Bicycle parking system station Delft

A study into the optimal bike parking system for underground bicycle facility one at station Delft

J. Spaargaren

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By

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PREFACE

This bachelor thesis is written for the completion of the bachelor's degree Civil engineering at Delft university of technology. The subject of this report belongs to the department of transport and planning. The research was conducted from September 2021 to October 2021.

Among the suggested subjects for the bachelor thesis, I saw the subject 'Bicycle parking reservation app' and it directly intrigued me. I park my bicycle about two times a week in at bicycle parking facilities at station delft and was convinced that parking your bicycle could be a more convenient process with a different parking system. Thus, in this report I will try to determine the best parking system.

I would like to thank my supervisors, Alexandra Gavriilidou and Yufei Yuan, and fellow students who provided me with feedback and support during this research. The outcome of the report would have been different without their help.

J. Spaargaren

Delft, October 2021

SUMMARY

In 2021 the capacity of the bicycle parking facilities at station Delft has increased significantly to a little over ten thousand bicycles. According to ProRail, responsible for railway infrastructure in the Netherlands, the capacity must increase with 25% for 2040. Because of the crowded surroundings at station Delft increasing the capacity of the bicycle parking facilities is difficult and extremely costly. Therefore, the current facilities should be used more efficiently. The focus of this report is to introduce the best parking system for the bicycle parking facilities at station Delft so that the capacity of the facility is optimally used.

The objective is to answer the question: “which bicycle parking system is most suitable for bicycle parking facility one at station Delft?”. The answer is found based on literature study, supported by three analyses: problem analysis, stakeholder analysis and multiple-criteria analysis.

First a bicycle parking system is defined, it consists of three elements: accessibility, signalling and regulations. Accessibility is how the bicycle rack is accessed. Signalling is how the user is guided to the available spaces. Regulations are all the regulation that apply to the facility.

From reference projects and a concept three new bicycle parking variants are constructed, the Utrecht variant, the app variant and the light indicator variant. The variants are constructed according to three competencies, complementing elements, costs and problem solving.

The most suitable bicycle parking system for facility one is the light indicator variant. The evaluation and redesign of bicycle parking facility two and three are needed to completely answer the main research question. The same systematic approach on evaluation and redesign could be applied to other bicycle parking facilities as well. As a last recommendation to determine the preferred bicycle parking system according to the users, a user survey can be conducted

Contents

1. INTRODUCTION

The symbiosis of the bicycle and the train is gaining popularity in the Netherlands. The train covers big distance fast and the bicycle is used for the first- and last kilometre (Kager, 2021). From Figure 1 one can conclude that home-end bicycle use has increased more than 25% from 2005 to 2015 and activity-end bicycle use has increased by 40% in the same period. This development is according to the policy goal of the national Dutch government and the Dutch ministry of infrastructure and water management (Kager, 2021). Cycling contributes to sustainability, reduces traffic congestion and is good for the public health (Kager, 2021). The increased use of the bicycle as egress and access mode is regarded as a crucial explanation for the increase in train ridership (Maat, 2015). To accommodate this increase and keep stimulating the use of the bicycle convenient bicycle related infrastructure is needed at train stations.

A big report has been drafted by municipality Delft: 'Mobility program Delft 2040' in 2021. The number of inhabitants and jobs will grow the next years and will increase the pressure on the available space and result in an increase in mobility. The challenge is to keep the city liveable, sustainable and accessible in combination with the population growth of the city (Municipality Delft, 2021). The bicycle facilities at station Delft do not accommodate enough places, the bicycle parking racks are overfull, and bicycles are parked in the middle of escape routes (Bonger, 2015). Therefore, finding a spot for your bike may not be as easy as one would like. According to Velden when people experience it is not convenient to park one's bike, they start to use the car again instead of the train (Velden, 2019). Parking one's bike should be a convenient process to promote the symbiosis of the train and the bicycle.

Recently the capacity of the bicycle parking facilities at station Delft has increased significantly to a little over ten thousand bicycles. According to ProRail, responsible for railway infrastructure in the Netherlands, the capacity must increase with 25% for 2040 (Municipality Delft, 2021). Because of the crowded surroundings at station Delft increasing the capacity of the bicycle parking facilities is difficult and extremely costly (Municipality Delft, 2021). Therefore, the current facilities should be used more efficiently. The focus of this report is to introduce the best parking system for the bicycle parking facilities at station Delft so that the capacity of the facility is optimally used.

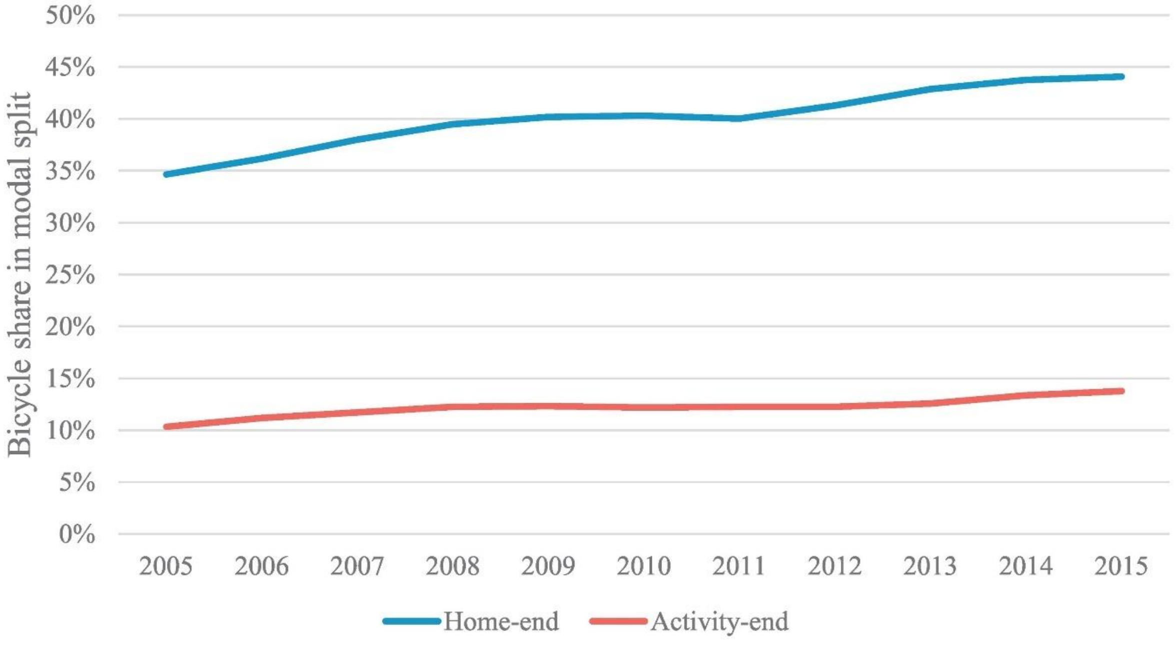

Figure 1 percentage of train travellers that uses the bike to reach the destination (activity-end) or the station (Home-end) at largest twenty stations in the Netherlands (Kager, 2021).

1.1 OBJECTIVE

In this report the objective is to answer the question: "*which bicycle parking system is most suitable for bicycle parking at station Delft?*". To answer this question a literature-based study is performed. The focus of this study is explicitly on the bicycle parking facilities at station Delft. To answer the research question as constructed and factually as possible the following sub-questions are stated:

1. How is a bicycle parking system defined?

   This sub-question is relevant to the main research question as it is crucial to understand what a bicycle parking system is before determining which is the most suitable system for Delft. To answer this sub-question a literature study will be done.

2. Why should the current bicycle parking system be adapted?

   This sub-question is relevant to the main research question as it is important to understand what the problems with the current bicycle parking system are in order to improve it and come up with the best possible solution. To answer this question a literature study will be done.

3. Which reference projects should be consulted?

   This sub-question is relevant to the main research question since reference projects need to be consulted to come up with improved alternative bicycle parking system. To find these reference projects literature will be consulted.

4. What are the different bicycle parking system variants based on the reference projects?

   This sub-question is relevant to the main research question as here the different bicycle parking systems will be described which is crucial to be able to determine the most suitable bicycle parking system for station Delft. This question will be answered by a literature study.

5. What is the interest and influence of the stakeholders involved in the design of the new system?

   This sub-question is relevant to the research question because the most suitable bicycle parking system should be chosen based on the stakeholders. The goal of this research is to come up with the most suitable bicycle parking system for station Delft. To be able to achieve this goal there must be determined what the most suitable means and for who it should be the most suitable system. This is dealt with this research question. To answer this question a stakeholder's analysis and literature research will be done.

6. Which criteria should be used to determine the most suitable bicycle parking system?

   This sub-question is relevant to the research question as it is crucial to determine the most suitable bicycle parking system. On which criteria the different variants are judged is important to conclude the most suitable variant. To answer this question a multi-criteria decision analysis and literature research will be done.

The methods for answering the sub questions will be discussed in chapter 2.

1.2 STAKEHOLDERS

The bicycle parking facilities have four main stakeholders. Pro Rail is the most important stakeholder since they were responsible for the construction of the bicycle parking facilities and are still responsible for the maintenance. Municipality Delft is a crucial stakeholder too since they are the owners of the bicycle parking facilities. Nederlandse Spoorwegen (NS) is responsible for the staff of the facilities. Finally, the users of the facility have a big interest in the facilities and are therefore an important stakeholder too.

1.3 STRUCTURE OF THE REPORT

The report consists of nine chapters. In chapter 2 the methodology of the study is stated on how the research questions are answered. In chapter 3 will be defined what a bicycle parking system is and are for each element possible solutions listed. Hereafter it is desirable to describe the current bicycle parking system, which will be done in chapter 4. In chapter 5 a stakeholder analysis is performed to determine which parties are involved and what their priorities are. In chapter 6 three parking system variants will be constructed and described. To make a constructed and rational ranking of the bicycle parking systems a multiple-criteria decision analysis is done in chapter 7. The answer to the main research question will be given in the conclusion in chapter 8. Finally, future research of the report is in chapter 9.

2. METHODOLOGY

In this are the methods for answering the sub-questions discussed, which lead to answer the main research question. Different methods are used to answer to sub-questions. The study will be mostly literature based, supported by a stakeholder analysis, problem analysis and multiple-criteria decision analysis. Below is described how each sub-question is answered.

2.1 LITERATURE RESEARCH

Literature is used to answer the sub-questions two till five. To answer sub-question 2 first google is used for journal and newspaper articles about the problems at the bicycle parking facilities at station Delft. Second to have a more scientific support Scopus and google scholar are used. The search terms 'mobiliteitsprogramma Delft 2040' and 'Sensor (bicycle OR bike) parking' provided the papers needed.

To answer sub-question 3 reference projects are consulted. The determine which reference projects are used, first google is used to find reference projects and general information about the reference projects. Second to have a scientific base for specific elements of the reference projects Scopus is used. The following search terms are used '(RTI OR real time information) sign (sensor OR data processing)' and 'garage parking guidance system'. A thesis of a fellow student called Bicycle parking is used as well.

For sub-question 4 the information gathered for sub-question 3 was used. To answer sub-question 5 information about the stakeholders needs to be gathered. If possible, the website of the stakeholder is accessed to determine the vision of each stakeholder. Scopus is used with search term 'fietsparkeren stations Delft' to add more literature-based support.

2.2 STAKEHOLDER ANALYSIS

The stakeholder analysis gives a great overview of which parties are involved in the project and how much influence they have. The goal of the stakeholder analysis is to determine what are the priorities and visions per stakeholder. A graph will be constructed with interest on the x-axis and influence on the y-axis. Each stakeholder will be rated on influence and interest between 1 and 5 and assigned to a certain place in the graph. Four main subcategories can be formulated as shown in Figure 2. The stakeholder analysis is in chapter 5.

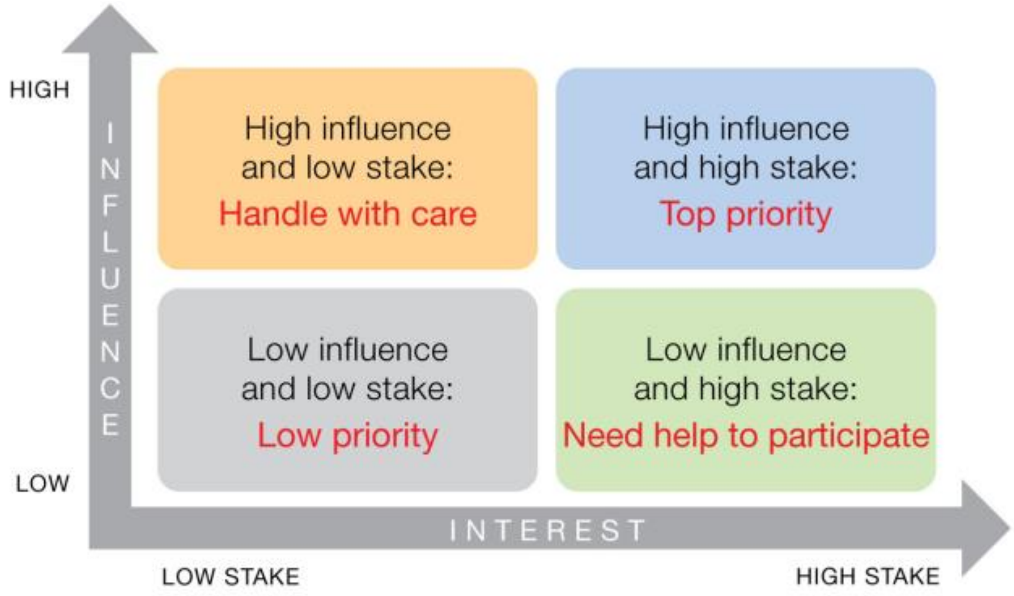

Figure 2 different types of stakeholders (International Atomic Energy Agency, sd)

To determine the weights of the criteria in the multiple-criteria decision analysis in chapter 2.4 the opinion and interests of each stakeholder in relation to the criterion must be determined and will be done through literature research.

2.3 CONSTRUCTING VARIANTS

As result of the literature research, reference projects and concepts are consulted. These reference projects and concepts are listed per system element. The three elements are combined to form a complete system. Not all system reference projects are compatible. A systematic approach is needed to design the best parking system variants. The variants are constructed according to three competencies. The first competency is complementing elements. The elements should complement each other to form a well function bicycle parking system. If the different elements can not be connected to each other it makes no sense to put them together. The second competency is costs, since the budget is limited, the costs are taken into consideration. If one element is very expensive for example it will be linked to a cheaper element or if one element generates money a more expensive element could be linked. The third competency is problem solving, the new variant should be able to solve the problems of the current system. Therefore, is shortly accessed whether the variant could redress the problems of the current system that follow from the problem analysis. The bicycle system variants are constructed in chapter 6.

2.4 MULTIPLE-CRITERIA DECISION ANALYSIS

Multiple-criteria decision analysis (MCDA) is performed to compare the new designed bicycle parking systems to each other and to the current bicycle parking system. MCDA is a scientific method to compare alternatives and make a rational and transparent decision (Guitouni, 1998). The goal of the MCDA is to find the best, according to the criteria and their weights, overall bicycle parking system. The MCDA is in chapter 7.

First the objective must be defined. The objective of the MCDA is to find the most suitable bicycle parking system for station delft. To determine which bicycle parking system is most suitable for station Delft multiple criteria most be formulated. These criteria follow from the stakeholder analysis and literature research. Based on these criteria will be concluded what the most suitable system is.

The weight factors are determined by making a comparison between all criteria. Two design criteria are examined and each time the most important criterion is determined. If the criterion in the first column is more important than the criterion in the first row, a 1 is assigned to the corresponding cell. When both criteria are equally important a half is assigned to the corresponding cell. In the case that the criterion in the first column is less important than the criterion in the first row a zero is assigned to the corresponding cell.

The score of each criterion is the sum of all scores in the row. To calculate the weight factor, the score of each criterion is divided by the sum of all scores and multiplied by hundred to form a percentage. The weight factor indicates how important each criterion.

Once the weight factors are determined. The variants plus the current system are ranked per criterion from worst to best. For the worst variant a score of one is assigned and for the best the maximum score (the total number of variants) is assigned. The current system is in the MCDA as well to compare the variants to the current system. Each score is multiplied by the weight of the corresponding criterion. The sum of these results is the final score of the variant. The variant with the highest total score is the most suitable bicycle parking system.

3. DEFINITIONS ON PARKING SYSTEM

In this chapter is first determined what elements a parking system consists of and is each element defined. After possible solutions for each element are listed per element.

3.1 ELEMENTS PARKING SYSTEM

First is defined what a parking system is and which elements it consists of. A parking system can be described as the rules that apply to the certain bicycle parking facility and the way the user is guided to the available parking spots. the system is divided into three elements: accessibility, signalling and regulations.

The first element is accessibility. The element accessibility are all actions the users must do from entering the facility to leaving the facility. So, how the facility is accessed, how the parking spot is accessed and how the exit is accessed are all part of the accessibility. How the facility is accessed could be for example by stairs of by a cycle lane but also a check-in point. How the parking spot is reached could be by cycling or walking or maybe even an elevator.

The second element is signalling. The focus of this elements is how the user of the facility is guided to the available parking spaces. For example signs, which indicate the number of available parking spots, could be used to guide the user to the available parking spots. The faster the user finds an available parking spot the better the system works. Limiting the time the user must search for a parking spot causing the process of parking the bicycle to be a more convenient process.

The third element are the regulations that apply to the facility. Regulations regarding:

- Maximum allowed parking time
- Ability to reserve parking spots
- consequences when exceeding the max parking time
- Parking costs

3.2 ACCESSIBILITY

This section provides solutions for the element accessibility of the bicycle parking system. The consulted reference projects or concepts are the bicycle parking facility at station Utrecht Central and OV-chipcard unlockable locks.

3.2.1 UTRECHT BICYCLE PARKING FACILITY ACCESSIBILITY

Since 2019 bicycle parking facility at Utrecht central is the biggest bicycle parking facility in the world, with a total capacity of twelve and a half thousand parking spots (Gemeente Utrecht, sd). At stations Zwolle (finished in 2020), Maastricht (finished in 2018) and Breda (finished in 2017) were all recently new underground bicycle parking facilities constructed and therefore these projects could be useful reference projects as well. However, all these facilities use almost the same system as the parking facility at station Utrecht. Since that is the most well-known facility and capacity wise the most similar one, the bicycle parking facility at station Utrecht is used as reference project.

Figure 3 map of bicycle parking facility at station Utrecht (Gemeente Utrecht, sd).

The facility is directly next to the train station and under the Station square as figure 3 shows. The parking facility can be entered by a cycle lane via the north or south and is entered on the middle level (level 0). Floors zero and one have a footpath in the middle and directly next to it on both sides are the bike racks as figure 3 indicates**.** The rows on each side of the footpath are rather short and do contain a maximum of twenty bicycle parking spots next to each other. On the outside of these racks is a cycle lane, which allows the user to cycle right up to the parking spot. The big advantage of the bicycle lanes on the outside and the footpath in the middle is that the pedestrians and cyclist are separated and therefore not impede each other. The footpath in the middle leads to three staircases which debouch into station square, only fifty meters from the entrance of station Utrecht central. Level minus one has a cycle lane on one side and a footpath on the other side. The footpath leads to two tunnels, which lead directly to the train platforms. From one tunnel platforms one to fifteen can be accessed, the other tunnel gives access to all platforms (one to twenty-one) as figure 3 illustrates. The facility can be used as tunnel to get from smakkelaarsveld to Moreelsepark and vice versa.

The central check-in/check-out system

Bicycle parking facility Utrecht has two systems regarding the accessibility. The first option is the most common one. When the facility is entered, one needs to check-in at a central check-in desk. For check-in an OV-chipcard is needed. the OV-chipcard is the public transport card in the Netherlands and gives access to all forms of public transport all over the country (Nederlandse Spoor (NS), sd). Without an OV-chipcard it is impossible to park one's bicycle at levels one and minus one. If check-in is succeeded, the bicycle is allowed to be parked at levels one and minus one. When leaving the facility, one must check-out at a central check-out desk of which on both exits of the facility is one. Check-out is done with the same OV-chipcard.

The year subscription system

The second option is the year subscription system. It is possible to sign up for a year subscription, which is €75, - per year. The whole middle level is reserved for these year subscriptions. The NS guarantees that if one has a year subscription, there always is a free spot for one's bicycle available (NS, 2021). Another perk of being a subscriber is one is allowed to store the bike as long as one likes, whereas for the other parking spots a maximum parking time of 28 days is applied. The first time, when a year subscriber enters the facility, one needs to check in. If the subscription is confirmed, a sticker is glued to the bicycle. With this sticker it is no longer necessary to check in and check out and therefore time can be saved (NS bicycle BV, 2021). Bicycles without a sticker are removed from the racks. The sticker indicates how long the year subscription is valid and each year a different colour is used.

3.3 SIGNALLING

This section provides solutions for the element Signalling of the bicycle parking system. The consulted reference projects are bicycle parking facility at station Utrecht Central and garages in Delft and Fort Collins and a concept of a bicycle parking app.

3.3.1 UTRECHT BICYCLE PARKING FACILITY SIGNALLING

When the facility is entered, a big and clear real time information sign (RTI-sign) states how much spaces are still available for each floor. Figure 4 is a picture of such a RTI-sign. RTI-signs work in the following way, each bike rack is fitted with a sensor that continuously monitors the slot's availability. The data is uploaded to an internet of things (IoT) repository in the cloud through a gateway (D. Angulo-Esguerra, 2017). Allowing the RTI sign to show the number of free spaces.

Figure 4 a RTI-sign at the entrance that indicates the number of available spaces of each direction (for each floor)

Because of the RTI-sign at the entrance the user now roughly knows where the available parking spots are located. To indicate the available spaces more specific each row has an RTI-sign which indicates the number of free spaces in the upper or lower racks. A rack has a maximum of twenty parking spots. Therefore, one RTI-sign is linked to a maximum of twenty parking spots. Because of this the Signalling is very clear and the user is easily guided to the available parking spots.

3.3.2 GARAGE PARKING GUIDANCE SYSTEM DELFT

A garage parking guidance system is designed to facilitate the vehicles circulation in controlled parking garages, by presenting the driver with dynamic information about the occupancy of the parking spots (HUB parking technology, sd). Each parking space has a senor connected to a light. When the parking space is empty the sensor measures that and the light turns green. when the space is occupied the sensor sends a signal to the light and the light turn red. The lights are placed where the driver can easily see the lights. Because of the red and green lights, it is for the driver very clear to see where the available spaces are located. Figure 5 shows what the light indicators look like.

The Prinsenhof garage in Delft is since 2020 fitted with so called park assist lightning (Parkeren Delft, 2020). The lights are right in the middle above the driving lane. Each light is linked to four parking spaces and has three colours. each colour explained:

- **Green:** if one or more parking space(s) is/are available
- **Red:** if none of the four linked parking spaces is available
- **Blue:** if one parking spot is for disabled parking

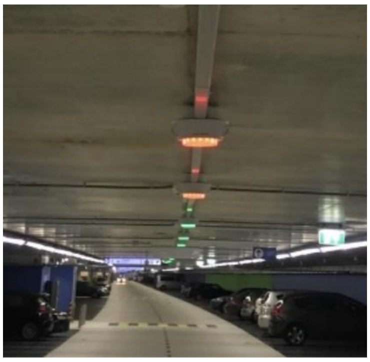

Figure 5 illustration of what the lights look like (Parkeren Delft, 2020)

3.3.3 GARAGE PARKING GUIDANCE SYSTEM LAKE STEET GARAGE

The lake street garage is in Fort Collins, Colorado United States of Amerika. Project engineer Stephen Evans: “What we’ve installed is a single-space parking guidance system, each parking spot is equipped with an ultrasonic sensor and an LED light indicator above the parking spaces” (Swanson, 2015). The light is green if the parking space is available and red if it is already in use. Disabled spaces are indicated with blue lights. Electric car charging stations are indicated with a purple light.

The sensors work with echo, an ultrasonic signal is emitted four times per second from ceiling to floor. The sensor listens for an echo, if something breaks the beam for a certain time, the sensor recognizes that as a stationary object and the spaces is marked as occupied parking space (Swanson, 2015). The sensors measure within two or three seconds that one has parked its car in the parking space and automatically turn the light red. It is like sonar on a submarine according to the chief engineer. Each parking space has its own light, in contrast to the Prinsenhof garage where one light is linked to four parking spots. To implement the whole system the costs were two hundred sixty thousand dollars for 838 spots (Swanson, 2015). Figure 6 gives an indication what the light indicators look like.

Figure 6 picture of the garage parking guidance system of the lake street garage (Swanson, 2015).

3.3.4 BICYCLE PARKING APP SIGNALLING

In 2021 van der Veer designed a bicycle parking app (Veer, 2021). It is only a concept version since it is not tested or used yet. However, it can be relevant and useful as a solution for the new bicycle parking system as according to Van der Veer 47% of the users would use a parking reservation app and 21,4% would maybe use it (Veer, 2021). The bicycle parking app can be used for the elements Signalling and regulations. The Signalling part of the app is described in this section and the regulation part is described in paragraph 3.4.2.

The app has an interactive map which shows exactly which parking spots are available and which parking spots are occupied. Therefore, the app is used for signalling, one could cycle to the facility and simply use the app to see where the available parking spaces are. It is even possible to reserve a spot beforehand. How one can reserve a spot and the regulations regarding serving a spot are described in paragraph 3.4.2. When a spot is reserved, the app shows the exact location of the spot. It is thus direct clear to the user where the parking spot is. Signalling was defined as how well the user is guided to an available parking spot, with a reservation the user knows beforehand at which spot the bicycle can be parked and is therefore guided efficiently to the parking spot.

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3.4 REGULATIONS

this section provides solutions for the element regulations of the bicycle parking system. The consulted reference project and concept are bicycle parking facility at station Utrecht Central and the bicycle parking app.

3.4.1 UTRECHT BICYCLE PARKING FACILITY REGULATIONS

The facility is opened 24/7. At all times at least one person must be present to run the facility, because the check-in/check-out procedure is not fully automated and involve human actions. The first 24 hours are free to park one's bike, after €1.25 per 24 hours must be paid. The parking fees must be paid at check-out. When the facility is entered one first needs to check-in with an OV-chipcard. When leaving the facility, one must check-out. For check-out one must cycle to the exit, where the check-out point is located, to scan the OV-chipcard and check-out. The system calculates how much must be paid and one can pay with debit card, or with credit card. It is even possible to pay with the OV-chipcard, but only after one has given online permission. It is allowed to park one's bicycle up to 28 days, after 28 days the bike is removed from the facility.

3.4.2 BICYCLE PARKING APP

Here the features of the app shortly will be described. When the app is opened for the first time, a login screen pops up. Here one should login-in with one's OV-chipcard account. If login is successfully completed, one is directed to the homepage. The app has four main pages:

- Homepage: here reservations can be made. Preferences in relation to upper/lower rack and which facility or section could be entered .
- My reservation: here the current reservation(s) is/are listed and what the involved costs are.
- History: past reservations up to two weeks prior are shown

Regarding the process of reserving a spot for one's bike as few regulations must be specified. The survey showed that 63.4% of the participants thinks a spot should be able to be reserved up to one hour in advance (Veer, 2021). Therefore, a spot can be reserved up to one hour in advance, if after one hour the spot is not accessed yet the reservation expires. A small fine is charged, to prevent users making unnecessary reservations.

Reserving a spot can be done in four different ways:

- Free choice, with free choice the user first selects the row in which the user wants to park. The app shows then an interactive map of all the parking spots of the row, available spots are marked green and occupied spots are marked red. The user selects the spot it wants to park in and the reservation has been made. The app subsequently shows the reservation with the row and the number of the reserved spot and a map of where the reserved spot is.
- Select row, the option select row allows the user too chose the row the user wants to park in and the system will assign the user the closest available spot to one of the entries of the station. If the reservation is confirmed a overview of the reservation is shown, same as the free choice option.
- Select section, the select section works the same as select row, only a section is now chosen by the user instead of a row.
- Automatic assignment, this is the option where the user hands the choice completely over to the system. The available spot closest to one of the station entries is assigned by the system to the user.

As the app is still a concept, the regulations will all be tested in the trial phase and therefore might still be adjusted.

4. CURRENT SITUATION

In 2009 the immense operation of transforming the Spoorsingel in Delft started. It is the biggest built project in Delft ever and it would cost about one billion euros (COB, 2015) (Heuts, 2014). The project contained a 2.3 kilometre long four railway line railway tunnel, a new underground train station in combination with an efficient junction for public transport, fifteen hundred residences and over fifty thousand square meters of office space (Duin, 2007).

The railway line used to be a viaduct right through the City centre. Over three hundred fifty trains used the viaduct each day, causing immense noise disturbance (COB, 2015). Another problem was that the viaduct formed a visible barrier between the different neighbourhoods. The viaduct had only two railway lines, whereas the new tunnel has four railway lines. The first two railway lines are in use since 2015. In 2025 the whole tunnel should be ready and all four railway lines and train platforms should be in use (GWW total , 2019). The old station, which is now a restaurant, was too small and old fashioned and therefore needed replacement (COB, 2015). In the end the tunnel costed 553 million euros, where 270 million was budgeted (Dankert, 2015). The tunnel is called the Willem van Oranjetunnel because Willem van Oranje, a significant person in Dutch history, was shot only hundred metres from the tunnel (Treinreiziger, 2015).

Part of the project was building three underground bicycle parking facilities. The first was finished in 2015 and has a capacity of five thousand bikes. Bicycle parking facility 2 opened in 2017. The last facility, bicycle parking facility 3 opened in 2021 completing the project in terms of building bicycle parking facilities. Together the facilities have a capacity just over ten thousand bikes. A map of the three facilities is shown below in figure 7.

Figure 7 schematic display of underground bicycle parking facilities (Gemeente Delft, 2021)

The current bicycle parking system is divided into the three elements described in chapter 3. The focus of the report is from now on specifically on bicycle parking facility one, because the system elements and problems of one specific facility must be determined. Focussed on the problems of the current system the different system variants can be constructed and thus fitted specifically to facility one. The MCDA will than determine the most suitable bicycle parking system for facility one. The same approach could be used to determine the most suitable bicycle parking system for facility two and three. Facility one is chosen because it is the oldest facility and therefore has the most old-fashioned system. It is the biggest facility, therefore upgrading the system has the biggest impact. Facility one is the system with the biggest problems and has direct access to the train platforms and is thus preferred by the users (Bonger, 2015).

4.1 ACCESSIBILITY OF CURRENT SYSTEM

All three bicycle parking facilities are accessible for everybody. It is not mandatory to use public transport to be allowed to park one's bike nor is one charged for parking the bicycle.

Two different types of bikes are specified, bicycle which fit in the bicycle racks and bikes which do not fit. These bikes which do not fit are in Dutch called 'buitenmodel fietsen' (in English: not example bikes). Examples of buitenmodel bicycles are a tandem, a cargo bike, a bicycle with panniers and bicycles with a crate (VerkeersNet, 2015). All these bicycles do not fit in the normal bicycle racks and therefore need to be parked elsewhere. Bicycle parking facility one has certain buitenmodel parking spots. Figure 9 shows where those buitenmodel parking spots are and what they look like.

Bicycle parking facility one is not only used to park one's bicycle but also a tunnel to cycle from the west side of the station to the east side or the other way around. Although it is not possible to directly cross the Westsingelgracht and cycle straight into the city centre, it is possible to cycle along the Westsingelgracht and cross it only a few hundred metres in both ways. Though bicycle parking facility one is often not the shortest route, but non the less it is still used as a passage.

From bicycle parking facility one, the station has two direct entries. The north side entry (at row six) leads to an intermediate platform from which the railway platforms can be accessed by a downward escalator and stairs. Straight ahead for the entry it is possible to use the upward escalator and stairs which lead to the station hall. The south entry between rows eleven and twelve gives direct access by stairs to platform one and two. Only parking facility one has direct entries to station Delft and therefore is preferred by its users. Users tend to want to park their bicycle as close to the entries as possible.

4.2 SIGNALLING OF CURRENT SYSTEM

For every row on the ceiling a real-time information (RTI) sign is placed, indicating the row number and the number of available spaces in the row, so upper and lower racks combined, as showed in figure 8. The row with the most bicycle racks is row eight, where a total of 610 bicycle can by parked and is about 75 meters long. Only one RTI-sign is used for these 610 bike racks, whereby the RTI is not as useful as it can be. The bicycle parking facility at Station Utrecht Central has a RTI-sign for each row section and each side of the row and distinguish the number of available parking spot between upper and lower racks as well. Which result in the fact that for each approximately fifteen bike racks a RTI-sign shows the number of available spot. A RTI-sign for one in fifteen spots is a massive difference form the one in six hundred in delft. If only a few spaces are available the RTI sign marks the row as full, to prevent users from searching to long for a spot (Stift, 2019).

The rows for buitenmodel parking spots do not have a RTI-sign, since there are not racks but just open space and therefore no sensors can be fitted. Without the sensors it is not possible to indicate the number of available parking spots and it is not possible to fit these rows with a RTI-sign indicating the number of available spaces. Row ten misses a RTI-sign as well, however row ten has 'normal' two tier bicycle racks and is perfectly able to be fitted with a RTI-sign. Row ten is hidden in the corner, which should be the more reason to fit the row with a RTI-sign and guide the users to the available parking spots.

Figure 8 Real-time information sign bicycle parking facility Delft

When the facility is entered from the east side (at row one) and RTI-sign, directly at the entrance mounted to the ceiling, indicates the number of available parking spots for the entire bicycle parking facility one. When leaving the facility at the west end (at rows nine and sixteen) two RTI-signs indicate the number of available parking spots for bicycle parking facility two and three as indicated in figure 9.

4.3 REGULATIONS OF CURRENT SYSTEM

The maximum allowed parking time if fourteen days. When the maximum allowed parking time is exceeded or the bicycle is parked in a dangerous spot (blocking an emergency exit or outside the racks), first a warning is issued in the form of a label on the bicycle which states when the bike will be removed. If the bicycle is not moved, the bicycle is removed from the bicycle parking racks and brought to a bicycle depot in Den Haag. All removed bicycles in the region Den Haag, Delft, Leidschendam-Voorburg and Pijnacker-Nootdorp are dropped at bicycle depot Den Haag (FIets Depot Haaglanden, 2021). Many bicycles are dropped at depot Den Haag, which makes the process of getting your bike back a time-consuming process. When the fine, for wrongly parking the bicycle or parking the bicycle to long, of 25 euros is paid one has one’s bicycle back. The facility is open 24 hours a day and seven days per week. Parking is free.

Figure 9 Map of bicycle parking facility one Delft

4.3 PROBLEMANALYSIS

All problems are linked to a bicycle parking system element.

4.3.1 PROBLEMS ACCESSIBILITY CURRENT SYSTEM

The first problem regarding the accessibility is that facility one is often full, which lead to bikes being placed outside the racks. No doubt it is inconvenient if the bicycle could not be parked near the station and when in a hurry some wrongly park their bicycle. These wrongly parked bikes are blocking escape routes, which can have fatal consequences in cause of an emergency (Bonger, 2015). Emergency services may not be able to reach the destinated spot in time, or in times of an evacuation people are not able to get to safety in time. Bonger plead for a solution of these problems and therefore questioned the college of the major and aldermen (Bonger, 2015).

The capacity of the facilities all together now is ten thousand and one hundred bikes. According to Pro Rail this must increase with at least 25% before 2040 (Municipality Delft, 2021). For station Delft this is going to be very difficult since it is not possible to add a deeper layer for the parking garage because the train run directly under the bicycle parking facility. The neighbourhood of station is very crowded which if the capacity is expended lead to very high expenses and is extremely difficult (Municipality Delft, 2021).

4.3.2 PROBLEMS SIGNALLING CURRENT SYSTEM

the users are often in a hurry as most of them who use the facility need to catch a train. Signalling therefore is essential to guide the user as fast as possible to an available parking spot. The biggest problem is not enough signs were used. Most rows only have one RTI-sign, except for rows one, two and ten which do not have a RTI-sign at all. Rows seven to nine are approximately 75 metres long and the biggest row has 610 parking spots. Therefore, the user still does not accurately know where the available parking spot are located.

Row 10 is completely in the corner and has now indicating of the number of available spaces. A RTI-sign, which is clearly visible from the main bicycle lane, should indicate the number of available parking spots for row 10, for the row to be used more optimally.

The RTI-signs of rows eleven and twelve are not in the middle of the row, but between the rows. For example, RTI-sign of row eleven is between row eleven and twelve, directly in front of the two-tier bicycle racks. The RTI-signs of these rows are parallel to the bicycle lane instead of perpendicular as all other signs. When entering the facility from the west side (rows nine and sixteen) the signs are not legible.

4.3.3 PROBLEMS REGULATION CURRENT SYSTEM

The main problem regarding the efficiency of the parking system is the long-allowed parking time. In particular for parking facility one this is a problem, as it is nearest to the station. From table 1 can be concluded that over 80 % parks it’s bicycle less than 24 hours. It is therefore unnecessary to allow a maximum parking time of fourteen days. The parking spots can be used far more often and therefore more efficient if the maximum parking time is significantly reduced. Three different travel motives are distinguished working, education and the remaining.

Table 1 parking time per travel motive (Municipality Delft, 2013)

Parking time	Working	Education	Remaining	Total
Till 4 hours	6	15	33	15
4-10 hours	50	57	37	49
10-24 hours	27	7	7	17
1 to 7 days	15	17	19	17
More than 1 week	2	4	3	3
total	100	100	100	100

.

since 2015 it is no longer possible to pay for parking one's bicycle. Municipality delft did research regarding the possibilities to pay for a parking spot and 33.5% prefers a paid parking spot with the additional advantages (Municipality Delft, 2013):

- More often free spaces available
- Nearer to the station
- Safer in terms of stealing

5. STAKEHOLDER ANALYSIS

As described in chapter 2.2 a stakeholder analysis will be performed. First all stakeholders will be placed in a graph that depends on their influence and interest. After their vision related to the criteria used for the MCDA will be listed.

Stakeholder	Interest	Influence	Motivation
Municipality of Delft	+	++	Municipality Delft was the big initiator in completely changing Station Delft in 2009. The municipality is big shareholder of the bicycle parking facilities and therefore has much influence (Kamerling, 2012). Municipality Delft also has great interest is a well-functioning bicycle parking facility since it represents the interest of the inhabitants of the municipality. secondly the city hall is located at station Delft and should be easily accessible.
Province governance Zuid-Holland	+/-	+	Province governance Zuid-Holland partially funded the Project of building three underground bicycle parking facilities and therefore has significant influence (Delftse post, 2020). Province Zuid-holland represents the interests of the inhabitants of the province thence a serious interest.
Ministry of traffic and water management (ministerie van verkeer en waterstaat)	-	+/-	The ministry of traffic and water management funded the three underground bicycle parking facilities as well and consequently has influence (Delftse post, 2020). Since the ministry represents the entire population of the Netherlands the interest significantly less that the municipality Delft.
ProRail	+	++	Pro Rail was responsible for the construction of the underground bicycle parking facilities and is responsible for the maintenance of the facilities, thus big renovations are the responsibility of Pro Rail too (Pro Rail, sd). This results in a significant Interest and Influence
NS (Nederlandse Spoorwegen)	+	+/-	NS is responsible for the personnel at the facilities and therefore has an interest in the way the facilities are operated (Delftse post, 2020). NS does not have big influence since is does not bring any money to the table for renovations.
Users	++	--	Users have a great interest in an optimal functioning parking facility, their influence however is very small.

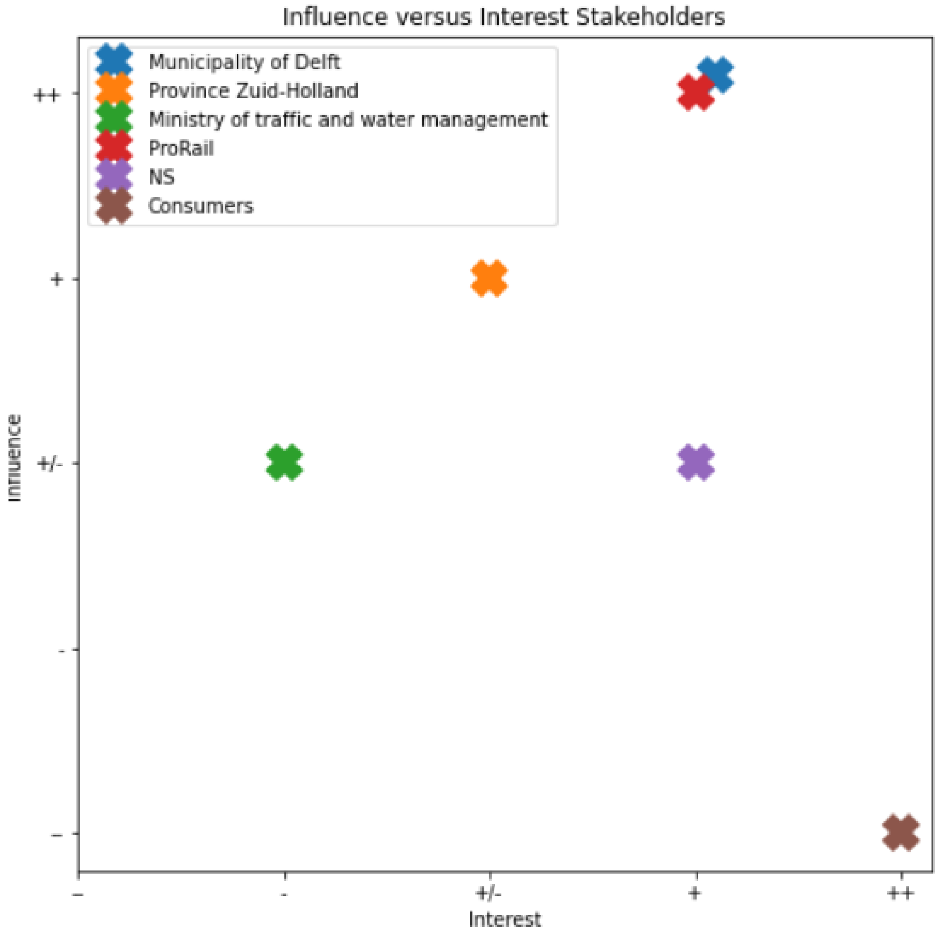

Figure 10 graph of the position of each stakeholder.

In figure 11 the influence versus the interest of each stakeholder is visualized. Thus, the top priority stakeholders are the municipality and ProRail. The top priority stakeholders should be greatly involved. Their goals and visions are important for the project to succeed.

Municipality Delft has set up all their goals and plans in a big report called mobility program Delft 2040, our Delft, sustainable accessible. Sustainable is even in the title of the report and therefore greatly important to the municipality. The goal of the report is to keep the city liveable, sustainable and accessible in combination with the population growth of the city (Municipality Delft, 2021). Since municipality Delft could be the main investor it is vital involve them tight in the process.

ProRail was responsible for the construction of the facility and therefore is likely to be responsible for big renovations of the facilities. Their vision is to connect people, cities and companies per railway and make traveling comfortable and sustainable (ProRail, 2021). Sustainable is an important goal of ProRail as well. Predicted is that the number of travellers will increase up to 45% by 2040 (ProRail, 2021). They want to keep promoting the bicycle as home-end or activity end vehicle (ProRail, 2021). Therefore, ProRail has significant influence and interest and must be dealt with accordingly.

The users have the biggest interest in a more efficient parking facility and are of the category need help to participate. Cause as individuals have small influence and need to be consulted to participate in the process. As the users are not a company with a concrete vision it is more difficult to determine the main concerns, therefore different survey have been consulted to construct an overall picture of expectation.

Since NS is responsible for running the facility, it is undesired to let them run a system which they did not agree on. Their goal is to offer safe, enjoyable and affordable travels (NS, 2021).

6. BICYCLE PARKING SYSTEM VARIANTS

In this chapter the best variants are constructed. A bicycle parking system consists of three elements thus a variant should have a reference project or concept for each element. The variants are constructed out of the reference projects and concepts in chapter 3. To form a good variant, the variant is checked according to three competencies, complementing elements, costs and problem solving.

Not all reference projects could be connected to form a well-functioning system. The different elements should complement each other instead of counter act. From the stakeholder analysis in chapter 6 can be concluded that the top priority stakeholders must pay the biggest part of the costs. Municipality Delft is nearly broke and ProRail has more pressing projects (Blommers, 2021) (ProRail, 2021). The costs are therefore limited and should be taken into consideration constructing the variants. The new variant should be able to solve the problems of the current system. The problems of the current system are in section 4.3. The first problem is users are not properly guided to the available parking spot. The second problem is wrongly parked bicycles blocking footpath. The third problem is a too long maximum parking time. The fourth problem is the option to pay for parking lacks.

6.1 UTRECHT VARIANT

The Utrecht variant is a copy of the bicycle parking system in Utrecht. The bicycle parking facilities at stations Maastricht, Zwolle and Breda have the same system and are all built in the last five years. It seems therefore argumentative to test with the MCDA whether the system could work for facility one as well.

The variant has a central check-in section and a year subscription section. These accessibility elements are described in section 3.2.1. How big each section should be needs to be further investigated if this is the most optimal variant. For now, is proposed that rows 10 up to 16 are destined for the year subscription section, since one third of the users would like a paid parking option and this is about a third of the facility (Municipality Delft, 2013). Row 1 till 9 will become the become the central check-in section.

Each row section has a RTI-sign indicating the number of available parking spots in the upper and lower racks. The signalling will have three levels, first indicating the number of available spots in the entire facility, second indicating the number of available spots in an entire row and third indicating the number of free spots in one row section. The row indication and row section indication will be two tier RTI-sings. A row section will have a maximum of fifty lower and fifty upper racks. All connected racks between footpaths need to be halve of what they now are. The sections have a distinguish colour and letter (Veer, 2021). For example, row section 4A with colour blue. The colour is applied on the flour and the RTI-sign of the section. To apply the variant fifty RTI-signs need to be added to the facility and all current RTI-signs for rows need to be adjusted to two tier RTI-signs.

For the central check-in section the following regulations apply, the first 24 hours of parking are free, subsequently €1.25 will be charged for every 24 hours. The fees need to be paid at check-out. Normally a maximum parking period of 28 days is allowed. However, since the facility has a capacity problem the maximum parking time is reduced to 72 hours for the whole facility. After 72 hours the bicycle is removed from the racks. The maximum parking time of 72 hours allows the users to park their bicycle in the facility for the whole weekend. If users wants to park their bicycle for a longer period they can use facilities two and three.

The variant must be tested to the three competencies. First the complementing ability of the different elements. As it is already a widely used system it is safe to say the different elements will work perfectly fine together. The costs of the variant are within the limits as well. Because both sections will generate a cash flow and the implementation of the RTI-signs will not be very expensive as the sensors are already in place only the RTI-signs need to be purchased and installed. Transforming the facility into a year subscription part and a central check-in part is the costliest process but as all components to implement this are already designed the costs are limited. The last test is whether the system redresses the problems of the current system. Through the extra fitted RTI-signs the users is more thoroughly guided to the available parking spots. because all users need to check-in for the central check-in part the maximum capacity is determined, users are refused if the maximum capacity is exceeded, thus no bicycles will be parked outside the racks. For the year subscription part NS guarantees an available parking spot, therefore users will not park their bicycle outside the racks. The maximum parking time is reduced to 72 hours. Users are therefore motivated to park their bicycles more shortly. The year subscription section allows users to pay for their parking spot with additional advantages.

6.2 APP VARIANT

The app variant are the year subscriptions of bicycle parking facility Utrecht (section 3.2.1) and the bicycle parking app (sections 3.3.4 and 3.4.2). Developing and integrating the parking app is a costly process (Klerk, 2019). To prevent the system from being too costly the app element is linked to the year subscription element which will make money. Paid users have higher expectations of the convenience of parking the bicycle. Therefore, an extra service must be granted which is the bicycle parking app. The elements thus complement each other.

According to Municipality Delft 33.5% of the users prefers a paid bicycle parking system. Therefore, the rows one to nine will be meant for year subscribers, which are approximately three thousand five hundred parking spots, thus a third of the total capacity of the three facilities. A trail period will decide whether too many parking spots are available for year subscribers only or too few parking spots are saved for year subscribers.

The app will only work for the year subscription section (row 1-9). Each year subscriber receives a sticker, which need to be glued to the bicycle. The sticker contains the expire date of the subscription and the name of the subscriber. Each year a new sticker with a different colour needs to be glued on the bicycle. The sticker needs to be glued on the rear end of the bicycle, so it is clearly visible when parked in the racks. The app is used to make reservation up to one hour in advance and shows the exact location of the spot as described in section 3.3.4. The staff member can check the reservation in the system and compare them to the name on the stickers. If a bicycle is wrong parked it will be removed. The stickers are necessary to prevent misuse of the year subscription and reservations with the app. These elements therefore complement each other. For the year subscription section all problems except the third problem are solved.

To make the system more problem solving the remainder rows will stay roughly the same but will have a maximum parking time of 24 hours and a RTI-sign for each row section (as described in section 6.1). When exceeding the maximum parking time, the bicycle is removed from the racks and send to the bicycle depot (the bicycle will always be at least a day in the removed bicycle section which is indicated in figure 9). The regulations in the year subscription part are that it is only allowed to park one’s bicycle in that part of the facility if the user has a year subscription. The maximum parking time is three days (72 hours). The standard maximum parking time for year subscribers is unlimited, for facility one this is way to long. The maximum parking time of three days allows the year subscribers to park their bicycle in the facility for the weekend but not longer. By reducing the maximum parking time to three days and 24 hours the third problem is taken care off.

6.3 LIGHT INDICATOR VARIANT

For the light indicator variant, a combination of the reference projects of Prinsenhof gargare Delft (section 3.3.2) and central check-in and check-out points (chapter 3.2.1) is made. The whole facility is fitted with light indicators. The parking garage in Fort Collin (section 3.3.3) has a light indicator for every parking spot. Because the bicycle racks are closer together this is unnecessary and even confusing. The Prinsenhof garage (section 3.3.2) has one light indicator per four parking spots. to keep down the costs one light indicator is used for five subsequent bicycle racks in the same tier. The upper bicycle racks are connected to a light which is mounted to the ceiling. The lower bicycle racks are connected to a light mounted to the floor. All bicycle racks already have an availability sensor, these sensors can be connected to the corresponding lights. The user is not interested in occupied parking spots and therefore not in the red lights. To provide the user with a clearer overview the lights are green when one or more of the parking spots is available and the lights are switched off if all spots are occupied. The first problem is thus taken care off.

Complementing to the light indicating system, the facility will be fitted with two central check-in/check-out points, at each entry one. These check-in points will function as a full gate, everyone who enters the facility must check-in at the check-in point. The check- in procedure is the same as described in chapter 3.2.1. The facility can still be used as a tunnel, one must check-in at one end and directly check-out at the other end. No costs are charged if the check-out is within 24 hours after the check-in. It is not possible to limit the number of checked-in bicycles and refuse check-in if the capacity is exceeded, because it will be no longer possible to use the facility as a tunnel. Therefore, the second problem is not entirely solved.

The third problem is solved by reducing the maximum parking time to 24 hours. 80% of the users parks their bicycle for less than 24 hours (Municipality Delft, 2013). The other 20% can use facility two or three as these have respectively maximum parking times of 28 days and 14 days. After 24 hours a fine need to be paid at check-out. That is the reason a central check-in point is necessary, to make user misuse of the system is minimized. The aim of the system is that the facility is strictly used for users who park their bicycle less than 24 hours. The paid parking option is not included in the system, however the biggest motivation for doing so it the guarantee of an available parking spot. As all five thousand bicycle racks will become available every 24 hours the number of available parking spot will increase.

The implementation costs of the light indicating system are significant but are reduced by using only one light indicator per five racks instead of one for each rack. The light only needs to have the green colour instead of more colours for the reference projects, this will reduce the costs are well. The central check-in points need to be constructed as well however ProRail has already done this several times before which will reduce the costs as well.

7. MULTIPLE-CRITERIA DECISION ANALYSIS

In this chapter the multiple-criteria decision analysis (MCDA) will determine which variant is most suitable for bicycle parking facility one at station Delft.

7.1 CRITERIA DETERMINATION

First the criteria are determined. The new system should solve the problems of the current system. subsequently the criteria efficiency capacity, safety and fastness follow from the problem analysis. The new system should also complement the visions of the main stakeholders. Therefore, the criteria investment costs, operating costs and sustainability follow from the stakeholder analysis.

Investment costs are the costs needed to implement the system and is chosen as a criterion as it is crucial for the project that the investments costs are paid. Without investment costs the renovation of the facility is cancelled. The two top priority stakeholders are most likely to be willing to pay the investment costs. Province governance Zuid-Holland and Ministry of traffic and water management might be willing to partially pay the investment costs, as they partially funded the construction of the bicycle parking facilities as well (Delftse post, 2020). Municipality Delft provided their vision in a report and no concrete plans for innovating the bicycle parking facilities are mentioned. However, the current and future problems regarding the facilities are stated in the report, the municipality acknowledges innovation is necessary (Municipality Delft, 2021). The renovation of the Spoorsingel has cost more than a billion and the Willem van orangjetunnel has cost twice as much as budgeted and is still in construction (Municipality Delft, 2021). Therefore, the municipality is nearly broke (Blommers, 2021). ProRail has more urgent projects as the oldest facility is just six years old and the third facility just opened (2021). If no stakeholder is willing or able to pay the investment costs the project will fail. It is difficult to have absolute values for the investment costs of the new systems, however it is possible to compare them to each other and rank the systems.

Operating costs are the costs needed to keep the system running smoothly. Staff members and maintenance for example. The operating costs are a continue cost item and needed for as long as the system is in operation. From the stakeholder analysis is concluded that NS is responsible for the staff members. The NS target for the next years is to offer affordable transport (NS, 2021). They will not be keen to pay high operating costs. ProRail is responsible for the maintenance of the system and therefore for the maintenance costs of the system. As NS and ProRail are important stakeholders operating costs is chosen as a criterion for the MCDA. If the system is labour intensive or maintenance intensive the operating costs will increase significantly. If the system generates money the operating costs are reduced. It will be difficult to find hard numbers but in relative sentence it must be possible to distinguish the order of the new systems.

The capacity is the number of bicycle parking spots, and the efficiency of the capacity is the capacity per time unit. So, the better the **capacity efficiency** the more bicycles can be parked in the facility in a certain period. The capacity efficiency is a crucial criterion in relation to the problems solving ability of the system and follow from the problem analysis sections 4.3.1 and 4.3.3. The capacity must increase by 25% for 2040 (Municipality Delft, 2021). Because of the crowded surroundings at station Delft increasing the capacity of the bicycle parking facilities is difficult and extremely costly (Municipality Delft, 2021). Since municipality delft is nearly broke and the long construction time it is not likely the capacity will be increased in the next period. The capacity must increase in another way. Therefore, the only way to increase the capacity is to increase the capacity efficiency. The maximum allowed parking time has a big influence on the capacity efficiency and is a problem of the current system described in section 4.3.3.

Sustainability means how harmful the new system to the environment is. the environment is a big reason why public transport and cycling are promoted (Municipality Delft, 2021). The sustainability follows from the stakeholder analysis as the two top priority stakeholders both make a big issue about the sustainability. Municipality Delft has set up all their goals and plans in a big report called mobility program Delft 2040, our Delft sustainable accessible. Municipality Delft even uses the terms in the title. ProRail vision of 2040 is to connect people, cities and companies per railway and make traveling comfortable and sustainable (ProRail, 2021). Prorail and municipality Delft both emphasize the importance of sustainability. However, bicycle parking system do not influence the environment drastically. Only the energy and construction materials have an environmental footprint.

Safety is a wide interpretable concept. The criterion safety follows from the problem analysis section 4.3.1. The first month facility one was in use, 18 bicycles were reported stolen (Delft on Sunday, 2015). However, the issue then was solved and not many bicycles were reported stollen afterwards. The problem regarding the safety are the wrongly parked bicycles that block the footpaths, which could have fatal consequences in case of an emergency (Bonger, 2015). The NS is responsible for the operating the system and thus for making sure all bicycles are correctly parked.

How fast one can find an available spot is the criterion **fastness.** Being able to find a spot for one's bike faster is a big corner stone for the users. The better the signalling the better the user is guided to an available parking spot and the faster the user can park one's bicycle. The criterion follows from the problems analysis section 4.3.2 and the stakeholder analysis chapter 5. How fast the system is in terms of an absolute number is difficult to determine and outside the scope of this report. However, a relative fastness can be determined with logical reasoning.

7.2 WEIGHT ALLOCATION

The criteria are not all equally important according to the stakeholders. From the stakeholder analysis two top priority stakeholders, municipality Delft and ProRail, have the highest priority in choosing the most suitable parking system. The weight factors are thus allocated from their point of view with the other stakeholders in mind.

The weight factors are determined by making a comparison between all criteria. Two design criteria are examined and each time the most important criterion is determined. The results are in table 3**.** If the criterion in the first column is more important than the criterion in the first row, a 1 is assigned to the corresponding cell. When both criteria are equally important a half is assigned to the corresponding cell. In the case that the criterion in the first column is less important than the criterion in the first row a zero is assigned to the corresponding cell.

The absolute key criterion is the efficiency capacity as from the point of view of both top priority stakeholders the capacity problem is the main reason for renovating the facility. The efficiency capacity is therefore more important that all other criteria it is compared to. The investment costs are also directly affecting the top priority stakeholders as they will be the largest investors. The operating costs directly affect stakeholders NS and ProRail. ProRail assigns a higher priority to the investment costs and NS is a less important stakeholder than the municipality, therefore the investment costs are more important than the operating costs (ProRail, 2020). Although both top priority stakeholders have a clear vision regarding sustainability, the impact on the environment by the facility will be low. Since the municipality is nearly broke and ProRail has more pressing projects, the investment costs are chosen over the sustainability (Blommers, 2021) (ProRail, 2021). The safety concerns the NS, which is a less important stakeholder then the top priority stakeholders, thus the investment costs have a higher priority. The fastness is the most important criteria to the users, however the users have little influence. Yet both priority stakeholders promote the active-end and home-end use of the bicycle. To convince the users of this travel mode, the wishes of the users must be taken into consideration. The investment costs are more important than the fastness as it is more important to the top priority stakeholders.

The operating costs affect the stakeholders NS and ProRail which are both important stakeholders. The operating costs are more important than the sustainability as the bicycle parking system has an insignificant Impact on the environment. The safety is a responsibility of the NS and they want to prevent a fatality on their watch. ProRail is a more important stakeholder than the NS, thus the operating costs are more important to the stakeholders than the safety. The fastness is supported by both priority stakeholders and therefore more important than the operating costs. Sustainability and safety have similar importance as the lack of safety can have fatal consequences and sustainability is supported by both top priority stakeholders. Fastness is more important than the safety and sustainability as it is a key characteristic of the parking system and could solve two problems in once.

Once the priorities are determined, the score of each criterion is the sum of all scores. To calculate the weight factor, the score of each criterion is divided by the sum of all scores and multiplied by hundred to form a percentage. The weight factor indicates how important each criterion is to determine the most suitable bicycle parking system. The calculated weight factors are: efficiency capacity has a weight factor of 33.3%, the investment costs 26.7%, the fastness 20.0%, the operating costs 13.3% and finally sustainability and safety have the same weight factor of 3.3%.

Table 2 calculating of the weight factors per design criterion

	Investment costs	Efficiency capacity	Operating costs	Sustainability	Safety	Fastness	Score	Weight factor
Investment costs		0	1	1	1	1	4	26,7%
Efficiency capacity	1		1	1	1	1	5	33,3%
Operating costs	0	0		1	1	0	2	13,3%
Sustainability	0	0	0		0.5	0	0,5	3,3%
Safety	0	0	0	0.5		0	0,5	3,3%
Fastness	0	0	1	1	1		3	20,0%

7.3 THE MCDA PER CRITERION

Now the weight factors are determined, the variant are ranked from worst to best for each criterion. The worst variant gets a score of one and the best variant is awarded a score of four. The four variants are the current system, the Utrecht variant, the app variant and the light indicator variant. The current system is in the MCDA as well to compare the variants to the current system. The variant with the highest total score is the most suitable bicycle parking system.

7.3.1 INVESTMENTS COSTS

The investment costs are difficult to compare to the current system as for the current system no extra investment costs need to be made. Therefore, the current system scores best on investment costs and is award a score of four. The Utrecht variant scores second best and is given a score of three. The investment costs consist of more RTI-signs and the construction of a central check-in and check-out point. As the system is already in use in several bicycle parking facility the necessary equipment is already developed and optimized. The fifty RTI-signs costs under hundred thousand euros as only the signs need to be installed (Brinc, 2018). Constructing the central check-in and check-out points is difficult to estimate but as all equipment is already available, it just needs to be ordered and implemented. ProRail can estimate the costs very accurately as they were responsible for constructing several parking facilities. The row sections need to be painted as well but will have minimal influence on the total investment costs.

The light indicator variant scores third best. The investment costs are mainly installing the light indicators. One light indicator is used per five bicycle racks. The facility has a total capacity of five thousand racks thus thousand light indicators are necessary. The total parking guidance system in the parking garage in Fort Collins was 260 thousand dollars, which is about 225 thousand euros (Swanson, 2015). The lights used for the parking facility only need to be green instead of green, red and blue. The facility already has bicycle parking sensors in the racks, thus new sensors are unnecessary. This leads to significant costs reduction. The total investment costs of the light indicating system will never exceed the 225 thousand euros. Two central check-in and check-out points need to be constructed as well, but as mentioned before the investment costs are likely to be relatively low. The light indicator system makes this variant more expensive than the Utrecht variant.

The app variant has the highest investment costs as the whole app needs to be developed. It is difficult to estimate the total investment costs of constructing the app. According to De Klerk developing an app for an enterprise is at least 625 thousand euros (Klerk, 2019). However, the total costs greatly depend on the number of functions on the app and the complexity of the app. As the design of the app is rather simple and straightforward 625 thousand euro seems a bit steep. Implementing the rest of the system has minimal impact on the total investment costs. Because the high development costs of the app the app variant scores worst on the criterion investment costs.

7.3.2 EFFICIENCY CAPACITY

All variants are compared to each related to the efficiency of the capacity. The efficiency of the capacity is greatly affected by the maximum allowed parking time, therefore all maximum parking times are listed in table 4 below. As all variants will increase the efficiency capacity the worst system regarding the efficiency capacity is the current parking system. The Utrecht variant is award two points. The maximum parking time decreases to 72 hours. The maximum parking time is thus significantly reduced. For three and a half thousand parking spots users are even motivated to park their bicycle less than 24 hour, because after 24 hours a fee of €1.25 needs to be paid per 24 hours. The users are stimulated to park their bicycle shortly or will use free of charge facilities two and three. Not the maximum parking time is the crucial factor for the efficiency capacity but how long on average each bicycle is parked. By this measure the average parking time will drop significantly compared to the current system.

Second best is the app variant. A third of the capacity has a maximum parking time of 24 hours. The average parking time for this section must be less than 24 hours, which means fifteen hundred bicycles can be parked in that section every 24 hours. The year subscribers are allowed to park their bicycle a bit longer. Therefore, the efficiency of the capacity of this section is lower. Conclusively the app variant as a better efficiency capacity than the Utrecht variant.

The light indicator variant increases the efficiency capacity most drastically as the whole facility has a maximum allowed parking time of 24 hours. The maximum parking time is thus by a factor fourteen reduced. The average parking time for the entire facility is thus less than 24 hours. Meaning a least five thousand bicycles can be parked in the facility every 24 hours. The efficiency capacity of the light indicator variant is thus higher than the app variant.

Table 3 the maximum parking times per variant

Variant	Capacity	Maximum parking time
Current system	5 thousand	14 days
Utrecht variant	Year subscription: 1500 Central check-in: 3500	72 hours 72 hours first 24 hours free
App variant	Year subscription: 3500 'normal 'racks: 1500	72 hours 24 hours
Light indicator variant	5 thousand	24 hours

7.3.3 OPERATING COSTS

Of all variants a rough indication of the operation costs is determined. The operating costs consist of three elements, the maintenance costs, the salary of the staff and the money generated by the system. the maintenance costs and the salary of the staff has a negative influence on the operating costs and the money generated by the system has a positive influence on the operating costs. The total salary needed for the staff is relatively determined by listing the tasks of the staff. In table 5 on oversight of all operating costs per system is created.

The current system is the worst regarding the operating costs. Because the system generates no money the operating costs are only negatively influenced. The staff has relatively many tasks, roughly the same as the Utrecht variant and the app variant but both systems generate a significant cash flow. The maintenance to the current system is limited, however the maintenance of the other system is limited as well.

The third best variant is the light indicator variant. The variant has the highest maintenance costs as thousand lights must be maintained. The variant has less staff tasks than the current system and also generates a small cash flow by parking fees. The light indicator variant scores slightly better than the current system.

The second-best variant is the Utrecht variant. The variant is mainly better than the light indicator variants because fifteen hundred year subscription racks generate a significant money flow. A least fifteen hundred year subscriptions are signed, each subscription generates 75 euros per year. A year subscriber will not park the bicycle every day at the facility therefore more year subscribers than the amount of year subscription racks could be collected. The other 3500 bicycles racks generate money as well because after the first 24 hours a fee of €1.25 per 24 hours is collected. The Utrecht variant has more staff tasks than the light indicator variant but less maintenance. The Utrecht variant scores better than the light indicator variant and is thus second best regarding the operating costs.

The best variant is the App variant. The app variant has 3500 year subscription racks, thus a least 3500 year subscribers. At least 262 thousand euro is generated by the system. The app variant thus generates the most money. The app variant has one more task for the staff than the Utrecht variant and has comparable maintenance costs. The high money flow ensures that the app variant is better than the Utrecht variant and thus the app variant is the best variant regarding the operating costs.

Table 4 all different forms of operating costs listed per variant.

Variant	Maintenance	Staff tasks	Money generated
Current system	The sensors in the racks	remove wrongly parked bicycles remove bicycles that exceed the maximum parking time	No money is generated
Utrecht variant	The sensors in the racks RTI-signs (50 more) Check-in point	remove wrongly parked bicycles Check stickers year subscribers	1500 year subscription racks 3500 central check-in parking spots
App variant	The sensors in the racks Maintenance app	remove wrongly parked bicycles Check stickers year subscribers and reservations Remove bicycles parked longer than 24 hours 1500 racks	3500 year subscription racks
Light indicator variant	The sensors in the racks Thousand light indicators	Remove wrongly parked bicycles	Only fees are generated from exceeding max parking time

7.3.4 SUSTAINABILITY

The sustainability is the impact the new system has on the environment. For parking system, the sustainability consists of the energy the system uses and the construction materials that need to be used. The three variants are compared to current system and to each other. The current system scores best on the sustainability part as no extra construction materials are necessary and all other variants use more energy.

The Utrecht variant scores second best. The Utrecht variant uses fifty extra RTI-signs which cause the energy consumption to increase. The central check-in points cause the energy consumption to increase as well. However, fifty additional lights and two OV-chipcard scanners do only increase the energy consumption by a margin. For construction the fifty RTI-signs what electronics and plastic are necessary. The paint for colouring each row section and the construction materials for the central check-in and check-out points have a small footprint on the environments as well. The Utrecht variants scores therefore slightly worse than the current system.

The app variant scores third best. The app variant will lead to a significant increase in energy consumption. Running the app costs a lot of energy. The variant is therefore the worst variant regarding energy consumption. However almost no construction materials are needed to implement the system. The app variant is thus worse compared to the Utrecht variant regarding the sustainability.

The light indicator variant is the worst variant regarding the sustainability. Thousand LED light are added to the energy consumption which is far more than the Utrecht variant and slightly better than the app variant. The light indicator variant needs a lot of construction materials to be implemented. Thousand LED lights need to be made and installed, plus two central check-in and check-out point need to be constructed. The light indicator variant scores slight better on the energy consumption compared to the app variant and significantly worse on the construction materials part. Conclusively the light indicator variant is the worse variant regarding the sustainability.

7.3.5 SAFETY

The safety improvement of each variant is ranked in this section. The safety is mainly keeping the footpaths passable, thus without obstruction by wrongly parked bicycles. The safety issue could be fixed by instructing the staff to remove all excess bicycles. The safety regarding the system is how well the system can refuse users when the maximum capacity is achieved. The safety regarding stealing is not a big issue at the current facility however I could always be improved.

The current system scores worst regarding the safety. The facility is always accessible for everyone. No measures are taken to reduces the number of wrongly parked bicycles. The staff cannot remove that many bicycles, right now only the badly parked bicycles are removed. However, all bicycles which are parked outside the racks should be removed to prevent fatal consequences during emergencies. Video cameras prevent the bicycles from being stolen however it is still possible to steal bicycles from the facilities as it is easily accessible.

The third best variant is the light indicator variant. The two central check-in points mean the facility is not as easily accessible. However, it is not possible to close the check-in point if the facility is full, because users may use it as a tunnel to cycle to the other side or facilities two and three. Through the central check-in point bicycles are less likely to be stolen as it is an extra obstacle.

Second best is the app variant. The year subscription part (3500 racks) uses reservations via an app. When the part is full no reservations can be made, the bicycles could not be parked in the year subscription part. When year subscribes park their bicycle outside the racks it is directly clear whose bicycle it is. The first time a warning is given, the second time the year subscription of the year subscriber is denied. The other part of the facility is almost the same as the current system, thus the same regarding the safety. On terms of the safety regarding stealing the variant does not improve the current system.

The best variant is the Utrecht variant. The central check-in section (3500 racks) is only accessible by bicycles if parking spots are available. A different check-in point should be integrated in the design to keep the section accessible for pedestrians as it is a short cut to the train platforms. No bicycles will therefore be parked outside the racks, improving the safety significantly. The year subscription part works the same as described in the app variant. When year subscribes park their bicycle outside the racks it is directly clear whose bicycle it is. The first time a warning is given, the second time the year subscription of the year subscriber is denied. Bicycles are less likely to be stolen from the system as the check-in point forms an extra barrier. The Utrecht variant is thus better regarding the safety then the app variant.

7.3.6 FASTNESS

The fastness is how well the users is guided to the available parking spots. This criterion is directly influenced by the signalling element of the system. the goal of signalling is to guide the user as direct and fast as possible to an available parking spot. In table 6 below all signalling techniques of each element are listed.

Table 5 signalling techniques of all the variants

Variant	Signalling technique
Current system	RTI-sign per facility RTI-sign per row
Utrecht variant	RTI-sign per facility RTI-sign per row and tier RTI sign per row section and tier
App variant	Year subscription section: interactive map in the app 'normal' section: RTI-sign per facility RTI-sign per row and tier RTI-sign per row section and tier
Light indicator variant	Light indicator per five bicycles racks

The current system score worst regarding the fastness. As all variants have improved signalling techniques compared to the current system. the third best variant is the Utrecht variant. The variant expends the two level RTI-sign signalling to three level RTI-sign signalling. Distinguishing the upper and lower racks. A RTI-sign is now used for each fifty racks. The Utrecht variant has better fastness than the current system.

The second-best system is the light indicator variant. For each five bike racks a light indicator is fitted. The light indicators also distinguish upper and lower racks. The lights for the upper racks are mounted to the ceiling and for the lower racks to the floor. As the ration sign racks is one in five for the light indicator variant and one in fifty for the Utrecht variant, the light indicator variant has better fastness.

The best system regarding the fastness is the app variant. The normal section (1500 racks) uses the same signalling techniques as the Utrecht variant. For the year subscription part (3500 racks) the app is used for signalling. The app contains an interactive map, which exactly indicates the locations of the available parking spots. if a reservation is made the user knows the parking spot the bicycle can be parked before entering the facility. Thence can straight cycle to the reserved parking spot. The app is different from all other systems as it is no longer necessary to search for a spot. Therefore, the app variant scores best on fastness.

7.4 RESULTS

Each score is multiplied by the weight of the corresponding criterion. The sum of these results is the final score of the variant. If one variant is for all criteria the best variant, the maximum score of 4 is achieved. Lowest possible total score is one. The calculations are provided in appendix A. The final scores from the multiple-decision criterion analysis are a score of 1.9 for the current system, the Utrecht variant has a score of 2.6, the app variant has a score 2.6 and finally the light indicator variant has a total score of 2.8, see table 7. Apart from the current system are the scores close to each other, even though the variants were ranked and thus had different values per criteria. The Utrecht variant and the App variant even have the same total score.

The current system only scores high for the investment costs and sustainability as the system is already implemented. For the rest of the criteria the system is last and thus the worst total variant. The Utrecht variant never is the worst option. The variant is best on operating costs and safety; however, these criteria have relative low weight. The most important criterion is the efficiency capacity where the variant is only better than the current system. The Utrecht variant is thus an average variant.

The app variant scores very high on fastness and efficiency capacity and operating costs are good as well. However, the variant score variant very low on investment costs, resulting in the same score as the Utrecht variant. The light indicator variant score best on the criterion efficiency capacity and is average on the other criteria resulting in the highest total score.

Table 6 the total scores of the MCDA of all varaints

	Current system	Utrecht variant	App variant	Light indicator variant
Total score	1.9	2.6	2.6	2.8

8. CONCLUSION

The goal of this report is designing a bicycle parking system that corresponds to the research question is: “which bicycle parking system is most suitable for bicycle parking at station Delft?”. To answer the main research question six sub-questions are formulated. From these sub-questions can be concluded.

A bicycle parking system consists of three elements, accessibility, signalling and regulations. These three elements together define a bicycle parking system. The elements accessibility are all actions the users must do from entering the facility to leaving the facility. Signalling is how fast and direct the user is guided to the available parking spots. the regulations are all regulations that apply to the facility, with the most important regulation the maximum parking time.

The current parking system has problems that followed from the problem analysis. The first problem is users are not properly guided to the available parking spot. The second problem is wrongly parked bicycles block escape routes. The third problem is the current maximum parking time is far too long. The fourth problem is the option to pay for parking lacks.

To redress these problems, alternative designs are developed. These designs are constructed out of reference projects and concepts. The consulted reference projects are bicycle parking facility Utrecht, Prinsenhof garage in Delft, lake street garage in Fort Collins and the bicycle parking app concept.

From these reference projects and concept three new bicycle parking variants are constructed, the Utrecht variant, the app variant and the light indicator variant. The variants are constructed out of three competencies, complementing, costs and problem solving. The Utrecht variant is a copy of the bicycle parking system at the bicycle parking facility in Utrecht, except for the decreased maximum parking time. The app variant is a combination of the bicycle parking app, which allows users to reserve a spot up to one hour in advance, and the year subscription. The light indicator variant has one light indicator per five bike racks and uses two central check-in and check-out point.

The important stakeholders are ProRail, Municipality Delft, NS and the users. The top priority stakeholders are ProRail and Municipality Delft, these stakeholders should be greatly involved in process. ProRail was responsible for the construction of the bicycle parking facilities and will be responsible for the renovation as well. The Municipality Delft is the main investor and has the biggest share in the facilities. To cover the investment costs for the renovation municipality Delft is needed. The NS is responsible for operating the facilities and thus for the staff members. The users have great interest in a new parking system but have low influence. The users need help to participate in process.

For the multiple-criteria decision analysis the following criteria with attached weight factor are used, investment costs 26.7%, efficiency capacity 33.3%, operating costs 13.3%, sustainability 3.3%, safety 3.3% and fastness 20%. The most important criterion is efficiency capacity as from the point of view of both top priority stakeholders the capacity problem is the main reason for renovating the facility.

Looking back at the main research question the most suitable bicycle parking system for facility one is the light indicator variant. The final scores from the multiple-decision criterion analysis are a score of 1.9 for the current system, the Utrecht variant has a score of 2.6, the app variant has a score 2.6 and finally the light indicator variant has a total score of 2.8. The evaluation and redesign for bicycle parking facilities must be further elaborated in order to determine the most suitable parking system for all three facilities. Different parking systems for each facility is among the possibilities.

9. FUTURE RESEARCH

The parking guidance system and the parking reservation app are still in the concept phase. The light indicator variant is the most suitable system for facility one, however the parking guidance system is still a concept. The parking guidance system should be developed. By a trial period the system can be analysed and further improved. Eventually if the parking guidance system is proven to be convenient and useful the system could be used for parking facility one at station Delft. A lot of time and effort is therefore still needed to develop the system.

ProRail and the NS possess over a lot more data regarding the investment costs, operation costs and user preferences. If those stakeholders are consulted the MCDA would be more accurate. All lot of the characteristics of the variants are now roughly estimated. With more input from the crucial stakeholders, it is possible to determine the characteristics more accurately.

The design solution and problem analysis only focus on facility one. the evaluation and redesign of bicycle parking facility two and three are needed to completely answer the main research question. The same systematic approach on evaluation and redesign could be applied to other bicycle parking facilities as well. As a last recommendation to determine the preferred bicycle parking system with specific regulation according to the users, a user survey can be conducted

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APPENDIX A

The appendix included the calculations of the MCDA for the three variants plus the current system.

Table A 1 calculations MCDA

		Utrecht variant		App variant		Light indicator variant		Current system	
	Weight factor	Score	Score * weight factor	Score	Score * weight factor	Score	Score * weight factor	Score	Score * weight factor
Investment costs	26,7%	3	0.800	1	0.267	2	0.533	4	1.067
efficiency capacity	33,3%	2	0.667	3	1.000	4	1.333	1	0.333
Operating costs	13,3%	4	0.533	3	0.400	2	0.267	1	0.133
Sustainability	3,3%	3	0.100	2	0.067	1	0.033	4	0.133
Safety	3,3%	4	0.133	3	0.100	2	0.067	1	0.033
fastness	20,0%	2	0.400	4	0.800	3	0.600	1	0.200
total score	100%		2,63		2,63		2,83		1,90