So, the first step concerns checking possible design solutions whether they could meet the boundary conditions.

Both boundary conditions form the basis of requirements set by Rijkswaterstaat. This is logical because a minimum transit of ships while safety can be guaranteed is the main interest of Rijkswaterstaat. Safety in this case is applied to both users of a possible bridge as well as ships passing the bridge. Minimum transit is not an exact number but it also based on the requirements set up by Rijkwaterstaat. Additionally, both boundary conditions also have a correlation to each other. For instance, a minimum height of a bridge ensures safety because the bridge does not have to open for every ship, but it also ensures that more ships can pass the canal because of less waiting time. The requirements of Rijkswaterstaat can be measured rather than terms as safety and minimum transit of ships. Therefore, the boundary conditions will be assessed in the form of requirements set by Rijkswaterstaat.

Requirements of bridge van Starkenborghkanaal class Va:

- Span of 54 meter across canal to ensure two-lane passage
- Symmetric underwater profile
- Height of:
  - 9,1 meters for a fixed bridge
  - 4 meters for a moveable bridge

Figure 9 below provides a visualization of the boundary conditions check. It works similar to a filter. As can be seen only possible design solutions 3, 4, 6 and 7 meet the requirements of Rijkswaterstaat. Design solutions 1 and 2 do not meet the height requirement while design solution 5, which is the repair of former Paddepoelsterbrug, fails all three requirements. The latter already became clear during the problem definition. Otherwise, there would probably not be a problem at all.

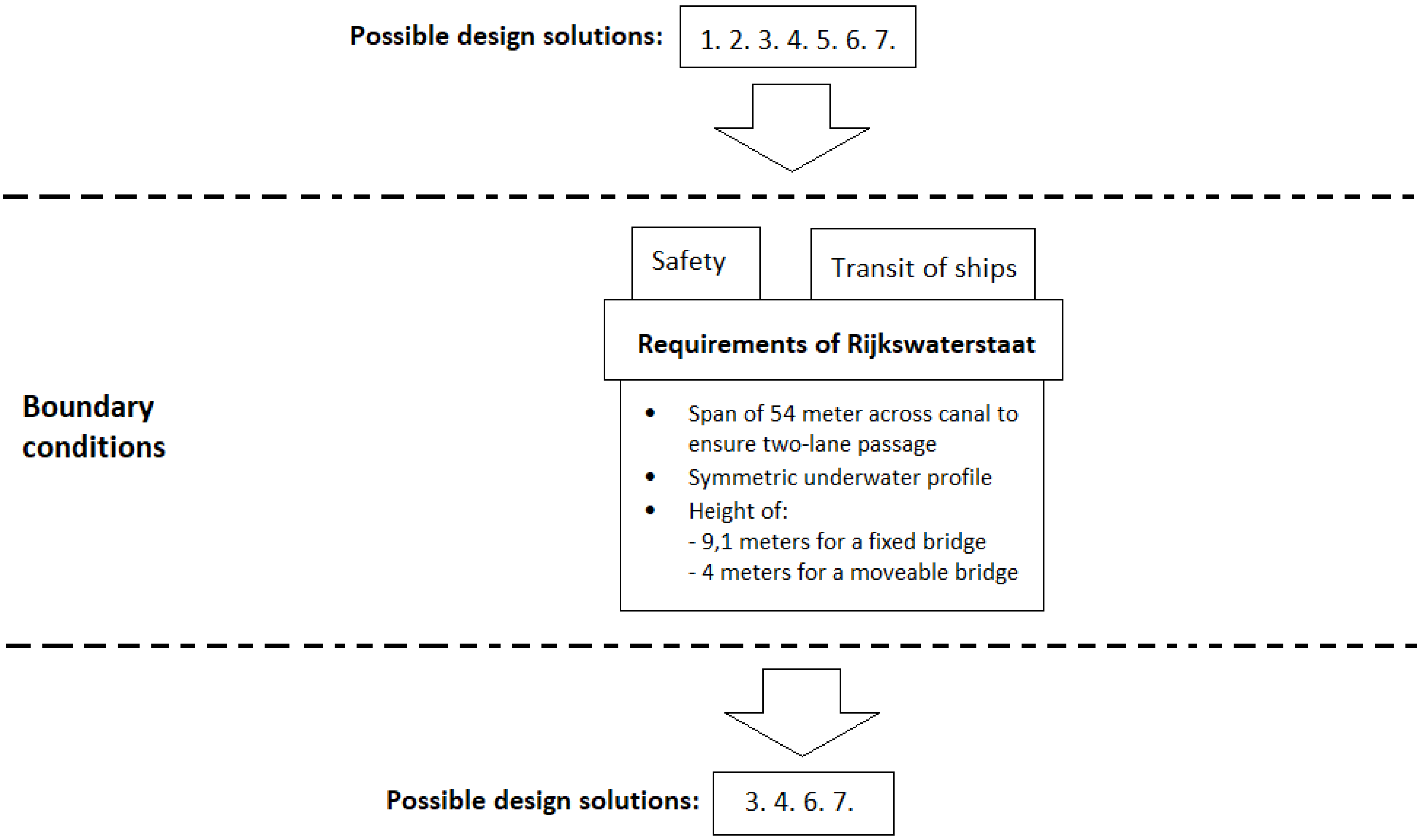

Figure 9: boundary conditions check

10. **Design selection**

10.1 Selection of design parameters

To start, all parameters which could be of interest will be considered. These parameters are a result of the described KPIs of different stakeholders in chapter 3.3 and experienced by cycling the routes of the 3 scenarios described in chapter 2.1.

The following design parameters will be assessed:

1. Costs
2. Fit into landscape
3. Transit of recreational shipping
4. Transit of cargo shipping
5. Travel time cyclist/walker
6. Travel time motorized destination traffic
7. Attractiveness for users
8. Unattractiveness for shortage traffic
9. Time for realization

Transit of ships is already an entry requirement. Moreover, the transit of ships is an important parameter. Therefore, transit of ships will be considered because even if it is sufficient it will differ for different design solutions. Transit of ships is divided into two separate parameters; recreational shipping and cargo shipping. For instance, there are lower bridges in particular where recreational ships could pass while largo cargo ships could not.

The route to be designed is intended for bicycles and walkers in the first place because they will mostly make use of it. However, there is a small number of motorized destination traffic which also made use of the Paddepoelsterbrug. Therefore, it is considered as one of the design parameters as well as unattractiveness for stealth traffic, which should be avoided.

10.2 Relative weight of design parameters

The AHP method will be used to determine the relative weight of each of the nine parameters (Goepel, 2013). The first step is to compare each parameter with each other and indicate which parameters are more important; this can be seen in the column ''A or B'' in table 3. The next step is to rate the intensity of importance with a number between 1 and 9, an overview of the meaning of these numbers can be seen in table 4. Both comparison and importance of parameters are based on previous findings in the problem definition, chapter 2, stakeholder analysis, chapter 3, and information available in documents submitted by Rijkswaterstaat and 'Brug terug'. Unfortunately, Rijkswaterstaat or ´Brug terug´ were not willing to participate in the rating of the design parameters.

		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-9)
1	2	Costs	Fit into landscape	A	2
1	3		Transit recreational	A	3
1	4		Transit cargo shipping	B	3
1	5		Travel time	B	2
1	6		Travel time destination	A	5
1	7		Attractiveness for users	B	2
1	8		Unattractiveness	A	5
2	3	Fit into landscape	Transit recreational	A	3
2	4		Transit cargo shipping	B	5
2	5		Travel time	B	5
2	6		Travel time destination	A	2
2	7		Attractiveness for users	B	4
2	8		Unattractiveness	A	5
3	4	Transit recreational shipping	Transit cargo shipping	B	5
3	5		Travel time	B	5
3	6		Travel time destination	A	3
3	7		Attractiveness for users	B	4
3	8		Unattractiveness	A	2
4	5	Transit cargo shipping	Travel time	A	2
4	6		Travel time destination	A	5
4	7		Attractiveness for users	A	2
4	8		Unattractiveness	A	5
5	6	Travel time walker/cyclist	Travel time destination	A	5
5	7		Attractiveness for users	A	3
5	8		Unattractiveness	A	5
6	7	Travel time destination traffic	Attractiveness for users	B	5
6	8		Unattractiveness	A	2
7	8	Attractiveness for users	Unattractiveness	A	3
1	9	Costs	Time for realization	A	2
1	10				
2	9	Fit into landscape	Time for realization	A	2
2	10				
3	9	Transit recreational shipping	Time for realization	B	2
3	10				
4	9	Transit cargo shipping	Time for realization	A	5
4	10				
5	9	Travel time walker/cyclist	Time for realization	A	5
5	10				
6	9	Travel time destination traffic	Time for realization	A	2
6	10				
7	9	Attractiveness for users	Time for realization	A	2
7	10				
8	9	Unattractiveness shortage traffic	Time for realization	B	1
8	10				

Table 3: comparing of criteria

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values		

Table 4: intensity of importance criteria

With the AHP method, given values in table 3 will result in a numerical value of relative weight for each of the nine parameters including an absolute error. An overview can be seen in table 5 and graphically in figure 10.

	Criteria	Relative weigth	+/-
1	Costs	11,6%	3,8%
2	Fit into landscape	7,6%	3,8%
3	Transit recreational shipping	4,6%	2,7%
4	Transit cargo shipping	26,3%	8,7%
5	Travel time walker/cyclist	22,9%	9,3%
6	Travel time destination traffic	4,1%	2,2%
7	Attractiveness for users	15,0%	6,9%
8	Unattractiveness shortage traffic	3,1%	1,3%
9	Time for realization	4,7%	2,0%

Table 5: relative weight of each criteria

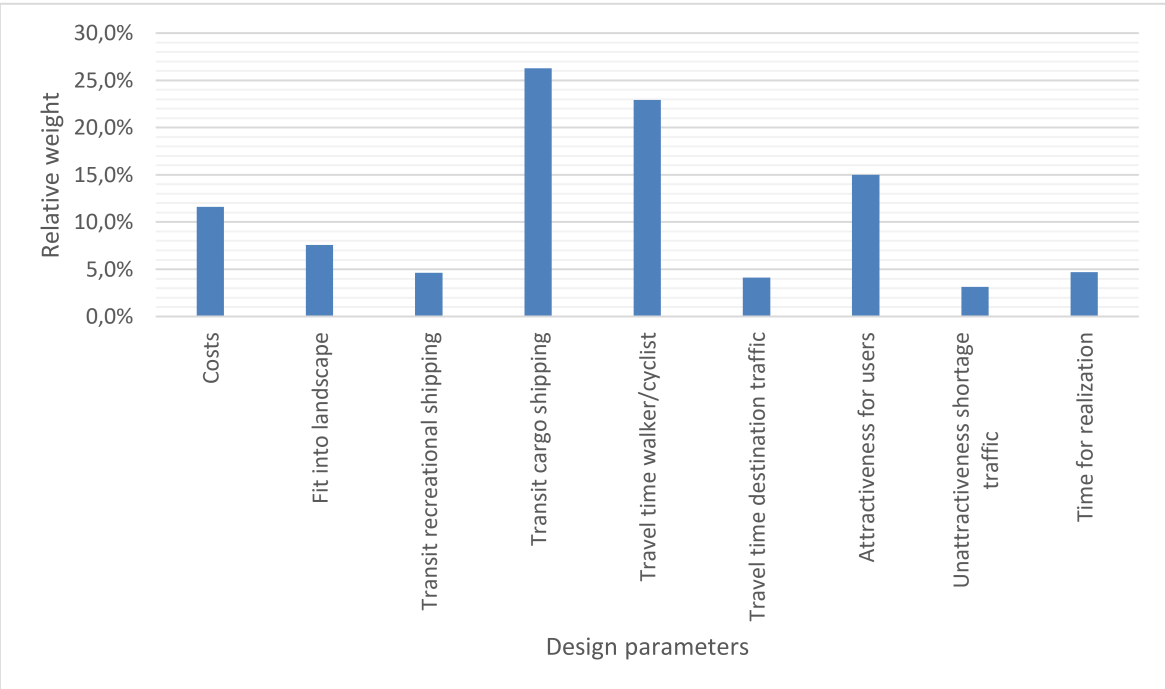

Figure 10: graphic relative weight and error of parameters

10.3 Design scoring

All possible design solutions are scored against the design parameters. This scoring will either be a ++, a +, a 0, a - or a -- depending on the performance of the possible design solution. All possible design solutions are compared to the current situation with no proper (alternative) route; therefore, all values in this column are 0. Additionally, the former situation with the Paddepoelsterbrug is assessed to visualize the relative improvement of each design solution. However, it should be mentioned that this design solution did not pass the boundary conditions check and will eventually never be the optimal design solution.

The relative weight of each parameter can be seen in the left column and is discussed in chapter 10.2. Each relative weight is multiplied with the corresponding score (--, -, 0, +, ++) to end up with a final score in the bottom row. Later on, it will be determined if a newly designed combination of possible design solution will lead to an even higher final score.

The final scoring can be seen in table 6 below and an explanation on how each score was determined is provided underneath.

Design criteria				**Possible design solutions (after boundary check)**					
Relative weight	**Design parameters**	Current situation: no proper (alternative) route present	Former situation: Paddepoels-terbrug still present	**3.** Lift bridge with 4 meters clearance height west of current location	**4.** Table bridge with 4 meters clearance height east of current location	**6.** High bicycle bridge with 9,1 meters clearance height	**7.** Improvement of alternative route (cycle paths towards adjacent bridges)	→	Newly designed combination of possible design solutions?
11,6%	Costs	0	++	+	+	++	++	→	~
7,6%	Fit into landscape	0	0	-	-	--	0	→	~
4,6%	Transit of recreational shipping	0	-	0	0	0	0	→	~
26,3%	Transit of cargo shipping	0	--	-	-	0	0	→	~
22,9%	Travel time cyclist/walker	0	++	++	++	++	0	→	~
4,1%	Travel time motorized destination traffic	0	++	++	++	0	0	→	~
15,0%	Attractiveness for users	0	++	++	++	++	+	→	~
3,1%	Unattractiveness for shortage traffic	0	-	-	-	0	0	→	~
4,7%	Time for realization	0	-	--	--	-	-	→	~
		↓	↓	↓	↓	↓	↓		↓
Final score		0	0,422+	0,492+	0,492+	**0,791+**	0,335+		~

Table 6: Scoring of design solutions

Costs:
As costs is one of the design parameters and the current situation is compared with other design solutions, the current costs should also be determined. It becomes clear that there will be no additional costs if the current situation is maintained. However, costs in the form of potential loss can be determined. Each former user of the Paddepoelsterbrug is required to take some extra time for his or her way to school or work for example. This required extra time can be converted into costs; vehicle loss hours. This is a known number for vehicles and is used for file calculations. Unfortunately, the exact costs for cyclist are not known.

According to the Ministry of Infrastructure and Environment, a vehicle loss hours costs on average €15,64 (Ministerie van Infrastructuur en Milieu). This results in the following calculation: 500 (passages per day) * 5 minutes (required extra time on average) = 2500 minutes = 41,67 hour * €15,64 (cost vehicle loss hour on average) = €651,67 per day.

In reality this number will be lower because the bridge was mostly used by cyclist and walkers and not by cars. Additionally, transportation of goods comes with the highest costs. The Paddepoelsterbrug does not enable transport of goods by trucks which is the case on regular highways. Furthermore, tourists may choose another route but in the end this will not result in extra costs because they spend their time somewhere else. Local economy such as small camping sites or Bed & Breakfasts in the neighborhood of the Paddepoelsterburg, could be affected by this. However, this is outside the scope of this project and they possible could be financially compensated, more on this in chapter 4.2.

Besides the potential loss occurring in the current situation, each possible design solution will come with building and maintenance costs. Currently build bridges of Rijkswaterstaat have a lifespan of at least 100 years (Rijkswaterstaat, sd). There is a budget available of 45 million for three bridges across the Van Starkenborghkanaal; the Paddepoelsterbrug, the Gerrit Krol-brug and a new bridge which is not build yet (Gemeente Groningen, 2018). It will be assumed that an originally calculated budget of 15 million is available. However, the less budget is needed the better the design solution will be. Dividing the maximum budget of 15 million by its lifespan of 100 years and 365 days results in costs of €410,96 per day compared to €651,67 for the current situation. This means that a possible design solution which does not exceed the budget of 15 million is a better solution in terms of costs. Therefore, all possible design solutions will be scored positive compared to the current situation. The relative more expensive design solution 3 and 4 are scored with + while design solution 5, 6 and 7 are less expensive and scored with ++.

Fit into landscape:
Fit into landscape concerns the esthetics of a bridge and the maximum slope for cyclists to cross the bridge. The height of a bridge has influence on the view of a landscape while the slope of a bridge will shape the landscape. Therefore, design solution 5 and 7 will have the least influence on the environment. This is in contrast to design solution 6, which has a clearance height of 9,1 meters. It requires a relative longer slope and it might be the case that surrounding trees have to be removed. In conclusion, design solution 5 and 7 are scored with 0, 3 and 4 with - and 6 with --.

Recreational shipping:
Recreational shipping concerns ships lower than 4 meters. They will be able to pass each possible design solution without any waiting time. This is in contrast with the former situation; the Paddepoelsterbrug was only 1 meter high and almost all ships had to wait. Therefore, design solution 5 is scored with - and all other design solution 0.

Cargo shipping:
Cargo shipping concerns ships higher than 4 meters. They will be able to pass the high bicycle bridge because it has a height of the required 9,1 meters. Obviously, the same counts for design solution 7 without a bridge. The former Paddepoelsterbrug does not enable two lane passage while design solution 3 and 4 do. However, all large cargo ships have to wait for the bridge to open. In conclusion, the former Paddepoelsterbrug is scored with --, design solution 3 and 4 with - and 6 and 7 with 0.

Travel time walker/cyclist:
The travel time for a cyclist or a walker will significantly decrease in case a bridge will be realized. There will be no absolute significant decrease in case of the improvement of alternative route. Therefore, design solution 3, 4, 5 and 6 are scored with ++ and design solution 7 is scored with 0.

Travel time motorized destination traffic:
Motorized destination traffic will only benefit if design solution 3, 4 or 5 will be realized because the other design solutions make car traffic impossible. These design solutions will be scored with ++ and the other ones with 0.

Attractiveness for users:
Attractiveness for users will mostly increase if a bridge will be realized because only then the old historic route is restored. In case of improvement of the alternative route the route itself will not change but only the conditions will increase. Therefore, all design solution which contain a bridge; 3, 4, 5 and 6, are scored with ++ while the improvement of alternative route, design solution 7, is scored with +.

Attractiveness shortage traffic:
Shortage traffic can only happen in case a bridge will be built which allows car traffic. These design solutions will therefore be scored with a - while the other design solutions are scored with 0. In general, this route is not very suitable for shortage traffic because of the road towards the bridge and the possible waiting time when a ship passes.

Time for realization:
A large bridge takes most time to realize while a cyclist bridge or improvement of the alternative route can be realized quickly. The former Paddepoelsterbrug requires some reparation but is preserved and could be replaced in theory. Therefore, designs solutions 3 and 4 are scored with – while design solution 5, 6 and 7 are scored with -.

11. **Conclusion and discussion**

To conclude from this project, possible design solution 6, which is a high bicycle bridge with clearance height of 9,1 meters, is the optimal design solution. The option which should be considered is the high cyclist bridge in combination with improvement of route towards the bridge. However, as most of these roads are well maintained this is not necessary. Design solution 7, the improvement of alternative route, was initially meant for roads towards adjacent bridges. Therefore, this combination will not add much value to the optimal design solution which is the high bicycle bridge.

It should be mentioned that many assumptions have been made and more data and information are required in order to make a substantiated decision. For instance, there is no data available on the number of exact users in terms of cars, cyclists and walkers. Besides this, there is little known about the fact where users are originated. The same can be said about the costs of possible design solutions; exact numbers are not known and are therefore scaled relative to each other. Besides the fact that assumptions have been made, the optimal design solution scores significantly higher than other design solutions. It is not depending on one high score and can therefore be considered as robust.

Two negative aspects that come along with the high bicycle bridge are connected to its height; fit into the landscape and inconvenience for elderly or disabled people. As mentioned before, the high bicycle bridge has more influence on its environment. Both the view as well as the adjacent land will be changed. The bridge can be seen from a distance while the long slope of the bridge will change the land next to the bridge. Figure 11 below shows the Walfridusbrug which has a clearance height of 9,5 meters and a total slope of around 400 meters. As can be seen, the slope has a significant effect on its environment and this is not preferable due to the houses located next to the former Paddepoelsterbrug. To prevent this, a staircase with bicycle track can be created which is also the case at the Gerrit Krolbrug. This can be seen in figure 12.


Figure 11: Walfridusbrug with long slope


Figure 12: Gerrit Krolbrug with two separate bridges for cyclist and walkers

Figure 13 below shows a location overview near the former Paddepoelsterbrug. According to the Fietsersbond, a long slope must have a maximum angle of 3,2% without stops (Faber, 2010). This means that the slope should be at least 9,1/0,032 = 284 meters long. As can be seen, several houses, two companies and a solar panel park are located within a radius of 100 meters near the bridge. Therefore, an extended slope of 284 meters is not preferable and a staircase with bicycle track will be considered as the optimal design solution.

Figure 13: overview of buildings near former Paddepoelsterbrug location

A short-term solution became public during the last phase of this design project on 7 June 2019. A high bicycle bridge in combination with a staircase and bicycle track will be built as a temporary solution (RTV Noord, 2019). This is similar to the optimal design solution according to this design project. However, it will become clear if this temporary solution will remain as a structural solution.

12. **Validation of designed route**

To validate the designed route the V-model will be used. The optimal route, the high cyclist bridge with staircases will be evaluated against all requirements set up during the project definition phase. This works as a last check to guarantee that the optimal route is achievable. Hereby, the route should satisfy the goal statement in order to solve the defined problem.

Regarding table 6 the high cyclist bridge is the optimal solution in terms of design parameters. At that moment it has already passed the boundary conditions check and requirements set up by Rijkswaterstaat are also met. Therefore, the goal statement: "To design a logistic route with optimized performance for former users of Paddepoelsterbrug, considering all relevant design parameters while boundary conditions (safety and transit of ships) are met.'' is fulfilled. This becomes also clear if the system description is taken into consideration because the optimal design solution will improve the system's performance. In the end, the problem defined as: "Former users of the Paddepoelsterbrug do not have a proper (alternative) route since it broke down'' is solved. If the three realistic scenarios of chapter 2 are taken into account, it becomes clear that the travel time for all scenarios is reduced, the attractiveness of the route has increased and safety and transit of ships are not affected at the same time.

Besides the theoretical validation it should be architectural achievable. A structural engineer has to validate the optimal design solution to determine whether it is actually possible to realize it for a certain budget. It could be the case that small adjustments have to be made. Afterwards, the final design will be assessed on the initial boundary conditions and all design parameters. This works as a feedback loop because a small adjustment can change the design in such a way that other design parameters might be influenced.

Finally, interviews with both Rijkswaterstaat and civil organization 'Brug terug' could take place in order to determine their satisfaction about the design solution. Rijkswaterstaat should be convinced whether it is the optimal solution because eventually they will have to realize it. Civil organization ´Brug terug´ should understand the reasoning behind the optimal design solution to satisfy their particular interest and to end the ongoing discussion.

13. References

Faber, G. (2010). *Adviesrapport fietsbrug Amsterdam Rijnkanaal.* Amsterdam.

Fietsersbond. (2019). *Fietsersbond.* Opgehaald van Fietsersbond: https://groningen.fietsersbond.nl/1902-paddepoelsterbrug/

Gemeente Groningen. (2018, November 27). *Studie bruggen vaarweg Lemmer-Delfzijl.* Opgehaald van Gemeente Groningen: https://gemeente.groningen.nl/sites/default/files/6.-beantwoording-vragen-Lemmer-Delfzijl.pdf

Gemeente Groningen. (2019). Opgehaald van Gemeente Groningen: https://gemeente.groningen.nl/paddepoelsterbrug

GIC. (2019). *Nu.nl.* Opgehaald van Nu.nl: https://www.nu.nl/groningen/5816247/stichting-groninger-landschap-paddepoelsterbrug-moet-snel-terugkeren.html

Goepel, K. D. (2013). Implementing the Analytic Hierarchy Process as a Standard Method for MultiCriteria Decision Making In Corporate Enterprises – A New AHP Excel Template with Multiple Inputs. *Proceedings of the International Symposium on the Analytic Hierarchy Process*, pp. 1-10.

Groningen, M. a. (2019, maart 8). Opgehaald van https://groningen.d66.nl/content/uploads/sites/335/2019/03/Beantwoording-vragen-ex-art.-38-RvO-D66-en-Stad-en-Ommeland-m.b.t.-Paddepoelsterbrug.pdf

Hevner, A. (2007). A Three Cycle View of Design. *Scandinavian Journal of Information Systems*, 19(2):87-92.

Hoofdvaarweg Lemmer Delfzijl. (sd). Opgehaald van Hoofdvaarweg Lemmer Delfzijl: www.lemmer-delfzijl.nl

Jackson, M. (1984). Applied System Thinking.

Knickel, N. K. (sd). *IVM VU.* Opgehaald van IVM VU: http://www.ivm.vu.nl/en/Images/MCA3_tcm234-161529.pdf

Lievaart, R. (2019). *Verslag klankbordgroep Paddepoelsterbrug 14 februari.* Adorp.

Ministerie van Infrastructuur en Milieu. (sd). *Doorstroom Evenementen.*

MIRT. (2019). *Meerjarenprogramme Infrastructuur, Ruimte en Transport.*

Pers nieuwsbericht Rijkswaterstaat. (2019, Maart 27). *Nieuwsbericht Rijkswaterstaat*. Opgehaald van https://www.rijkswaterstaat.nl/nieuws/2019/03/omleidingsroutes-voor-aangevaren-paddepoelsterbrug.aspx

Pieterpad. (2018). *Omleiding etappe Groningen - Winsum.*

Rijkswaterstaat. (2017). *Deelrapportage Vaarwegen voor de Nationale Markt- en Capaciteitsanalyse (NMCA).* Rijkswaterstaat Water Verkeer en Leefomgeving (WVL).

Rijkswaterstaat. (2019). *Verslag klankbordgroep Paddepoelsterbrug 14 februari.* Adorp.

Rijkswaterstaat. (sd). *FAQ*. Opgehaald van https://www.rijkswaterstaat.nl/wegen/wegbeheer/bruggen/veelgestelde-vragen.aspx

Rijkswaterstaat verkeer informatie. (2008, Januari). Opgehaald van Rijkswaterstaat verkeer informatie: https://rijkswaterstaatverkeersinformatie.nl/Nieuws/article/VID.2008.001.02

RTV Noord. (2019, Juni 7). *Tijdelijke fietsbrug op locatie Paddepoelsterbrug*. Opgehaald van https://www.rtvnoord.nl/nieuws/209509/Tijdelijke-fietsbrug-op-locatie-Paddepoelsterbrug

Sauser, B. (2010). Integration maturity metrics: Development of an integration readiness level. *Information Knowledge Systems Management*, 17-46.

www.allecijfers.nl. (2019).

14. Log

Date	Progress
01-03-2019	Information literacy: literature search (''Logistics'', ''Bridge logistics'', ''Bridge location'', ''Logistic route'' and ''Route decision'') in Smartcat and Google scholar
01-03-2019	Preliminary PA (problem analysis)
06-03-2019	First meeting first supervisor and project group
13-03-2019	Meeting project group: discussing index -> include content
15-03-2019	Deliverable: PAL
19-03-2019	Meeting second supervisor and presentation PAL
20-03-2019	Meeting project group: discussing structure figure -> include arguments, scope, system and RDP
23-03-2019	Set of scope, system description and goal
26-03-2019	Meeting Rijkswaterstaat and Brug terug in Adorp
27-03-2019	Deliverable: RDP
01-04-2019	Meeting project group: practice presentation RDP go/no go moment
13-04-2019	Feedback presentation: figures bigger and more practicing
15-04-2019	Presentation RDP: go/no go moment
16-04-2019	Process feedback supervisors on RDP
22-04-2019	Call with Stephan Bauman of Brug terug to discuss survey; proposal via email -> unfortunately they do not want to send survey
23-04-2019	Academic writing and feedback: correct mistakes in current IP
30-04-2019	Separate system boundaries and design parameters and preparation session 01-05
01-05-2019	Group session + supervisor
01-05-2019	Call with Municipality of Groningen, statement will follow via email
01-05-2019	Improve table of contents and system description, better idea of how to use scoring mechanism AHP
03-05-2019	Introduction of 'design orientation' and 'design selection' + layout improvement
04-05-2019	Possible design solutions identified

06-05-2019	Boundary conditions check + definition route
08-05-2019	Contact with Ryan Lievaart of Rijkswaterstaat; questions will be answered via email
09-05-2019	Design scoring and validation
10-05-2019	Deliverable: Intermediate results
14-05-2019	Preparation practice session of tomorrow
15-05-2019	Practice presentation intermediate results
15-05-2019	Feedback supervisors and group
18-05-2019	Include three possible scenarios problem definition
19-05-2019	Practice intermediate presentation
20-05-2019	Intermediate presentation
21-05-2019	Feedback received and processed
23-05-2019	All alternative routes adjacent bridges have been cycled
27-05-2019	Email contact with 'Brug terug' and call with Ryan Lievaart of Rijkswaterstaat: 'Brug terug' is not willing to participate, Ryan Lievaart will answer all questions this week by email
28-05-2019	Continuation on scoring and preparation of individual session of tomorrow
29-05-2019	Individual feedback session; assumptions, cost-benefit analysis, v-model validation
31-05-2019	Relative weight parameters using AHP method
01-06-2019	Scoring of each design on each parameter
02-06-2019	Discussion/conclusion and specify validation
06-06-2019	Feedback supervisors: process of simple feedback
07-06-2019	Image + summary symposium booklet
08-06-2019	Include comparison Walfridusbrug and Gerrit Krolbrug in discussion staircase/slope
11-06-2019	Elaborate on discussion and conclusion
13-06-2019	Start of making poster
15-06-2019	Abstract
18-06-2019	Check of whole document on content and grammar