Applying the concept of mobility hubs in the context of the Achtersluispolder

BSc thesis Civil Engineering

Author	Alex Mouw
Student number	1974319
Internal supervisor	Prof. dr. ing. K.T. Geurs
External supervisor	Ir. M. H. W. B. Derksen
Organisation	Arcadis
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UNIVERSITY OF TWENTE. ARCADIS

Preface

This bachelor thesis has been conducted to analyse how mobility hubs could be implemented in the Achtersluispolder in Zaanstad. The aim was to offer recommendations on how to apply the concept of mobility hubs in terms of location, number, user and criteria, in the context of the Achtersluispolder. By reviewing literature and interviewing experts in the field of mobility hubs, valuable information was collected. This information was subsequently used to design three scenarios on how mobility hubs can be realised in the area. Finally, these three scenarios were evaluated using a multi-criteria decision analysis. Before delving into the research, I would like to take a moment to thank those that have helped me during this process.

During my research, I have been supervised by professor Karst Geurs from the University of Twente and engineer Martijn Derksen from Arcadis. I would like to thank them for their feedback and support, as their input helped me to write this report. Furthermore, I want to thank Milko Buter, Mark Degenkamp and Gijs van der Kolk from the municipality of Zaanstad for offering me the opportunity to use the Achtersluispolder as a case for my thesis and for answering my questions. Moreover, I want to thank my fellow students Leon Besseling and Niek Klein Wolterink for their willingness to read my thesis (proposal) and provide me with valuable feedback. Lastly, I want to thank Roos for her willingness to listen, think along with me, support when I needed it and clever ideas.

Alex Mouw
Almelo, June 2020

Summary

Note: a Dutch summary is provided below.

To reduce the negative environmental, spatial and societal impacts of private car ownership, a shift from private ownership towards shared mobility is needed. One of the means to accomplish this is the concept of mobility hubs. A mobility hub offers various shared modes of transport at the same location, such that users can easily use and switch between modes that best suits their mobility needs. This study focuses on offering recommendations on how to apply mobility hubs in the context of the Achtersluispolder. This neighbourhood is an area within the municipality of Zaanstad and will transform in the coming decades from an industrial district into a mixed residential and working area.

In order to offer recommendations, first the characteristics of hubs and its users were examined. When considering the location and number of hubs, it appeared from literature review and interviews that there is not a single manifestation of hubs, as a result hubs can be large and small, there can be a large or small number of hubs and they can be located above-ground or underground. Looking at the user characteristics, it became clear that the most influential aspects are being younger, living in a high density area, having a higher education level and a lower car dependence. Lastly, the criteria that are most decisively for a successful hub usage are: ease of use, distance to the hub and vehicle costs.

To develop scenarios for hubs in the Achtersluispolder, three frameworks based on the Technology Acceptance Model in combination with the key design element *distance to the hub* were developed. First, when users experience more effort to reach a hub compared to reaching their private car, shared mobility is an additional service. Since the goal of the municipality is to decrease the use of private cars in the Achtersluispolder, this option was not used in one of the three scenarios. Second, if the same amount of effort is experienced in order to reach a hub compared to a privately owned car, shared mobility becomes an interesting option. Last, when users experience more effort to reach their private car compared to reaching a hub, mobility hubs have the greatest chance to replace the private car. These concepts were used to develop three scenarios for mobility hubs in the Achtersluispolder.

The first scenario focuses on offering all modes of transport, both private and shared, within a distance of 150 meters. This results in 35 small hubs, spread across the area. The second scenario focuses on offering shared mobility closer to the users than privately owned cars, such that shared mobility is actively stimulated. This results in 5 big parking garages and 13 smaller mobility hubs. The last scenario highly focuses on sustainable transport and car-free streets, which means there is an emphasis on walking, cycling and public transport. This results in 9 bigger hubs with both private and shared cars and 20 smaller hubs that offer shared light electric vehicles.

To encourage the use of mobility hubs and to discourage private cars, several boundary conditions – which are again linked to the Technology Acceptance Model – have to be met. One of the most important boundary conditions is a low parking standard: when lowering the parking standard, the effort of owning a private car increases, while the effort of using shared mobility remains the same. Another important boundary condition is paid parking, to increase the attractiveness of shared mobility. Lastly, residents should be able to use the mobility hubs from the moment they settle in the area, because otherwise habitual travel behaviour without mobility hubs will be formed. It is essential that these boundary conditions are fulfilled, such that the greatest chance of success is ensured.

To assess the three scenarios, a Multi-Criteria Decision Analysis (MCDA) with weighting has been performed. To determine the importance of the different criteria, the interviewed experts and experts of Arcadis divided 100 points among criteria they see as important. This resulted in the following ranking from high to low: ease of use, distance to the hub, vehicle costs, availability of the vehicles, state & (social) safety of the hub, visibility of the hub and diversity of the vehicles.

Using the Analytic Hierarchy Process, the ranking of the seven mentioned criteria was translated into weights. Also, the three scenarios were compared on each of the seven criteria. This resulted in a weighted comparison, in which scenario 1 contributed the most to achieving the goal of a successful implementation of mobility hubs in the Achtersluispolder. It should be noted that the various stakeholders may have other priorities such as sustainability, next to the mentioned seven criteria, which makes it important to see the performed multi-criteria decision analysis as an indication.

Finally, it is important to notice that the presented scenarios are not the solution. Rather, they serve as a starting point from which the strategy for implementing mobility hubs in the Achtersluispolder can be determined. Within this strategy, it is recommended to develop each hub fitting the wishes and needs of the area it serves. If a neighbourhood needs a supermarket for example, locating it in or near a mobility hub can increase the attractiveness of both the supermarket and the mobility hub, and with that also the (social) safety of these hubs. Furthermore, it is recommended to make the hubs fit in with the residents of a specific neighbourhood and vice versa. For example, an area with residents that have a lower car dependence – such as students and social housing – probably need a hub with a public transport connection and without many shared cars. The results suggest that mobility hubs can contribute to a more sustainable way of travelling in the Achtersluispolder. Since mobility hubs are a new phenomenon, it is important to apply the concept in a flexible way, such that it can be adjusted to unexpected situations and future developments.

Samenvatting

Om de negatieve gevolgen van privé-autobezit op het milieu, de (openbare) ruimte en de maatschappij te verminderen, is een transitie van privé-autobezit naar gedeelde mobiliteit nodig. Een van de methoden om dit te bereiken is het concept mobiliteitshubs. Een mobiliteitshub is een plek waar verschillende gedeelde voertuigen worden aangeboden, zodat gebruikers makkelijk kunnen wisselen tussen transportmiddelen die het best aansluiten bij hun mobiliteitsbehoefte. Dit onderzoek had als doel een advies te geven over hoe mobiliteitshubs in de toekomstige Achtersluispolder kunnen worden toegepast. De Achtersluispolder is een industrieel gebied in de gemeente Zaanstad dat de komende decennia zal worden getransformeerd tot een gemengd woon- en werkgebied.

Om aanbevelingen te kunnen doen, zijn eerst de eigenschappen van mobiliteitshubs en de gebruikers onderzocht. Kijkende naar de locatie en het aantal hubs, bleek uit literatuur en interviews dat er niet één type hub is. Hubs kunnen klein en groot zijn, er kunnen veel en weinig hubs worden geïmplementeerd en ze kunnen ondergronds of bovengronds worden gebouwd. De karakteristieken van hub-gebruikers zijn met name: jonger, levend in een gebied met een hoge dichtheid wat betreft mensen en banen, hoger opgeleid en minder autoafhankelijk. De hubeigenschappen met de grootste invloed zijn: gebruiksgemak, afstand tot de hub en voertuigkosten.

Om scenario's te ontwikkelen die ingaan op hoe mobiliteitshubs in de Achtersluispolder toegepast kunnen worden, zijn drie kaders ontwikkeld op basis van het Technology Acceptance Model in combinatie met het ontwerpcriteria *afstand tot de hub*. Ten eerste, als gebruikers meer moeite ervaren om een hub te bereiken vergeleken met hun eigen auto wordt gedeelde mobiliteit een extra service. Aangezien de gemeente Zaanstad het privéautobezit wil verlagen in de Achtersluispolder, is dit idee niet verwerkt in een van de drie scenario's. Ten tweede, als dezelfde mate van moeite wordt ervaren om een hub te bereiken als een privéauto, dan wordt gedeelde mobiliteit een interessante optie. Ten derde, als gebruikers meer moeite ervaren om hun eigen auto te bereiken vergeleken met het bereiken van een hub, dan hebben mobiliteitshubs de grootste kans van slagen. Deze concepten zijn gebruikt om drie scenario's voor mobiliteitshubs in de Achtersluispolder te ontwikkelen.

Het eerste scenario focust op het aanbieden van alle vervoersmiddelen, zowel privé als gedeeld, binnen een afstand van 150 meter. Dit resulteert in 35 kleine hubs verspreid over het gebied. Het tweede scenario richt zich op het dichterbij aanbieden van gedeelde mobiliteit ten opzichte van de privéauto. Dit resulteert in 5 grote parkeergarages en 13 kleinere mobiliteitshubs. Het derde scenario focust zich met name op duurzame mobiliteit en autoluwe straten, wat betekent dat er extra nadruk ligt op lopen, fietsen en openbaar vervoer. Dit resulteert in 9 grotere hubs met zowel privé als gedeelde auto's en 20 kleinere hubs met e-bikes, e-scooters en e-bakfietsen.

Om het gebruik van mobiliteitshubs aan te moedigen en het gebruik van een eigen auto te ontmoedigen, moet er aan verschillende randvoorwaarden worden voldaan. Deze randvoorwaarden zijn opnieuw gebaseerd op het Technology Acceptance Model. Een van de belangrijkste voorwaarden is een lage parkeernorm: als de parkeernorm laag is, kost het bezitten van een eigen auto extra moeite, terwijl de moeite voor het gebruik van een gedeeld voertuig gelijk blijft. Een andere voorwaarde is betaald privéparkeren, opnieuw om het gebruik van gedeelde mobiliteit aantrekkelijker te maken. Daarnaast moeten inwoners van het gebied de mobiliteitshubs kunnen gebruiken vanaf het moment dat zij verhuizen, omdat er anders weer gewoonte reisgedrag ontstaat. Het is essentieel dat aan deze randvoorwaarden wordt voldaan, zodat de mobiliteitshubs de grootste kans van slagen hebben.

Om de genoemde drie scenario's te beoordelen is een gewogen Multi-Criteria Analyse (MCDA) toegepast. Om de mate van belangrijkheid van de verschillende criteria te bepalen, zijn twaalf experts gevraagd om 100 punten te verdelen over de criteria die zij belangrijk vinden.

Dit resulteert in de volgende ranglijst van zeven criteria, van hoog naar laag: gebruiksgemak, afstand tot de hub, voertuigkosten, beschikbaarheid van de voertuigen, staat & (sociale) veiligheid van de hub, zichtbaarheid van de hub en diversiteit in het aanbod van voertuigen.

Door gebruik te maken van de Analytic Hierarchy Process (AHP) kon de bovengenoemde ranglijst omgezet worden in wegingen. Daarnaast, konden de drie scenario's worden vergeleken op elk van de zeven criteria. Dit resulteerde in een gewogen vergelijking, waarbij scenario 1 het meest bijdraagt aan de succesvolle implementatie van mobiliteitshubs in de Achtersluispolder. Een belangrijke kant-tekening hierbij is dat verschillende stakeholders waarschijnlijk verschillende belangen hebben, zoals duurzaamheid, naast de genoemde zeven criteria, wat aangeeft dat het belangrijk is om de uitgevoerde MCDA als een indicatie te zien.

Ten slotte is het belangrijk om te benoemen dat de ontworpen scenario's niet dé oplossing zijn. Ze fungeren als startpunt, van waaruit de strategie voor het implementeren van mobiliteitshubs in de Achtersluispolder kan worden vastgesteld. Binnen deze strategie is het aanbevolen om elke hub te ontwerpen op een manier die past bij de wensen en behoeften van het bedieningsgebied. Als een buurt behoefte heeft aan bijvoorbeeld een supermarkt, dan kan het plaatsen van een supermarkt in of vlakbij een mobiliteitshub de aantrekkelijkheid van zowel de supermarkt als de mobiliteitshub vergroten. Hierbij zal waarschijnlijk de (sociale) veiligheid van de hubs ook verbeteren. Daarnaast is het aanbevolen om de hubs aan te laten sluiten bij de bewoners van dat gebied en vice versa. Als de bewoners van een bepaalde buurt een lager autobezit hebben, zoals studenten en sociale huur, dan heeft die buurt waarschijnlijk behoefte aan een hub met openbaar vervoer en die minder gedeelde auto's aanbiedt. Samenvattend kan worden gesteld dat mobiliteitshubs kunnen bijdragen aan een duurzamere manier van reizen in de Achtersluispolder. Aangezien mobiliteitshubs een nieuw fenomeen zijn, is het belangrijk om het concept zo toe te passen dat het in de toekomst kan worden aangepast aan ontwikkelingen en onvoorziene omstandigheden.

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1. Introduction

1.1 Background

To reduce the impacts of climate change, the Paris Agreement was formulated in 2015 (UN, 2015). The Netherlands has used this agreement to (re)formulate its climate goals: 49% less greenhouse gas emission in 2030 compared to 1990 and 95% less greenhouse gas emission in 2050 (Rijksoverheid, 2019). An objective per sector has been defined in order to reach this goal. This means for the transport sector a minimal reduction of 60% CO_2 emission by 2050 compared to 1990 (Ministerie van Economische Zaken, 2016). The transport sector as a whole contributes to climate change by being one of the largest sources of greenhouse gas emission and by causing environmental problems like noise, habitat fragmentation and air pollution (EEA, 2018a). Using private cars, on which our current transportation system is heavily based, contributes to depletion of resources, inefficient land use and congestion, next to the above mentioned problems (EEA, 2018b). In 2018, between 3,3 and 4,3 billion euros – which is 0,5% of the GDP – were lost due to congestion on the road network in the Netherlands (KiM, 2019). Research conducted in the province of Zuid-Holland, showed that circa 20% less houses were built on the researched locations due to parking (Provincie Zuid-Holland, 2017).

To transform the transportation sector and to make it more sustainable, three revolutions can be distinguished: the introduction of automated vehicles, the shift from private ownership towards shared mobility and the replacement of fuel-powered vehicles by electric vehicles (Sperling, 2018). For this research, the shift from private ownership towards shared mobility is of particular interest. A core method towards this shift is carsharing. Carsharing can be defined as “a system that allows people to rent locally available cars at any time and for any duration” (Frenken, 2015, p. 9). Research has shown that carsharing can decrease private car ownership and the number of car-driven kilometres (Shaheen, Mallery, & Kingsley, 2012; Nijland & Van Meerkerk, 2017). Next to that, carsharing has also positive effects on the amount of used (public) space. Using the research of Nijland, Van Meerkerk and Hoen (2015), it can be calculated that carsharing with 90.000 users saves 120.000 m^2, because of the lower parking needs (KiM, 2015). As the number of users is expected to increase in the near future, this space saving will further increase (CROW, 2019a).

1.2 Carsharing and mobility hubs

Carsharing is a broad concept, which makes it necessary to distinguish between the various forms. As depicted in Figure 1, there are typically two carsharing types: Business-to-Consumer (B2C) and Peer-to-Peer (P2P). With B2C, an individual rents a vehicle from a firm that has its own fleet of carsharing vehicles. With P2P, cars are shared between individuals, with a firm as mediating platform. Within B2C, two types can be distinguished: roundtrip and one-way. Roundtrip means that cars have to be returned to the same depot as to where they were rented from. One-way means that users return a car at a different location than where it was picked up (Münzel, 2020; Shaheen, Chan, Bansal, & Cohen, 2015).

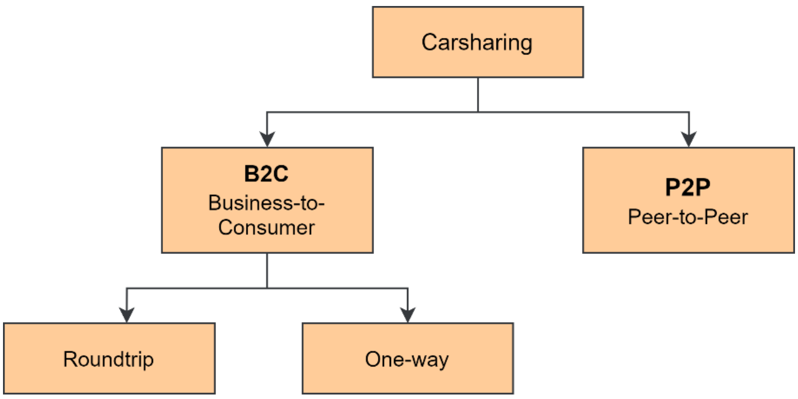

Figure 1 - Types of carsharing

Mobility hubs, which is the concept that will be used for this research, uses the idea of carsharing. Since the mobility hub has not been defined consistently, the following definition will be used in this research:

A place where various shared modes of transport are available, such that users can easily use and switch between modes that best suits their mobility needs. A connection with public transport is possible but is not a requirement.

Elaborating on this definition, a mobility hub offers shared vehicles, such as (e-)bikes, (e-)scooters and (e-)cars. All these vehicles can be reserved through one digital platform and are offered as B2C and/or P2P. At the mobility hub, users can use and switch between private modes of transport to shared modes, vice versa or between shared modes; a connection with public transport is possible, but optional. An impression of a mobility hub is shown in Figure 2.

To get a clearer picture of the concept of mobility hubs, different types of mobility hubs are examined. The categorisation as described in the Deltaplan 2030 is followed (Mobiliteitsalliantie, 2019), since this document is written especially for the Netherlands which makes it fitting within the Dutch context. The first kind of hub is at the edge of the city where national and regional public transport, car traffic, shared mobility, and bicycles meet. At these locations there are also other services possible, such as restaurants, shops and parcel services. A current example are Park & Ride facilities, although these locations are at the moment mainly focused on cars and public transport (PT). The second type are hubs as PT nodes including space efficient transport, both private and shared. These types are within cities and at locations which are suitable for housing, such that living and travelling naturally merge.

Figure 2 - Artist impression of a mobility hub, designed by Tyler Stevermer (2014)

Furthermore, in rural areas hubs can serve as transfer locations for public transport, (e-)cars and (e-)bikes. A current example is a regional train station, which could be improved by offering shared mobility. The fourth type of hub is situated at a business park, with shared mobility for employees. A current example can be business-to-business (B2B) carsharing, where an employee can use shared mobility through their employer (Clark, Gifford, Anable, & Le Vine, 2015). The fifth kind is a logistics hub at the edge of cities, from where goods are transferred efficiently and emission-free to the city. Recently, such a hub has been announced for the city of Amersfoort (AD, 2020). The last type are temporary hubs, for example to guarantee the accessibility of an area during the (re)development of an area. Van Rooij (2020) adds a seventh type of hubs, the so-called neighbourhood hubs. These small hubs do not have a public transport connection, but are located at a distance of 2 km of a PT stop. Residents can use the shared mobility offered at these hubs for first/last-mile transport to the PT stop. These last hubs are already being implemented in the Netherlands (Gemeente Amsterdam, 2019).

1.3 Problem description

To deal with the increasing urban pressure in the Amsterdam metropolitan area, a new residential area is planned near the river IJ in the municipality of Zaanstad (see Figure 3). This neighbourhood will be located on what is currently an industrial area, called the Achtersluispolder. The municipality of Zaanstad wants to transform this district into an area where people can work, live and recreate. In 2040 there will be 8.500 houses and 8.500 jobs located in the Achtersluispolder. The Achtersluispolder will be the hinge point between Zaandam and Amsterdam (see Figure 4).

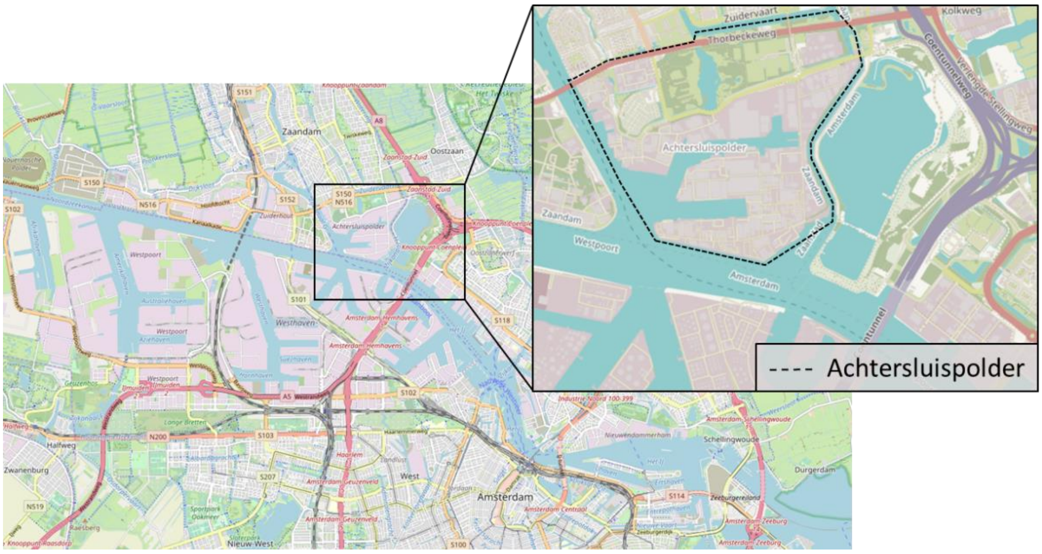

Figure 3 - Location of the Achtersluispolder

One of the challenges of this development is the mobility of the Achtersluispolder. In general, Zaanstad faces serious challenges regarding accessibility because of high traffic intensities. These intensities cause traffic jams, but also reduce the local air quality with the high emissions of particulate matter. The Achtersluispolder is located near the A8/A10 and an important regional road, the 'Torbeckeweg'. Both the A8/A10 and the Torbeckeweg are bottlenecks, which asks for smart and futureproof mobility solutions (Gemeente Zaanstad, 2018). Arcadis has been asked by the municipality of Zaanstad to come up with mobility solutions that will address these mobility issues. The main question of the municipality is: how can we make sure that the Achtersluispolder remains accessible and liveable with the addition of jobs and houses? The municipality wants to focus on high-quality public transport and prioritises cyclists and pedestrians. However, because of the existing and remaining industrial companies, the area should remain sufficiently accessible by car. One of the promising intelligent and futureproof mobility possibilities is the mobility hub. This fits the mobility policy for the Achtersluispolder and the vision for the future of the municipality, since Zaanstad stimulates electric driving and carsharing and wants to be carbon neutral in 2040 (Gemeente Zaanstad, 2018; Gemeente Zaanstad, 2019).

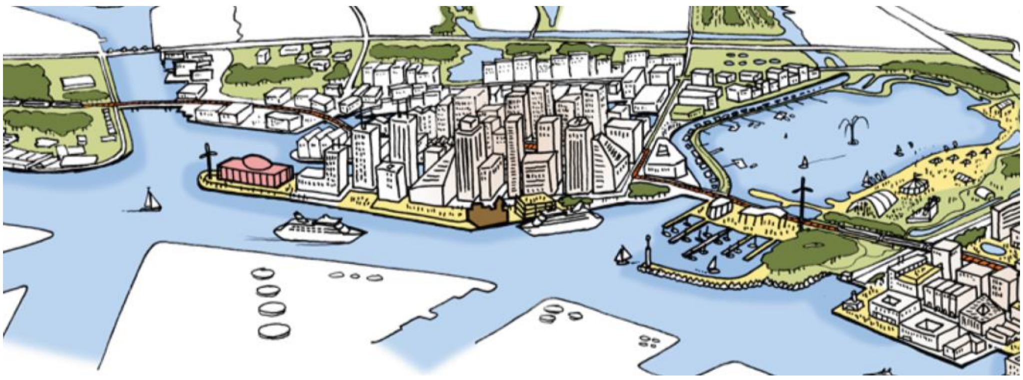

Figure 4 - Artist impression of future Achtersluispolder (Hagens et al., 2017)

1.4 Research aim and questions

The objective of this research is to offer recommendations on how to apply the concept of mobility hubs in terms of location, number, user and criteria, in the context of the Achtersluispolder. To get to these recommendations, the main question has been formulated as:

> *How can the concept of mobility hubs (theoretically) successfully be implemented in the context of the Achtersluispolder?*

This main question has subsequently been divided into four sub-questions:

1. Which characteristics of mobility hubs in terms of location, number, criteria and users, emerge from literature research, survey results and interviews?
2. How do the various stakeholders prioritize the hub criteria mentioned in research question 1?
3. How can the identified hub characteristics be applied to develop three scenarios for hubs in the future Achtersluispolder?
4. Which scenario follows from the MCDA as most promising for the future Achtersluispolder?

The scope of this research includes A) determining the important characteristics of the mobility hub in terms of location, number, criteria and (potential) users, B) designing three scenarios based on the identified characteristics and C) select the most promising scenario using an MCDA. The environmental consequences of mobility hubs in the Achtersluispolder are not discussed, nor is the spatial design of the Achtersluispolder itself. Moreover, also the business case of the scenarios has not been discussed. These topics are relevant and important, but do not fit the timeframe.

1.5 Outline of the thesis

In chapter 2 the research questions and techniques are explained. Next, the theoretical framework and literature review are addressed in chapter 3, including a short summary in section 3.10. In chapter 4 the interview results are presented. The literature review and interview results are used to develop three scenarios, which are described in chapter 5. In chapter 6 these scenarios are evaluated by means of an MCDA, which results in a preferred scenario. The performed study will be discussed, including its limitations in chapter 7. This leads to the conclusion and recommendations regarding mobility hubs in the Achtersluispolder in chapter 8. To conclude, chapter 9 contains the recommendations for further research.

2. Methodology

Several methods were used to answer the research questions. An overview of the applied methods is given for each question. In Figure 5, the methods in relation to the entire research are depicted.

1. Which characteristics of mobility hubs in terms of location, number, criteria and users, emerge from literature research, survey results and interviews?

Three methods were used to answer this question: literature research, survey results from the Hague collected by a master student from the University of Twente and expert interviews. The literature review focused on all mentioned characteristics of mobility hubs, i.e. location, number, criteria and users. Due to the novelty of mobility hubs, not many articles regarding this topic have been published. Therefore, most of the information is retrieved from master theses, PhD dissertations and reports written by consultancy firms concerning the proposed implementation of mobility hubs in the Netherlands, such as Merwedekanaalzone in Utrecht (so-called grey literature).

The second method covered the results of a survey, conducted by a master student from the University of Twente that is currently graduating on the topic of mobility hubs. He collected information regarding the attitudes and preferences of inhabitants living in the city centre of the Hague and inhabitants living in VINEX neighbourhoods towards mobility hubs. The data of this stated preference survey has been used for this study, to determine the hub criteria and the characteristics of (potential) users of hubs.

The third method involved interviewing experts in the field of mobility hubs. The information that was collected during the literature review was used to formulate the (mainly) open questions for a structured interview (see Appendix A – Interview scheme). There were three reasons to choose for a structured interview. First, from literature it was known which topics were of interest to this study, but the exact content was not clear. Structured interviewing guaranteed that the topics of interest would be discussed, while the experts had the opportunity to provide information they saw as relevant. Second, a structured interview allowed for a reliable comparison of the given answers, which made it possible to examine the views of the different stakeholders (Van der Donk & Van Lanen, 2019). Last, experts from the field have in general not that much time available for interviewing, which made it important to organise short interviews (≤ 45 minutes) while still collecting enough information to answer the research question. Targeted open questions enabled an in-depth conversation in a small amount of time (Migchelbrink, 2010). Furthermore, the questions were checked in advance by two interview experts to control as much as possible for errors. The collected information was used to determine the location characteristics and the hub criteria. The interviewed experts are given in Table 1. The interviews have been transcribed and coded, to make an objective comparison of the criteria and weights possible.

Table 1 - Interviewed mobility experts

Name	Organisation	Position
Auke Adema	Municipality of Amsterdam	Program/Project manager Hubs & bicycle parking Amsterdam Central Station
Back Hilckmann	Municipality of Amsterdam	External advisor from *Duurzaam in mobiliteit*
Milko Buter	Municipality of Zaanstad	Vision/ strategy mobility specialist
Mark Degenkamp	Municipality of Zaanstad	Strategic mobility advisor
Mirza Hotic	Seconded from Arcadis to the municipality of The Hague	Project leader mobility
Charles Huijts	Municipality of The Hague	Policy advisor mobility
Kjell Knippenberg	Shared mobility provider Hely	Operations Coordinator and BI analyst

2. How do the various stakeholders prioritise the hub criteria mentioned in research question 1?
To understand and determine important mobility hub criteria according to the various stakeholders, the interviewed experts were asked to divide 100 points among hub criteria they saw as important (Weber & Borcherding, 1993). Next to that, five experts of Arcadis were asked to do the same in order to collect additional input and with that, a more comprehensive interpretation. The results of this sub-question were used to evaluate the three developed scenarios (sub-question 4).

3. How can the identified hub characteristics be applied to develop three scenarios for hubs in the future Achtersluispolder?
The characteristics of mobility hubs that were determined by sub-question 1, were used to design three scenarios. The expertise and knowledge of the experts from Arcadis was used during the design process, by discussing and evaluating the designs with them. In this way, valuable practical knowledge was incorporated in the designs. Furthermore, the designs differ in terms of location, number and hub criteria. The answer of this question contained for each scenario: A) the number and the locations of the mobility hubs on a map of the Achtersluispolder with an explanation and B) a description of the mobility hubs itself in terms of important hub criteria that were identified by sub-question 2.

4. Which scenario follows from the MCDA as the most promising for the future Achtersluispolder?
The three scenarios were subsequently evaluated using a Multi Criteria Decision Analysis (MCDA), to perform a reproducible, transparent and analytic rigour assessment (Dunning, Ross, & Merkhofer, 2000). A weighting was applied because the various criteria were not of equal importance. The criteria and the accompanying importance that followed from the interviews with the experts (see sub-question 1) were used for this MCDA. In particular, the Analytical Hierarchy Method (AHP) was applied to establish weights for the various criteria and the three scenarios (Saaty, 1990). This method was chosen because it is able to check for inconsistencies, it helps to make the importance of each criteria clear and is able to deal with various stakeholders (Ramanathan, 2001; Macharis, Springael, De Brucker, & Verbeke, 2004; Zahir, 1999). By using AHP, the problem has been decomposed into a hierarchy of criteria, which can be more easily analysed. (Vargas, 2010). More explanation on the AHP can be found in Appendix B – The Analytic Hierarchy Process.

As depicted in Figure 5, answering the above mentioned sub-questions answered the main question: how can the concept of mobility hubs (theoretically) successfully be implemented in the context of the Achtersluispolder?

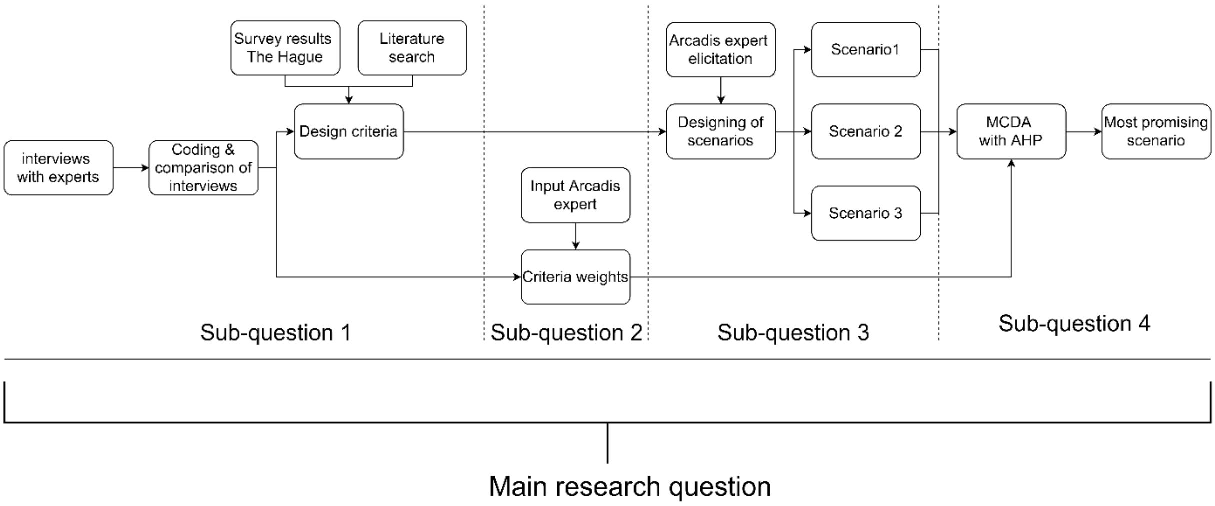

Figure 5 - Structure of research process

3. Literature review

In this section, the findings from literature are presented. First, to understand the theoretical background of the user's acceptance of a new technology, the Technology Acceptance Model is discussed. Then, the characteristics of (potential) users of carsharing, bikesharing and mobility hubs are discussed. Since shared cars are an important transport mode at hubs and because there has been extensive research performed to carsharing users, these results can be used to get a comprehensive view on important user characteristics of mobility hubs. Next, the characteristics of hub users and the motives that follow from literature are discussed. The characteristics of bike sharing systems are examined subsequently. Furthermore, it is argued what the added value of mobility hubs is compared to separate shared modes. The number and location of hubs are discussed in 3.7 and finally the hub criteria in 3.8. These results combined give a good impression of the characteristics of mobility hubs.

3.1 Technology Acceptance Model

To understand the factors that influence the adoption of a new technology such as the concept of mobility hubs, the Technology Acceptance Model (TAM) is discussed (Davis, 1989; Davis, Richard, Bagozzi, & Warshaw, 1989). As depicted in Figure 6, *usage behaviour* in relation to a technology is determined by the *intention to use*. This is subsequently influenced by the *perceived usefulness* and *ease of use*. *Perceived usefulness* is the degree to which people believe that using the technology will enhance their productivity. *Perceived ease of use* is the extent to which a person believes that using the technology will be free of effort. These two 'major beliefs' are affected by the beliefs of a person towards the system, which are the *system design characteristics*.

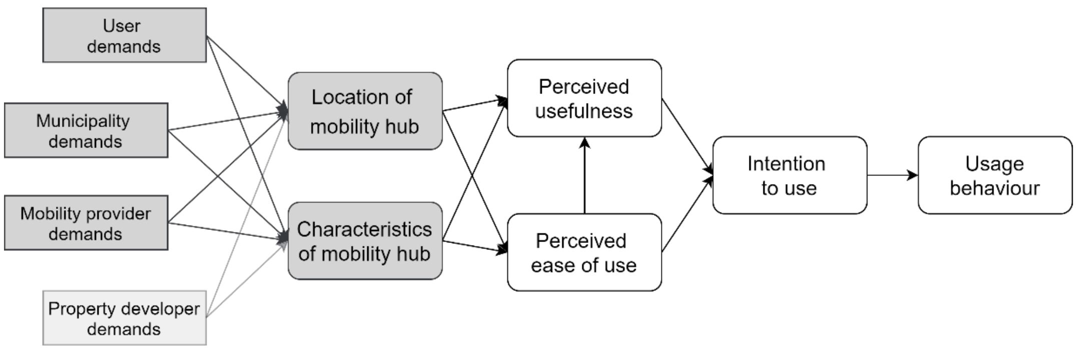

Figure 6 - Technology Acceptance Model, original by Venkatesh & Davis (2000)

In the case of the Achtersluispolder these characteristics are represented by the *location of the mobility hub* and the *characteristics of the mobility hub*. The various stakeholders will have their own views on these characteristics, as depicted in Figure 6. These stakeholders include the future users of the mobility hubs, the municipality of Zaanstad and the mobility provider. The property developer(s) that will develop the Achtersluispolder are beyond the scope of this research, because of the limited timeframe. The reason to exclude the property developer and not another stakeholder, is because of the available contacts with the other stakeholders via Arcadis. Lastly, *perceived usefulness* is influenced by *perceived ease of use*, as the easier a technology is to use, the more useful it can be (Marangunić & Granić, 2015; Venkatesh, 2000). The TAM method has received extensive support through validation and applications (see for an overview Lee, Kozar, & Larsen, 2003).

In the original TAM, as proposed in the doctoral dissertation of Davis (1986), 'attitude toward using' was included in the model, while *intention to use* was excluded. However, Davis (1989) found that 'attitude toward using' did not fully mediate *perceived ease of use* and *perceived usefulness*, which made that 'attitude toward using' was omitted. Further development of the model led to the addition of *intention* (Davis et al., 1989).

There are more developments of TAM, but TAM as it is depicted in Figure 6 is used in this study, because further enhancements would make it too detailed for its purpose. Therefore, 'TAM2' without the variables that may influence perceived usefulness, is used.

The main conclusion that can be drawn from TAM when applying it to the Achtersluispolder, is that people should perceive the mobility hubs as useful and as free of effort. However, each stakeholder will have its own view on how mobility hubs can be useful and how they can be free of effort, which makes it necessary to determine these different views. This will be done by literature research, survey results and performing interviews.

3.2 Characteristics of carsharing users

Münzel, Piscicelli, Boon and Frenken (2019) analysed a survey dataset regarding carsharing, which was collected by the knowledge institute TNS-NIPO in 2014 and existed out of 1.835 responses. These answers were analysed on socio-demographics, attitudes and motivations of the respondents. Next to that, they also performed six multiple logistic regression analyses to identify influencing variables, three of which are relevant to this study: carsharing adopters versus non-adopters; potential carsharing adopters versus not interested non-adopters and P2P versus B2C users.

Looking at the age of carsharing users compared to non-users, it appears that age has a significant influence on the likelihood of being a carsharing adopter (Münzel et al., 2019). Dutch people between 30 and 40 years old and to a lesser extent between 40 and 50 years old, use relatively often shared cars (see Figure 7 - Age distribution of carsharing users and potential users Figure 7). Also, people between 18 and 30 years old are an important user group (TNS NIPO, 2014, as cited in KiM, 2015)[1]. This is in line with other studies that found that a younger age positively influences the adoption of carsharing (e.g. Hahn, 2015), whereas an older age has a negative influence (e.g. Dias et al., 2017). When examining the influence of age on being a potential adopter or being not interested in adopting carsharing, age has again a significant influence (Münzel et al., 2019).

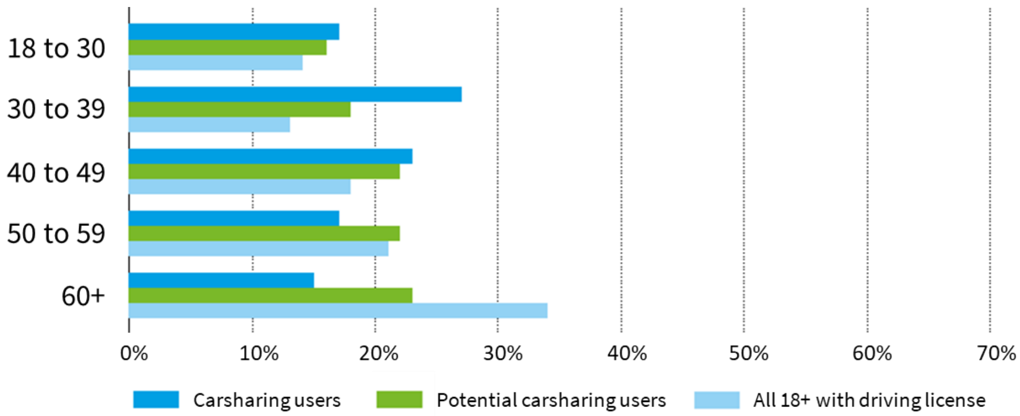

Figure 7 - Age distribution of carsharing users and potential users (KiM, 2015)

Education level is often found to have a significant positive effect on the adoption of carsharing (e.g. Hahn, 2015; Becker, Ciari, & Axhausen, 2017). This is also reflected by the survey results of TNS NIPO analysed by Münzel et al. (2019), where 63% of the carsharing users have at least a bachelor's degree, which is much higher than the Dutch average. Furthermore, Münzel et al. found a significant positive effect of education level on being a car sharer and on being a potential adopter. Finally, they found that a higher education level has a positive effect on the likelihood of being a B2C user compared to a P2P user.

[1] Note: It is likely that this is partly the same data as Münzel et al. (2019) use. This is not problematic, since they complement each other, but it does not contribute additionally to the story in terms of soundness.

Literature indicates that living in a densely populated area, positively influences the likelihood of being a car sharer. In the Netherlands, more than 40% of carsharing adopters live in highly urbanised areas, while only 15% of the total population lives there (TNS NIPO, 2014, as cited in KiM, 2015). Münzel et al. (2019) found that living in a G4 city[2] significantly influences the likelihood of being a carsharing adopter; the same holds for the likelihood of being a potential car sharer. It was also found that living in a G4 city significantly influences the likelihood of being a B2C user, compared to being a P2P user.

Research also shows that car sharing adopters are less car dependent. Münzel et al. (2019) found in their analysis of the survey sample, that two-thirds of carsharing users have a public transport subscription and more than half live in car-free households. In their logistic regression, they also found significant influences of having a public transport subscription and living in a car-free household on the likelihood of belonging to the user group compared to the non-user group: having a PT subscription more than doubles the likelihood of being a carsharing user, while living in a car-free household increases the likelihood by a factor of 4,5. Significant influences of PT subscription and living in a car-free household were also found when comparing potential adopters to non-adopters. Considering living in a car-free household, it can be noted that especially people using a shared car via an organisation (B2C) live in car-free households, where almost 60% does not own a car; a third live in a household with one car (TNS NIPO, 2014, as cited in KiM, 2015). By way of comparison, in the Netherlands around 30% of the households do not own a car and around 50% own one car (CBS, 2015).

When looking at household composition, carsharing seems to be most popular among households without children and singles; households with young children (≤ 12 years old) follow at some distance (TNS NIPO, 2014, as cited in KiM, 2015). This is in line with literature that states that having children leads to more complex trips and more activities in general, which is more difficult to combine with shared mobility (Dias et al., 2017; Sopjani, Stier, Hesselgren, & Ritzén, 2020). In contrast with the above studies, Münzel et al. (2019) did not find a significant influence of having children in the household.

Next to the above mentioned significant factors, there are also two notable factors that do not seem to have a significant influence. Münzel et al. (2019) found no significant influence of income and gender on the adoption of carsharing. Other studies show varying results: Costain, Ardron and Nurul Habib (2012) found that carsharing is popular among people with lower incomes, while Hahn (2015) and Becker, Ciari and Axhausen (2017) found that it is popular among people with higher income. Juschten, Ohnmacht, Thao and Gerike (2019) found that carsharing is popular among men, while (Kim, Ko and Park (2015) found that women have a higher propensity to use carsharing.

When considering user's motives, Münzel et al. (2019) found that 40% of the carsharing users consider cost savings as the most important reason and 11% mentioned the convenience of not owning a private car. It is notable that only 9% of the users see sustainability as the main motivation to adopt carsharing, especially since 18% of the carsharing users have voted for a 'green party'[3] in the last general election (against 4% of the Dutch population). However, from their logistic regression analyses it appears that voting for a green party significantly influences the likelihood of being a carsharing adopter; the same goes for being a potential carsharing adopter. Similar reasons are mentioned by a focus group among car sharers and potential sharers living in Amsterdam (KiM, 2015).

[2] G4 are the four biggest cities in the Netherlands, which are: Amsterdam, Rotterdam The Hague and Utrecht.

[3] These are *GroenLinks* and *Partij van de Dieren*.

3.3 Characteristics of mobility hub users

Statistics from the users of shared mobility provider Hely demonstrate that younger people are more inclined to use shared mobility, as 54% of the user group is between 25 and 44 years old and 32% is between 45 and 64 (Korsaan & Groenewold, 2019). This is consistent with the study by Claasen (2020), who researched the potential effects of mobility hubs among residents of The Hague. He found that older people are less likely to relinquish a car when a mobility hub is provided which suits their needs.

It can be noted that the education level of hub users is in line with that of carsharing users. The users of the mobility hub in Munich are highly educated, with 64 percent having at least a bachelor's degree (Miramontes, Pfertner, Rayaprolu, Schreiner, & Wulfhorst, 2017). The same applies to Hely users, where two-thirds has at least a bachelor's degree (Korsaan & Groenewold, 2019; Knippenberg, 2019).

When Van Rooij (2020) asked experts on mobility hubs, they all emphasised that hubs should be located – at least in the early stage – in areas with high parking pressure, which means that potential users live in cities. This is in line with reports that state that mobility hubs should be situated at locations with higher land use intensities (Metrolinx, 2011).

Knippenberg (2019) found that users of shared mobility provider Hely are less car-minded compared to the Dutch population, as they prefer either bike or PT as a means of transport (see Figure 8). The same was found in the study of Korsaan and Groenewold (2019). Miramontes et al. (2017) found that more than half of the users have a PT subscription and uses PT at least once a week. Claasen (2020) found that people who travel frequently by train are more likely to relinquish their car in favour of a mobility hub; the same applied to infrequent car users.

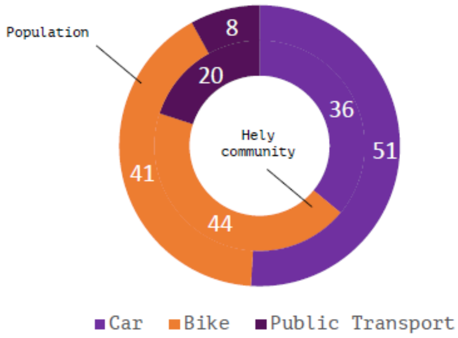

Figure 8 - Modal split of Dutch population compared to Hely users (Knippenberg, 2019)

Korsaan and Groenewold (2019) found that Hely users consist out of households with children (41%), followed by households without children (27%) and singles (25%). Surprisingly, Knippenberg (2019) found that most of the Hely users are households without children or households with children. When examining the studies, it appears that the study by Korsaan and Groenewold considers the users of Hely hubs in Amsterdam, Delft, Haarlem, Rotterdam and the Hague, while Knippenberg considers the users of the Hely hubs in Delft and Amsterdam. Additionally, the survey answers by Korsaan and Groenewold were collected between January 2019 and September 2019 with 114 respondents, while Knippenberg collected the results between December 2018 and March 2019 with 80 respondents. When comparing this, and including also the carsharing users, the results suggest that there is no consensus about the influence of household composition (see Table 2).

Table 2 - Household composition carsharing users and Hely users

	Carsharing users (TNS NIPO, 2014 as cited in KiM, 2015)	**Hely users (Korsaan & Groenewold, 2019)**	**Hely users (Knippenberg, 2019)**
Biggest user group	Households without children	Households with children	Households without children
Second biggest user group	Singles	Households without children	Households with children
Third biggest user group	Households with children	Singles	Singles

Furthermore, when looking at the mobility needs per household type it can be noted that singles prefer mainly the small car and the e-bike, while households with and without children prefer the e-cargo bike more than singles; see Figure 9 (Korsaan & Groenewold, 2019).

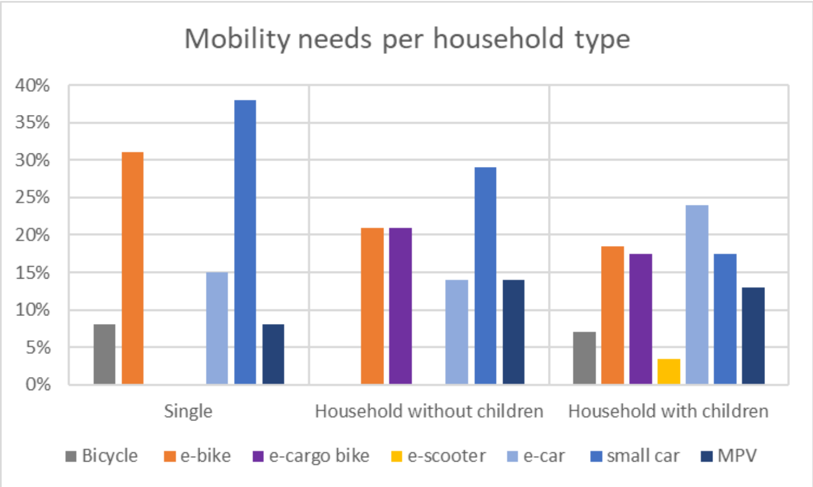

Figure 9 - Mobility needs per household type (n=198), data from (Korsaan & Groenewold, 2019)

Lastly, Claasen (2020) found no significant influence of gender on the likelihood of relinquishing a car in favour of a mobility hub. Knippenberg (2019) found that 65 percent of the Hely users is male. In Munich, 76 percent of the users were male (Miramontes et al., 2017).

3.4 Motives to use mobility hubs

When looking at users' motives, Knippenberg (2019) found that Hely users prefer a "convenient service that is all-inclusive, from planning their journey to receiving their monthly invoice" (p. 47). Next to that, flexibility that does not ask much commitment is often seen as very important (see Figure 10). Costs and sustainability are also import drivers, although to a lower degree. Miramontes et al. (2017) found that most of the users decided to use the mobility hub, because it offered the closest available vehicle. Another important reason was that the hub was conveniently located on their way. For users that ended their rental at the mobility hub, the proximity to their final destination was an important reason.

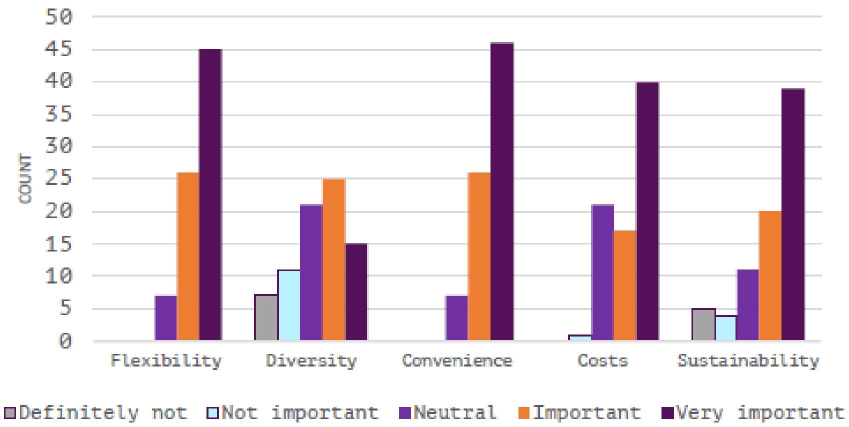

Figure 10 - Motives for subscription at Hely (Knippenberg, 2019)

Where in the above paragraph, the reasons why to adopt carsharing are mentioned, Claasen (2020) asked people that would not give up their car in favour of a mobility hub, why they were not willing to do so. As depicted in Figure 11, freedom or convenience of a private car is often mentioned as a reason to not relinquish a car. Furthermore, people need their car for work, appreciate the independence of owning a car or want/need a private car for holiday.

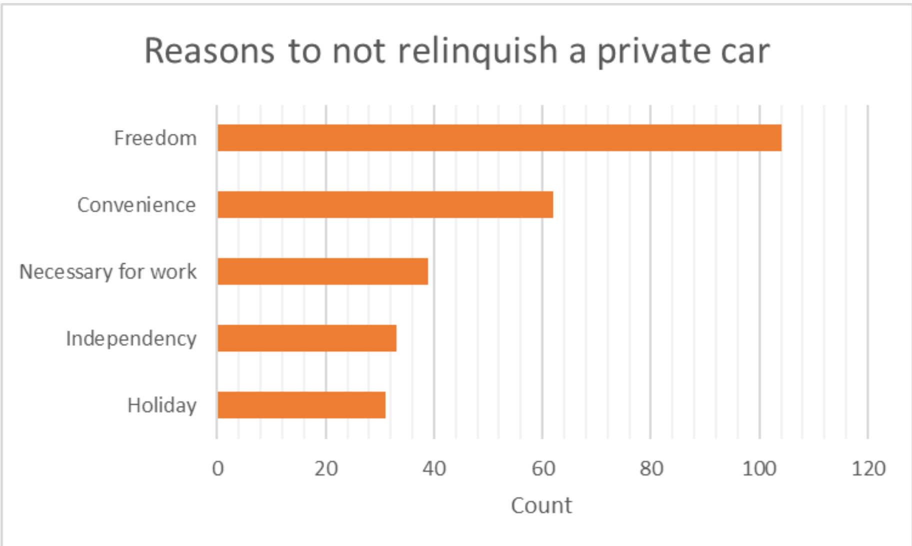

Figure 11 - Reasons to not relinquish a private car in favour of a mobility hub (Claasen, 2020)

3.5 Bikesharing analysis

Since the Netherlands has one of the highest rates of cycling and private bicycle possession in the world (Pucher & Buehler, 2008), it could be argued that Dutch shared bicycle systems are redundant. Rijkswaterstaat (2018) reported that shared bicycles are often a replacement of a second bike, used as a first/last mile integration in combination with public transport. These shared bicycles lead to an increased train usage and a decreased car usage. An important boundary condition is high quality bicycle infrastructure, including enough parking spaces (Rijkswaterstaat, 2018). Research from North America showed that e-bikes have the potential to replace car trips (Langford, 2013; MacArthur, Dill, & Person, 2014. However, it is unknown if this is also applicable in the Netherlands.

When looking at the usage of (e-)bikes at Hely hubs, it appears that the e-bike is one of the most frequently used modes, while the regular bike is no longer offered because it was rarely rented (Korsaan & Groenewold, 2019). Additionally, they reported that Hely users appreciate the e-bike and the e-cargo bike because it offers additional features compared to a regular bike. A possible explanation why the shared bicycles used at stations (*OV-fiets*) are a success while they were not at Hely hubs, is that regular shared bikes are mainly used as first/last mile solution in combination with public transport, while e-bikes can be used to replace (car) trips. This explanation is supported by the fact that Hely hubs are not connected with public transport. In the case of the Achtersluispolder, this could indicate that shared bikes should be placed at hubs with a public transport connection, while e-bikes can be placed at every hub.

3.6 Added value of mobility hubs compared to separate shared modes

One might wonder what the added value of mobility hubs are compared to the separate systems of shared cars, shared bicycles, etc. The first benefit is the increased convenience for the users. Since mobility hubs provide by definition multiple means of transport, users can choose which mode best suits their needs at any given time. This in turn enables people to reduce their car use and the negative impacts associated with that (CoMoUK, 2019). Also, when additional services – such as parcel services, supermarket, shops etc. – are provided, hubs bring supply and demand of mobility and other services together, which can turn hubs into (socio-)economic nodes. In this way, the convenience for the users further increases (Mobiliteitsalliantie, 2019). The second benefit is that mobility hubs can raise the profile and visibility of shared and sustainable means of transport, which can provide them with a renewed positive status and appeal (CoMoUK, 2019). Last, mobility hubs can help to solve the problem of 'street clutter' from free floating mobility services, by integrating them at one location and providing them with an efficient electric charging infrastructure (CoMoUK, 2019). However, a disadvantage of mobility hubs in comparison with free-floating, is that people are obliged to bring the vehicle back at one specific location, while free-floating enables people to leave the vehicle at a location they prefer. To conclude: "an efficient integration of multiple mobility services has the potential to compete against the flexibility and convenience of private cars by enabling comfortable, cost and time-effective door-to-door travel" (Miramontes et al., 2017, p. 2).

3.7 Number and location characteristics of mobility hubs

Unfortunately, there has been almost no scientific literature published regarding the number of hubs and location characteristics. Therefore, three Dutch projects that incorporate mobility hubs in area development plans are discussed. These projects are Sluisbuurt in Amsterdam (Burmanje et al., 2019), Strandeiland in Amsterdam (Derksen et al., 2019a) and Merwede in Utrecht (Boshouwers, Kandel, Govers, & Van der Linde, 2018a). Where possible, additional literature has been examined.

All three projects have in common that there is, next to shared mobility, also a strong emphasis on walking, cycling and public transport; shared mobility is seen as one of the key elements in the mobility strategy. Something that is also highly stressed by all reports, is the vital need of flexibility in the implementation of mobility hubs. Mobility hubs and shared mobility are seen as promising, but also as concepts that still need to prove themselves. Therefore, it is important that the implementation is not rigid, but can be adapted to future developments and insights. Lastly, all three projects focus on sustainability and well-being, which is partly achieved by sustainable mobility and car-free streets, but also includes other topics like energy transition. That makes mobility part of a bigger program.

When looking at the number of mobility hubs, it becomes clear that there is not one preferred number and size of hubs. In Sluisbuurt and Merwede, a small number of hubs (4-6) has been advised (Burmanje et al., 2019; Boshouwers et al., 2018a), which results in approx. 1.000 – 1.500 households per hub. At Strandeiland, a large number of hubs (20-25) has been proposed (Derksen et al., 2019a), which results in 300 – 400 households per hub (see also Table 3). The reason to choose for bigger hubs in Sluisbuurt, is because this led to economies of scale in realisation and operation and to higher availability of vehicles. In Merwede they chose for bigger hubs because they wanted a large part of the area car-free, which led to four access roads towards the four hubs. For Strandeiland bigger hubs did not match the spatial scale of the area and led to larger distances to the hub and a negative business case. Smaller hubs had the advantage that they can be built along with the construction stages of houses and other buildings. While it is often suggested that more hubs and more vehicles in the hubs contribute to a better performing network (the so-called network effect), research by Chardon, Caruso and Thomas (2017) found “absolutely no evidence supporting this” when they examined 75 bicycle sharing systems. Therefore, it is uncertain if more hubs lead to a better performing network.

Another aspect of the mobility hubs is whether the hubs are located above or below ground level. At Sluisbuurt and Merwede they advised to locate all the hubs in parking garages beneath buildings, such that the spatial quality improves and that parking for residents is nearby. However, at Merwede they located the ‘mobility store’ (location where users pick up baby seats for example) at the ground floor, to increase the ease of use. Disadvantages of parking below ground level are the high building costs and inflexibility. At Strandeiland the hubs are located above ground level because flexibility with regard to future developments is considered essential. Therefore, hubs should not be totally integrated within housing blocks, but should be part of a housing block with the possibility to transform it in the future. Also, the authors of the report thought that the small scale of the hubs enables above ground building without decreasing the spatial quality.

As mentioned in the reports, parking policy and parking pressure are closely related to shared mobility and mobility hubs. Therefore, the parking standard of the three projects are examined. In Sluisbuurt a parking standard of 0,3 for residents and 0,1 for visitors is maintained. At Merwede, the parking standard is 0,3 (in total) within the area, with additionally 1.500 parking spaces for residents and visitors which translates to about 0,3. This makes in total a parking norm of 0,6. Finally, at Strandeiland a parking standard of 0,5 for residents and 0,1 for visitors is advised. These parking standards are rather close to the average car ownership of 0,4 to 0,6 per household in the highly urbanised municipalities Amsterdam, Delft, Groningen, Rotterdam and The Hague (Provincie Zuid-Holland, 2017).

When applying a low parking standard, it is important to introduce also paid parking. Paid parking in the area itself to discourage people to take the car and paid parking in the adjacent areas, to avoid that residents park in other districts. Another possible aspect of the parking policy can be parking at a distance. In Sluisbuurt they focus for this moment on parking nearby, but they see parking at a distance as possible measure in the future, especially when autonomous vehicles become available. For Merwede there will be parking at a distance with a maximum of 1.500 parking spaces in total. In this way, people that do not want to park in Merwede because of the high parking fees or cannot park in Merwede because of full parking garages, are still able to park their car. These parking garages are located within 1 – 2 km of the residents. At Strandeiland parking at a distance (max. 1,5 km) applies to non-electric vehicles of residents and visitors, to central facilities, to shared bicycles and to bicycle parking spaces for residents. However, most of the parking will be situated nearby. Something to be aware of, is that parking at a distance can lead to an unwanted effect. If parking is located too far away, people on their way home might first go home to drop off passengers or belongings before parking at the hub (Derksen et al., 2019b).

The evaluation of the mobility hub in Munich by Miramontes et al. (2017) showed that about a third of the respondents learnt about the mobility hub while walking past, which shows the importance of visibility and recognisability. Next to that, walking was one of the most frequently used modes to access the hub. This emphasises the importance of visibility and a high-quality urban environment. Next to that, respondents were asked on preferable locations for mobility hubs. The answers can be categorised as follows: central places in the city centre, public transport nodes along high-capacity public transport lines and residential areas in central districts and suburbs.

Finally, reports have stated that it is recommended to situate mobility hubs at locations with a high density of jobs and houses, together with mixed land use in order to provide a diverse mix of houses, jobs and public spaces (Metrolinx, 2011). In this way, a large number of potential users is within close proximity (Aono, 2019). Also, the social safety is increased because of natural surveillance of "eyes-on-the street" (Urban Design Studio, 2016).

Table 3 - Characteristics of preferred alternative in recent projects in the Netherlands

	Sluisbuurt	**Strandeiland**	**Merwede**
Location	Amsterdam	Amsterdam	Utrecht
Number of households	5.640	8.000	5.800
Number of hubs	5	20 – 25	4
Households per hub	1.130	320 – 400	1.450
Footprint of one hub	Bigger (ranging from 5.000 to 17.000 m^2)[4]	Smaller (approx. 2.000 m^2)	Bigger (no dimensions given)
Above or below ground level	Below	Above	Below
Parking standard	0,3 for residents 0,1 for visitors	0,5 for residents 0,1 for visitors	0,3 in area 0,3 at a distance
Parking at a distance	Not at the moment, maybe in the future	Mainly for non-electric vehicles at entrance of the area (max. 1,5 km)	Parking can be at a distance for a low price (1 – 2 km)
Paid parking in area and in adjacent districts	Yes	Yes	Yes

[4] The preferred alternative did not include sizes, therefore the sizes of the second best alternative were used. These dimensions seem to approach the dimension of the preferred alternative.

3.8 Mobility hub criteria

In order to determine important mobility hub criteria, several studies were examined. Van Rooij (2020) found various characteristics that seem to be important to mobility hubs. His research focused on neighbourhood mobility hubs, which are central points in a neighbourhood, that offer shared car, (e-) bikes and/or e-cargo bikes to residents and do not have a public transport connection. Although this slightly differs from the mobility hubs that are discussed in this report, the many similarities provide a good starting point. Next to the study of Van Rooij, other studies that examined mobility hubs and carsharing will be discussed. Table 4 gives an overview of identified hub criteria.

The most important characteristic according to Van Rooij (2020) is the distance that persons are willing to travel for the hub. He found a range of 300 to 500 metres. This is in line with the study of Celeste (2019) who also found a maximum distance of 300 to 500 meters. Also Claasen (2020) found that walking time, together with costs, is the most important factor to people that consider to relinquish their car in favour of a mobility hub. He found that people experience a nine minute walk twice as negative compared to a six minute walk. Finally, Dieten (2015) found that carsharing users prefer a vehicle within a five minute walking distance, which is around 400 meters.

Van Rooij (2020) also found that costs for the users are an important factor. Research by Dieten (2015) suggests that a low price per kilometre is, together with walking time, one of the two most preferred attributes for carsharing; in particular a price of 0,30 euros per kilometre. This is consistent with the results of Claasen (2020), that also indicated travel costs and walking time as the two most important factors to relinquish their car. Next to that, Claasen found that a price of 0,10 euros per kilometres for a shared scooter/e-(cargo) bike has a positive influence on the use of a mobility hub. The notion that costs are an important aspect to mobility hubs is in line with the motives to use hubs.

Diversity in vehicles is also often mentioned as important. In his study, Van Rooij (2020) interviewed several experts in the field of mobility hubs and all the experts mention that a hub should offer multiple types of modes. The e-cargo bike was mentioned explicitly as an important mode, because the experts see the e-cargo bike as a potential replacement for short car trips, e.g. to get groceries or to drop off the children at school. Claasen (2020) found the car being the most important mode at a mobility hub, followed by the e-bike; the e-cargo bike was considered less important. When looking at the data of Hely, it appears that the car is the dominant mode choice, of which the small car is most frequently used. Next to the car, also the e-bike is often rented, while the e-cargo bike is less frequently used (see Figure 12). The regular bike was rarely rented, which is why it is no longer part of the offer at the hubs. Finally, scooters are not offered by Hely (Korsaan & Groenewold, 2019).

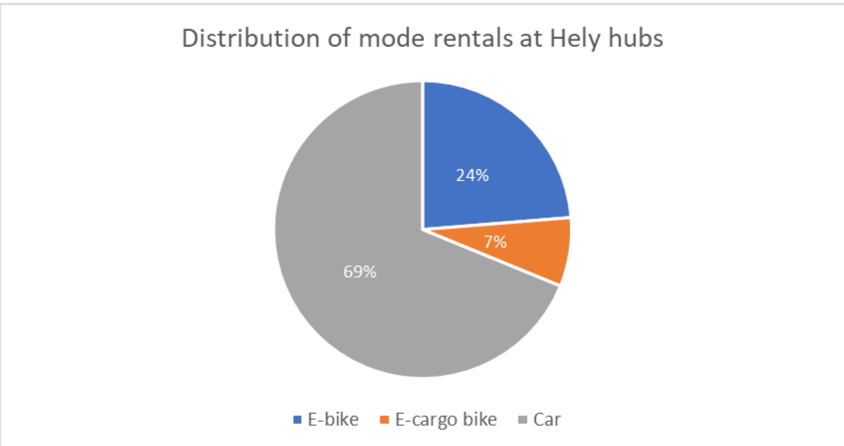

Figure 12 - Distribution of mode rentals at Hely hubs (n=1169), data from (Korsaan & Groenewold, 2019)

Next to diversity of vehicles, also availability of vehicles is mentioned by Van Rooij (2020). The experts interviewed by Celeste (2019) mentioned that experience from practice show that availability is very important to the users. Also, it is important that from the first moment that people settle, other modes than private cars are available. In that way it can be prevented that habitual travel behaviour arises.

As mentioned in the introduction, carsharing can be one-way or roundtrip. Dieten's study (2015) suggests that 'not mandatory to return a car' is a welcome addition. The same goes for shared mobility: do users have to return the mode to the same location as where they have picked it up (roundtrip) or can they return it at another location (one-way)? Van Rooij (2020) found that people have a neutral perception towards the roundtrip nature of mobility hubs. Since the round-trip nature is perceived the most negative, "a point-to-point hub network would be an improvement" (p. 63). Claasen (2020) found no significant preference towards an one-way or roundtrip system in his sample.

As noted in the introduction, a connection with public transport can be seen as an important aspect for some types of hub (Mobiliteitsalliantie, 2019). In this way, users are connected to a sustainable, rapid means of transport. This is also supported by the study in Munich, where the connection with public transport was rated as (very) important (Miramontes et al., 2017). In combination with public transport, shared modes can also serve as the first/last mile connection to a PT stop. In this way, a door-to-door travel can be ensured which increases the convenience (CoMoUK, 2019).

Other important aspects that were mentioned by Van Rooij (2020) are: sustainability of the vehicles, visibility of the hub, state of the hub, hub costs, ease of use, safety of the hub, safety of the vehicles, state of the vehicles and vehicle costs. Sustainability was also found as a motive to use mobility hubs, although not the main reason (see section 3.4 Motives to use mobility hubs). Next to that, the study of Miramontes et al. (2017) showed the importance of visibility (see section 3.7, p.24). No supporting literature was found on the other aspects, which makes it harder to determine the influence. Therefore, the interviewed experts were also asked on these aspects.

Table 4 - Important mobility hub criteria

Criteria	Findings
Distance	Maximum distance of 300 – 500 metres
User costs	Carsharing: €0,30/ km Scooter/ e-(cargo) bike: €0,10/ km
Diversity in vehicles	Multiple types of vehicles important Car is most rented vehicle, followed by e-bike Different household types have different needs
Availability of vehicles	Vehicles should be available from the start
Carsharing model	One-way is found to be slightly preferred, although Claasen (2020) did not found a significant preference
Connection with public transport	Important aspect for most types of hub
Sustainability	Important motive, but not the motive to use shared mobility (see section 3.4 Motives to use mobility hubs)

3.9 Boundary conditions

When implementing mobility hubs, it is important to realise that certain boundary conditions have to be fulfilled to maximise the chances of success. Van Rooij (2020) found that parking pressure will likely be the main motivator to use a hub, as parking pressure introduces additional effort to use a private car. Literature on carsharing supports the idea of lowering the parking standard (e.g. Akyelken et al., 2018; Enoch & Taylor, 2006).

Münzel (2020) held a workshop on the impact and feasibility of various measures regarding carsharing in the Netherlands, with relevant stakeholders from the automotive sector, governments and knowledge institutes. Measures with the highest perceived impact were changing parking policies, promoting carsharing and integrating carsharing in planning around urban development and mobility. This means in practice: lowering the parking standard, providing parking spaces for shared cars against reasonable prices and facilitating charging infrastructure for shared electric vehicles. It is important to note that it is difficult to remove existing parking spots and/or raise existing parking prices, as citizens feel their 'right' to have an affordable parking space. That means in the case of the Achtersluispolder that the parking prices and low parking standards should be set from the start. Also, when using low parking standards, it is important to also consider surrounding areas since people may park in these areas when the parking pressure and/or price is lower (Korsaan & Groenewold, 2019; Burmanje et al., 2019). Finally, it is important that from the first moment that people settle, other modes than private cars are available. In that way it can be prevented that habitual travel behaviour arises (Celeste, 2019). The boundary conditions are given in Table 5.

Table 5 - Boundary conditions for mobility hubs

Condition	Implementation
Parking standard	Low parking standard
Paid parking	Introduce paid parking within the area and in the surrounding districts
Shared cars parking	Providing affordable parking spaces for shared cars
Integrate carsharing in urban planning	Facilitate charging infrastructure for shared electric cars

3.10 Summary of literature review

The literature review has resulted in relevant information. In this section, a brief overview of the most important aspects is given, which will be used as input for the development of the 3 scenarios. An overview is given in Table 6.

When looking at characteristics of (potential) mobility hub users, it becomes clear that younger people (≤ 45 years old) are more inclined to use it. Next to that, a high education level increases the likelihood of being a (potential) user, which is also reflected by the Hely community from which two thirds have at least a bachelor's degree. Furthermore, living in a high density area stimulates mobility hub use. Finally, (potential) users are less car dependent, as they travel more often by public transport and own on average less cars. The same characteristics were found for carsharing users. The most important motive to use mobility hubs is convenience, which is also an important selling point of mobility hubs compared to separate shared modes, such as carsharing services.

In order to analyse the number and location of mobility hubs, grey literature was consulted. It appears that there is no single manifestation of mobility hubs. Both bigger and smaller hubs are proposed, as well as a small and large number of hubs, and above or below ground level. Furthermore, there are other aspects which are stressed by all three examined reports. First it is important to mention that mobility hubs are one part of the mobility strategy, together with walking, cycling and public transport. Second, since the concept of mobility hubs is a recent development it is important to implement it in a flexible manner, such that it can be adapted to future developments and insights. Third, mobility hubs should be combined with low parking standards and paid parking. Other boundary conditions are offering affordable parking spaces for shared cars and providing charging infrastructure.

Distance to the hub is seen as one of the most important hub criteria. In literature, a maximum distance of 300 to 500 meter is found. Other important aspects are ease of use, vehicle costs and state & (social) safety of the hub. From Hely usage statistics, it appeared that the car is the most used mode, followed by the e-bike. In addition, public transport is an important means of transport to mobility hub users. Finally, from the bike sharing analysis it appeared that regular bikes can be of added value when used for first/last mile transport in combination with public transport, while e-bikes can be situated at every mobility hub.

Table 6 - Most important identified mobility hub characteristics

Characteristic	Aspect	Positive influence mobility hub use
User	Age	Younger (≤ 45 years old)
	Education level	Highly educated (at least bachelor's degree)
	Living environment	High density areas
	Car dependency	PT subscription and lower car possession
Location & number	Number	*Multiple options possible*
	Size	*Small and big hubs possible*
	Level	*Above and below ground possible*
Hub criteria	Distance	Maximum 300 – 500 metres
	Ease of use	Lower
	Vehicle costs	Lower
	State & (social) safety of the hub	Higher
	Modes of transport available	Most important: car, e-bike and public transport connection
Boundary conditions	Parking policy	Low parking standards & paid parking
	Stimulation of carsharing	Affordable parking spaces for shared cars & charging infrastructure for shared e-cars

4. Interview results

In this section, the main results of the conducted interviews are given. The aim of the interviews was to determine the location characteristics and hub criteria. In order to compare the answers of the shared mobility provider and the municipal experts, their answers are described separately.

According to the mobility provider, mobility hubs are most effective if they are situated nearby the residents. Next to that, hub usage is the highest if services like public transport are located further away. The location also influences the dominant mode choice: cars will probably be used most often at hubs at the edge of the area and located closely to a highway, while e-bikes and cargo bikes will be the dominant modes at hubs in the centre of an area. This demonstrates that you can influence the most frequently used mode with the location and its characteristics. If you would like to stimulate cycling in an area, the distance between the residents and the hubs is of special importance.

Most of the municipal experts distinguished two or three locations/types of mobility hubs. The first type are hubs at neighbourhood-level, where the most important characteristic is that the hub should be situated very close to the users since this enhances the ease of use. Second, hubs as Park & Ride locations, where the most important characteristic is to keep cars as much as possible away from the (centre of the) neighbourhood by letting people park their cars at this facility and enable them to travel further with public transport and/or shared mobility. This relieves the traffic intensities and the parking pressure caused by cars within the area. Some experts also mention a third type, although this can coincide with the above mentioned types, which is the public-transport node. By combining the additional mobility possibilities of PT with mobility hubs, a powerful combination can be achieved because people can use it for their entire journey. Additionally, it is important that the complete area remains accessible by car because people should be able to reach their houses – e.g. disabled people or to drop off furniture – and the emergency services should be able to reach every location.

When asked about public transport connections at mobility hubs, the mobility provider mentions that Hely hubs are currently not connected with PT, which makes them compete with it. This leads to users that exchange PT with a shared car, which in turn contributes to higher traffic intensities. Therefore, the mobility provider thinks that having a public transport connection at mobility hubs, will positively influence the usage of shared mobility and will also lead to a more efficient usage of the mobility network. All the municipal experts agreed that a (high-quality) connection with public transport is of added value for mobility hubs, but it is not a requirement. Especially for bigger hubs, the PT connection is important, while for neighbourhood hubs this is less or not important. This is consistent with the findings in the literature, where a public transport connection is considered as an advantage (see p.24).

Both the mobility provider and the municipal experts take the view that business-to-consumer (B2C) fits best in the context of the Achtersluispolder. Reasons for this are: bigger and more varied offer of cars, easier to implement on a big scale because only one or a few parties are involved, and it is easier to steer on how the carsharing is offered and for what period. Most of the experts see peer-to-peer as a possible addition to B2C, such that you can provide a broader offer with for example lower costs.

When talking about side-services, the mobility provider sees every service that is related to carsharing and logistics as potential added value for mobility hubs. Additionally, if the hubs are located at central points in the neighbourhood – bringing many people together – it can lead to more social safety at these hubs, which can further stimulate the use. Logistics services are mentioned by most municipal experts as promising services. By locating the mobility hubs at the edges of the area, they can lower the amount of vehicle movements in the area itself. Other side-services like a supermarket can also be useful and make the hub more attractive, which can increase the social safety of the hub again. It is important that the additional services match with the location because the users and their wishes will differ per location.

The mobility hubs may not offer one-way trips, as mobility hubs are a recent development and there is not a regional or national network of hubs. The mobility provider thinks that this will probably not influence the success of mobility hubs in the Achtersluispolder. With roundtrips, you can serve people's first mobility needs which makes people use the hubs for their entire journey. A network of hubs has another goal, e.g. people that want to use shared mobility to come home after they first travelled by train. The municipal experts are divided about this question: 4 experts (out of 7) think you need a network of hubs because otherwise the possibilities are too limited, 2 experts think it is not necessary, because people know when they move to the Achtersluispolder that there will be an roundtrip model and most trips are roundtrips, and 1 expert thinks it is too early to decide that, because at this moment there are only some experiments with this system. Therefore, the system should be flexible, such that it can be added later if necessary.

The experts were asked to assign points to criteria they see as important for a successful implementation of mobility hubs. In Figure 13, it is indicated how many experts assigned a certain amount of points to which criteria. When looking at the similarities between the municipal experts and the provider, it can be noted that *state & (social) safety of the hub* and *distance to the hub* are mentioned by all experts as important. *Distance to the hub* was also found to be an important criterion in literature (see p.25). Furthermore, *diversity in vehicles, ease of use, availability* and *vehicle costs* are mentioned by most of the municipal experts and the provider. As mentioned by various experts, it is important that there is a viable business case, which means that the *vehicle costs* (for the user) and the *hub costs* (for the operator and possibly for other parties such as the municipality or the real estate developer) are balanced. *Visibility of the hub* was considered important by half of the municipal experts and the provider.

When looking at the differences between the municipal experts and the provider, it can be seen that the criteria *roundtrip* (which indicates whether or not people have to return their vehicle to the same location as where they have picked it up) was considered influential by almost all municipal experts, while the provider does not think this is (considerably) influential; this was already noted earlier in the interviews, see also above. Furthermore, the sustainability of the vehicles is mentioned by half of the municipal experts as an important criterion. As noted by some municipal experts during the interviews, municipalities may want sustainable vehicles in the hub to reach their climate goals, but they do not consider *sustainability* as a (very) important criterion for a successful implementation of mobility hubs since users are less interested in the sustainability of the vehicles. This is in line with the remark of the provider that sustainable vehicles are not that important to users, especially because of the higher price. Finally, connection with PT depends on the type and size of mobility hub.

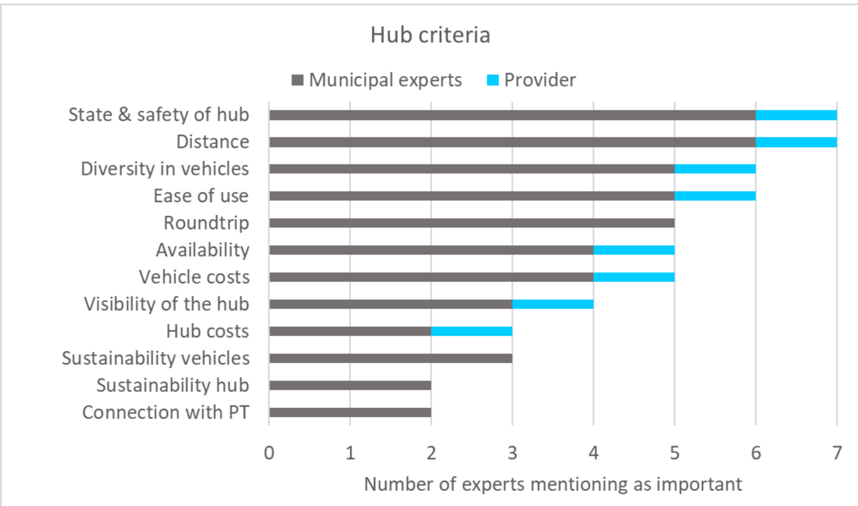

Figure 13 - Hub criteria mentioned as important by experts

Where Figure 13 gives an impression about which criteria are important, it does not distinguish how important the criteria are. Therefore, the criteria have been ranked after the amount of points they received. In Figure 14, the top 3 of all interviewed experts is given. Since the provider assigned the same amount of points to *ease of use* and *distance*, these criteria share second and third place. As can be seen, *ease of use*, *distance* and *vehicle costs* are often mentioned as the most important characteristics. It is interesting to see that the provider considers *vehicle costs* as more important than *ease of use and distance*. Furthermore, the *state & (social) safety of the hub* is also seen as important, but not as important as the aforementioned three. It is surprising that *diversity in vehicles* is not one time in the top 3, since it was mentioned by six (out of seven) experts. A possible explanation is that they see *diversity* as part of *ease of use*.

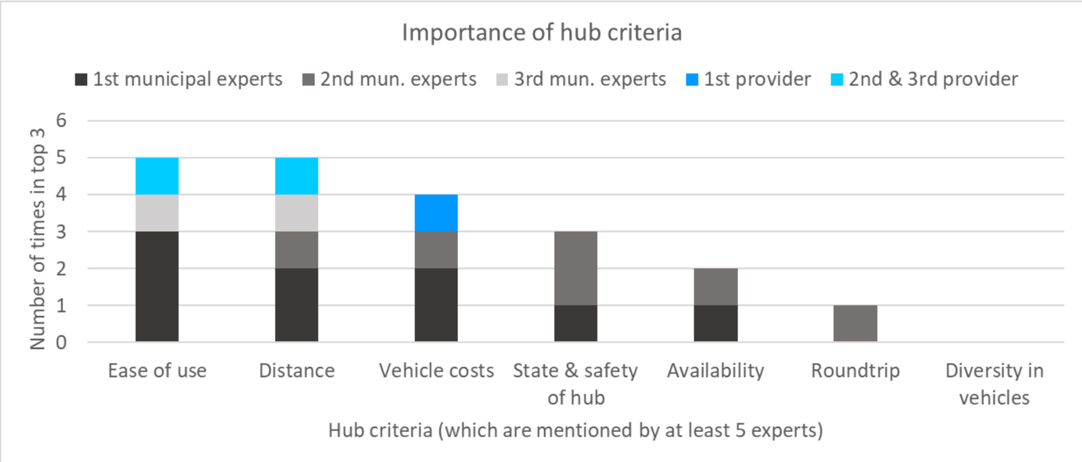

Figure 14 - Importance of hub criteria[5]

When the provider was asked on requirements before starting a hub in a certain area, two aspects were mentioned. The first aspect is the financial side. The hub will face start-up losses, which means that the provider needs financial support to cover these costs. Second, it is important that the hub is an integral part of the plans for the area, which means a location close to the users and to be involved in certain decision-making.

[5] It occurred that experts gave the same amount of points to multiple criteria, which results in a higher number of 1st places than municipal experts.

5. Mobility hubs applied in the Achtersluispolder

The information that was collected in the previous chapters is used to develop three scenarios. Before discussing the actual scenarios, the potential impact of carsharing is shown. Next, it is explained how the three scenarios are based on the Technology Acceptance Model. Finally, the three scenarios are explained.

5.1 Carsharing potential

As mentioned ealier, parking standards are an important instrument. Therefore, the parking standards of the municipality of Zaanstad were examined (Gemeente Zaanstad, 2016). It should be noted that at the time of this report the classification of the houses was not known, i.e. it was not possible to see how many houses of which types would be built. However, it was known that the future parking standards of the Achtersluispolder will be similar to those in the centre of Zaandam. As a result, the average of the categories expensive, medium and cheap for the most urban zone was taken, which resulted in a parking standard of 0,6 for residents and a parking standard of 0,3 for visitors (see Table 7). This leads to 7.650 parking spaces, which is equal to 191.250 m^2. This is about 9 percent of the total area of the Achtersluispolder, just for car parking (CBS, 2020).

Table 7 - Number of parking spaces per household

Target group	According to Parking policy Zaanstad
Residents	0,6
Visitors	0,3
In total	0,9
Number of parking spaces	7.650 (191.250 m^2)

Shared cars are much more space efficient than privately owned cars. For this study, it is assumed that 1 shared car replaces 4 private owned cars, which is consistent with CROW (n.d.), similar projects like Sluisbuurt and Merwede (Burmanje et al., 2019; Boshouwers et al., 2018a) and parking policies of Utrecht and Wageningen (Gemeente Wageningen, 2015; Gemeente Utrecht, 2013). To see the potential space saving, the impact was examined when 30 percent, 40 percent and 50 percent of the total parking need of residents was replaced by shared cars. This is in line with similar projects like Sluisbuurt and Merwedekanaalzone, where 30 to 40 percent of the total parking need is replaced by shared mobility (Burmanje et al., 2019). As given in Table 8, 29.000 m^2 is saved when 30% of the parking need is replaced by shared cars, 38.000 m^2 when 40% is replaced and 48.000 m^2 when 50% is replaced. This space can be used to increase the spatial quality of the area, with for example parks and/or playgrounds.

Table 8 - Potential effects of using shared cars

	0% shared car	**30% shared car**	**40% shared car**	**50% shared car**
Number of shared cars	-	385	510	640
Applied parking standard for residents	0,6	0,57	0,52	0,48
Space savings	-	29.000 m^2	38.000 m^2	48.0 m^2

5.2 TAM as foundation for the scenarios

As shown by literature and interviews, the distance that users have to travel to a mobility hub is a crucial factor in persuading people to adopt and use shared mobility. Therefore, the distance between the users and the mobility hubs is chosen as key element in the design process. As mentioned in the theoretical framework, the Technology Acceptance Model indicates that perceived ease of use leads to usage behaviour. In other words, the perceived effort influences the usage behaviour. That means for this study, that the perceived effort of owning and using private means of transport should be compared to the perceived effort of using shared mobility. In particular, the possession and usage of a private car compared to shared mobility, since the car takes up most of the space, is most polluting and leads to congestion (see also the introduction on p. 10).

When using this concept and combining this with distance to the hub, three approaches can be distinguished. The first approach is providing shared mobility as an additional service, next to private owned means of transport. In practice this means that private car parking will be closer to the user than shared mobility, which makes the effort of using shared mobility higher than using a private car (see Figure 15). The second approach is that a privately owned car takes the same amount of effort as shared mobility (see Figure 16). In practice this can mean two things: providing private car parking and shared mobility close to the users or providing private car parking and shared mobility at a larger distance (400 – 600 meters). The last approach is that shared mobility takes less effort than the privately owned car (see Figure 17). In practice this means providing private parking at a distance and shared mobility close to the users. This concept of varying the distance to shared mobility and private car parking is also applied at Strandeiland (Derksen et al., 2019b). Since this study focuses on providing mobility hubs in a (theoretically) successful manner, the first approach is not applied in one of the scenarios.

Figure 15 - Shared mobility as an additional service

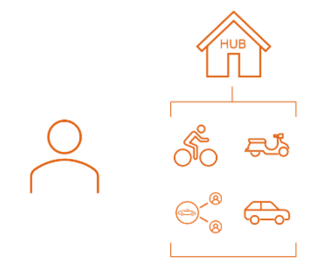

Figure 16 - Shared mobility equal to own car

Figure 17 - Shared mobility takes less effort than own car

Finally, the *Koersnota* of the municipality of Zaanstad (2020) mentions mobility hubs at the edges of the Achtersluispolder. However, that concept is not applied in this study, because it followed from the literature review and the interviews that a small distance to the mobility hub is very important. Therefore, and also to broaden the scope, other possibilities have been explored. These can be found in the next section.

5.3 Three scenarios discussed

Before discussing the three scenarios, a few remarks have to be made. First, in Figure 18, Figure 20 and Figure 22 a PT connection is depicted. However, the exact location of this connection is still subject of research. Second, as a result of the interviews, it has been determined that all scenarios use a roundtrip model. Last, to calculate the spatial consequences, it has been assumed that one parked vehicle needs on average 25 m^2, in line with the Strandeiland project (Derksen et al., 2019a).

The first scenario has as main focus to provide excellent mobility options nearby the residents of the Achtersluispolder. This means that the maximum distance between a resident and one of the ± 35 mobility hubs is 150 meters, which is within a two-minutes' walk. At these hubs, the privately owned cars are parked, together with shared cars and shared Light Electric Vehicles (LEV's), which are e-bikes, e-cargo bikes and e-scooters. Also, visitors can park at the hubs. Some hubs provide a connection with public transport, to offer more mobility options. The reason that not every hub provides a connection with PT, is because of the large number of hubs, which would result in an inefficient PT network.

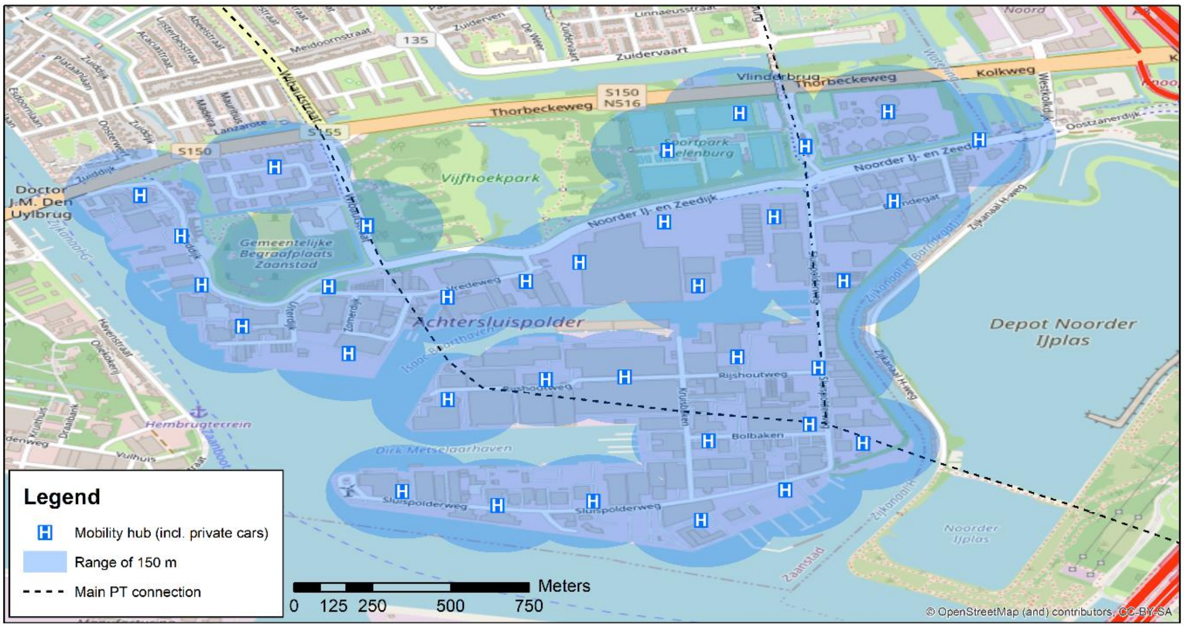

Figure 18 - Scenario 1

In Table 9 the characteristics of the mobility hubs can be seen. When 40 percent of the parking need is replaced by shared cars, 15 shared cars will be offered per hub and 111 parking spaces are in total available to residents and visitors. It is assumed that each hub has 3 levels, which results in a footprint of 1.050 m^2. In Figure 19, such a mobility hub is depicted and compared with a housing block in Zaandam (Acaciastraat 2 – 32) and an apartment building in Amsterdam (Eva Besnyöstraat 207 – 459).

Table 9 - Characteristics of the mobility hubs in scenario 1

	30% shared car	40% shared car	50% shared car
Parking spaces for shared cars	11	15	18
Parking spaces for private cars	102	87	73
Parking spaces for visitors	24	24	24
Total number of parking spaces	137	126	115
Footprint per hub	1.140 m^2	1.050 m^2	960 m^2

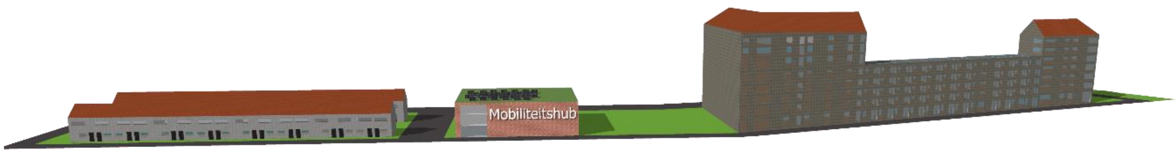

Figure 19 - Size of a mobility hub in scenario 1

The second scenario has as main focus to stimulate shared mobility by locating it closer than private cars. As depicted in Figure 20, visitors and residents can park their private car within 600 meters in one of the 5 bigger parking garages. In 13 smaller mobility hubs with a maximum distance of 300 meters shared mobility is offered, to minimise the effort of using shared mobility compared to a private car. The maximum distance of 300 meters is within the range mentioned by literature (see also p.25). In this scenario, all parking garages are connected with public transport, such that the effort to go to a public transport stop is equal to the effort of going to a private car. Furthermore, several mobility hubs are also close to or connected with public transport stops to make sure that public transport is also easily accessible to people without a private car.

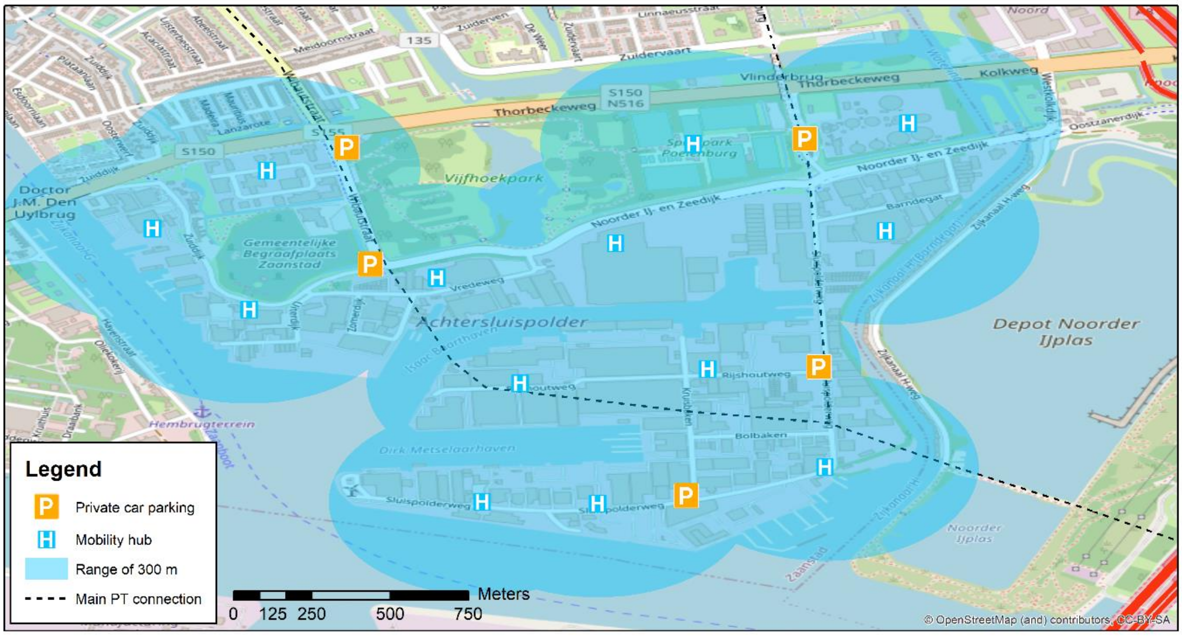

Figure 20 - Scenario 2

As can be seen in Table 10, the parking garages and the mobility hubs differ considerably in terms of size. Therefore, the parking garages are located at central points and next to main roads and not in the middle of residential areas. With that, also the number of car movements in the residential areas will be lowered. Furthermore, if 40 percent of the parking need is replaced by shared cars, 30 shared cars will be offered per mobility hub and 782 parking spaces will be located in the parking garages. It is assumed that each parking garage has 4 levels, which results in a footprint of 4.900 m^2. Such a parking garage is depicted in Figure 21, compared to the same housing block of terraced houses and the apartment building as for scenario 1.

Table 10 - Characteristics of the parking garages and mobility hubs in scenario 2

	30% shared car	40% shared car	50% shared car
Parking spaces for private cars	714	612	510
Parking spaces for visitors	170	170	170
Footprint per parking garage	5.500 m^2	4.900 m^2	4.250 m^2
Parking spaces for shared cars	30	40	50
Footprint per small mobility hub	750 m^2	1.000 m^2	1.200 m^2

Figure 21 - Size of a parking garage in scenario 2

The third and last scenario has as main focus to stimulate sustainable and healthy modes of transport. This means that the effort to take an active mode, i.e. (e-) bike, e-cargo bike, is lower than taking a car, shared or private. Furthermore, high-frequency public transport and high quality bicycle and walking infrastructure are crucial for this scenario. As depicted in Figure 22, there are 9 bigger hubs that offer shared and private cars. These hubs are within a distance of 400 metres and also visitors can park their car at these locations. Within a distance of 250 meters, 20 smaller hubs that offer shared-LEV's are located.

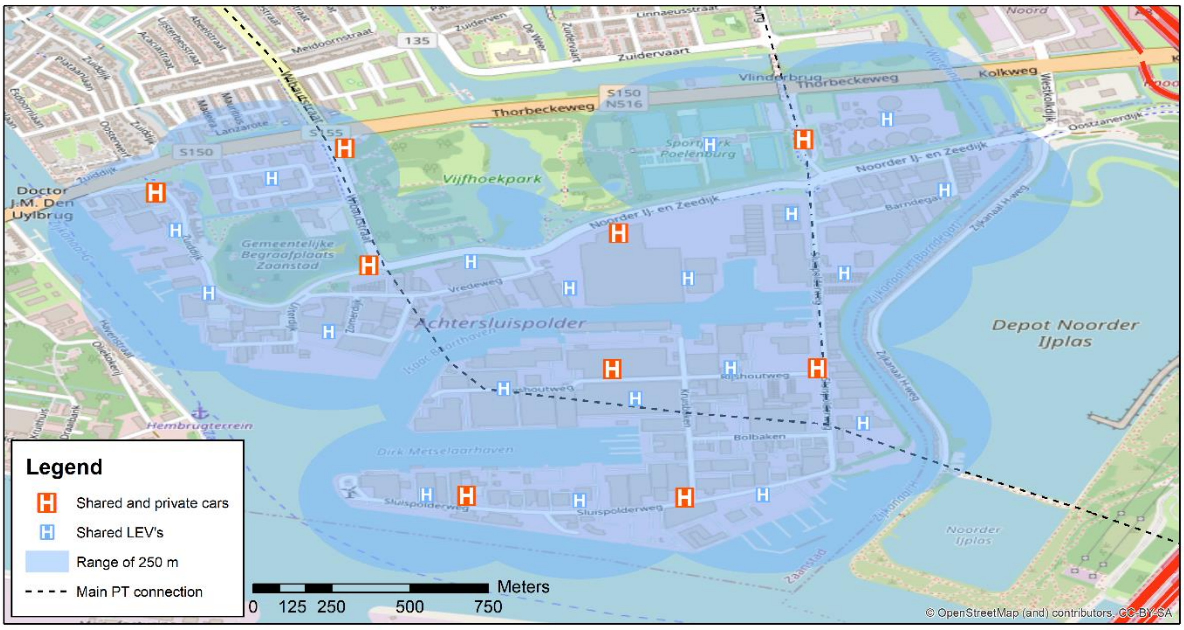

Figure 22 - Scenario 3

As can be seen in Table 11, the size of a big hub is comparable to the size of a parking garages in scenario 2, although somewhat smaller. Furthermore, when 40 percent of the parking need is replaced by shared cars, 57 shared cars are located per bigger hub and 435 parking spaces for residents and visitors. It is assumed that each bigger hub has 3 levels, which results in a footprint of 4.100 m^2. In Figure 23, the bigger hub is depicted, compared to the same housing block of terraced houses and the apartment building as for scenario 1 and 2.

Table 11 - Characteristics of the bigger mobility hubs in scenario 3

	30% shared car	40% shared car	50% shared car
Parking spaces shared cars	43	57	70
Parking spaces residents	400	340	280
Parking spaces visitors	95	95	95
Footprint per big hub	4.400 m^2	4.100 m^2	3.700 m^2

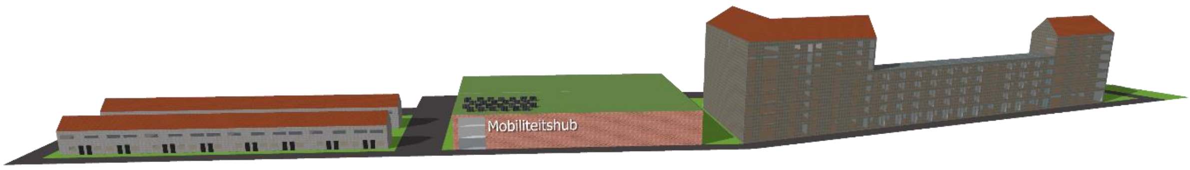

Figure 23 - Size of a mobility hub in scenario 3

Concluding, it can be noticed that the scenarios have similarities and differences. When looking at the differences, it can be seen that the main differences lie in: distance to the hub, number of hubs, size of hubs, diversity in vehicles per hub and number of vehicles per hub. This shows that many of the mentioned aspects are related to distance to the hub, or number of hubs (since these are correlated). The following aspects are similar for all scenarios: parking is located in a mobility hub or parking garage (so no street parking) and the number of total vehicles within the area. The reason to situate parking in built facilities is to show future residents of the Achtersluispolder the advantages of a low car ownership. As noted by shared mobility providers, residents should experience the benefits of this (Van der Linde, Oldenburger, Kwantes, Govers, & Boshouwers, 2018b). Finally, the vehicle costs/ business case has not been taken into account. This will be evaluated in the discussion (see p.45). In the following chapter, the three scenarios will be compared and assessed.

6. Multi-Criteria Decision Analysis

To compare and assess the three proposed scenarios, an MCDA will be used. First the important hub criteria following from the interviews and the elicitation of the Arcadis experts will be discussed. This will lead to the weighting of the various hub criteria using the Analytic Hierarchy Process (AHP). Then, the scenarios and their scores will be examined per criterion and finally the total scoring of the three scenarios will be discussed. The calculations are explained in detail in Appendix B – The Analytic Hierarchy Process.

6.1 Weighting

As mentioned in the interview results (see also p. 29), the municipal experts and the provider were asked to award points to criteria they consider important for a successful implementation of mobility hubs. The same was asked to 5 Arcadis experts, to get a more comprehensive insight in the important mobility hub criteria.

To get a better understanding of the interests of the various stakeholders, the average number of points awarded by the different experts among the various criteria, have been analysed. It is important to note that these data should be interpreted with caution, because the experts were not asked on their interests, but rather on what they see as important criteria for a successful hub. When looking at Figure 24, it can be noted that *ease of use*, *vehicle costs*, *availability*, *distance* and *state & (social) safety of the hub* are considered as very important by all elicited experts. An interesting finding is that the municipal experts on average consider *state & (social) safety*, *sustainability* (of both the vehicles and the hub) and whether or not users have to return their vehicle to the same depot as where they have picked it up (*roundtrip*) as more important than the other experts. When looking at the Arcadis experts, it appears that they consider *availability of the vehicles*, *connection with public transport* and, *state* and *safety of the vehicles* as more important compared to the other experts. The provider sees *vehicle costs* as much more important than the other experts, and to a less extent *distance* and *diversity.* Last, it can be noticed that *hub costs* are considered as more important by the provider and the experts of Arcadis than by the municipal experts.

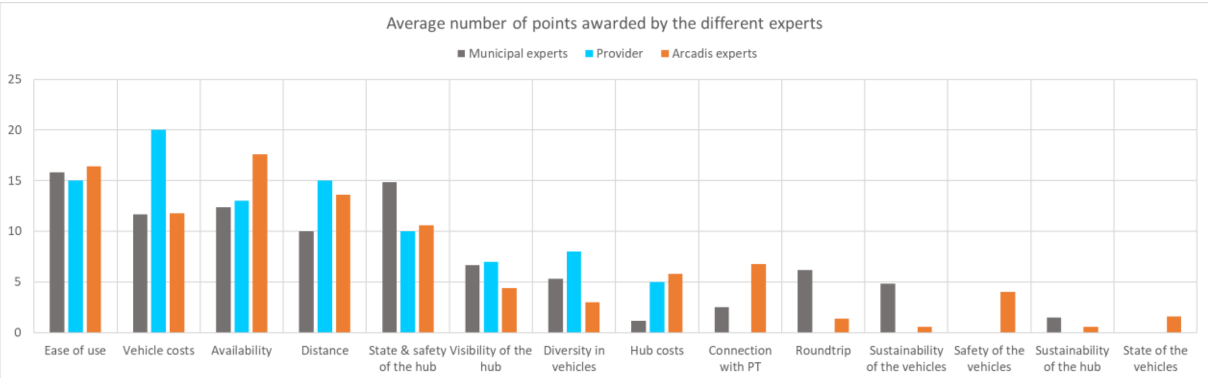

Figure 24 - Average number of points awarded by the different experts

In order to determine hub criteria that are considered as important by all experts, it has been determined which criteria receive how many times a certain amount of points. As depicted in Figure 25, criteria that are often mentioned as important (as they received points) include: *distance to the hub*, *state & (social) safety of the hub*, *ease of use*, *diversity in vehicles*, *availability*, *vehicle costs*, *roundtrip*, and *visibility of the hub*.

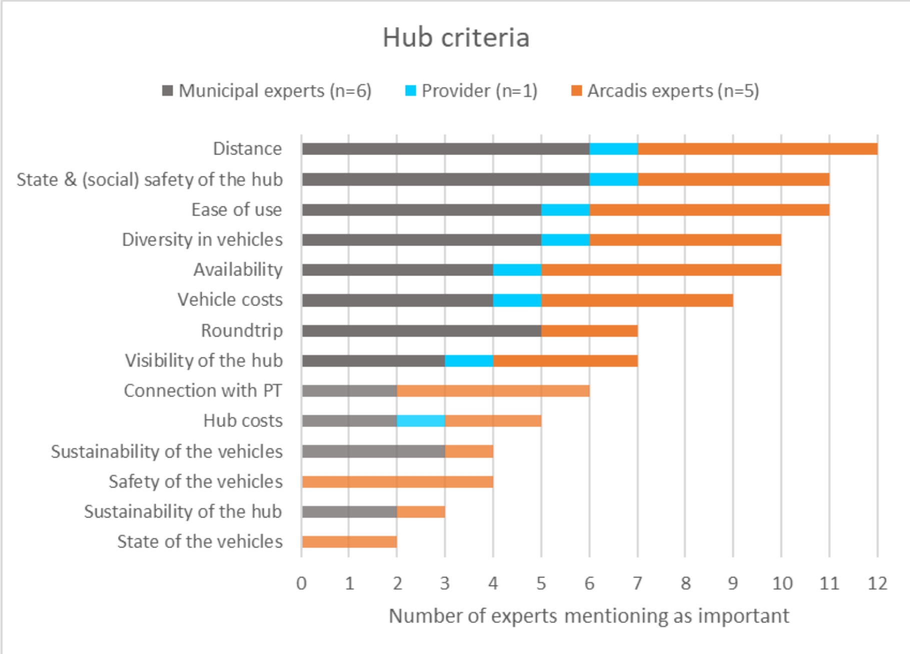

Figure 25 - Number of times that criteria are mentioned by all elicited experts

In order to determine hub criteria that are considered as important, the scores of experts have been ranked. By doing this, it is avoided that outliers influence the mean considerably. Rather, it is examined, which criteria are often found as most important, second most important and third most important. Therefore, the criteria that are mentioned by more than half of the total number of experts, which makes seven, are ranked after the amount of points they received. As depicted in Figure 26, *ease of use* and *distance* are the two most important hub criteria according to the consulted experts, followed by *vehicle costs, availability, state and (social) safety of the hub, visibility,* and *roundtrip*. As with the interviews, diversity in vehicles is for none of the experts in the top 3 of most important hub criteria.

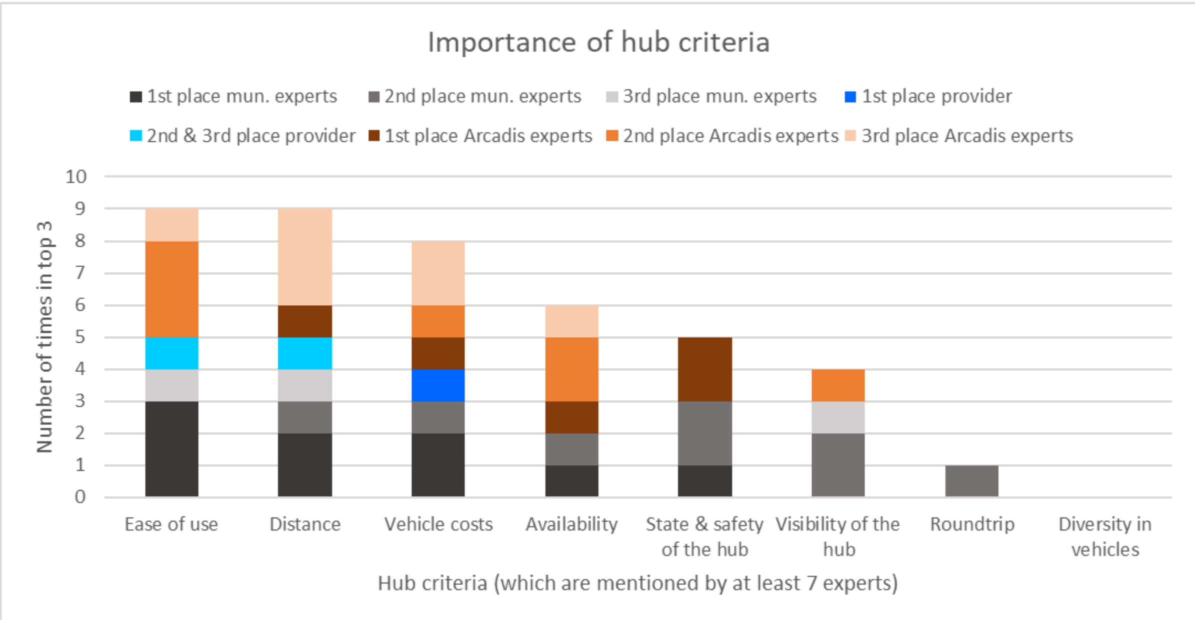

Figure 26 - Importance of hub criteria according to elicited experts

These 8 criteria form the basis of the MCDA, but since it is assumed that there will be a roundtrip model in the Achtersluispolder this criterion is omitted. Therefore, the MCDA will use *ease of use, distance, vehicle costs, availability, state and (social) safety of the hub, visibility of the hub* and *diversity in vehicles*.

As demonstrated by Saaty and Ozdemir (2003), it is important to have no more than 7 elements within a group of the AHP, because otherwise the human mind cannot properly detect and correct which element causes the greatest inconsistency. The discussed MCDA satisfactorily meets this rule. Applying the AHP, using the ranking of Figure 26, results in a weighting as given in Table 12. As noted in the introduction of this chapter, the detailed calculations can be found in Appendix B – The Analytic Hierarchy Process.

Table 12 - MCDA criteria and their weights

Criteria	Weight
Ease of use	0,35
Distance	0,25
Vehicle costs	0,17
Availability	0,10
State & safety of the hub	0,07
Visibility of the hub	0,04
Diversity	0,02

6.2 Assessing three scenarios

The next step in the AHP, is comparing the alternatives on each of the 7 criteria.

Ease of use

The first and most important criterion is *ease of use*. Scenario 1 (SC1) scores best on this criterion, because of the small scale of the hubs (see Table 13). Users can easily access the building and find their preferred mode of travel and do not have to walk large distances within the mobility hubs. Scenario 3 scores moderately less, because most of the hubs have also a small scale, only the bigger hubs with shared and private carparking are significantly bigger. Scenario 2 is less preferred than the other alternatives, because of the large scale of the big parking garages. Other aspects of ease of use, such as the ease with which vehicles can be unlocked, the ease of reservation, etc. cannot be distinguished between the scenarios at this stage of the development.

Table 13 - Comparison matrix: ease of use

	SC1	***SC2***	***SC3***
SC1	1,00	5,00	3,00
SC2	0,20	1,00	0,33
SC3	0,33	3,00	1,00

Distance

When looking at the distance between the users and the mobility hubs, it becomes clear that scenario 1 is strongly preferred compared to scenario 2 and 3. As given in Table 14, users have to travel at most 150 meters to all modes of transport, while in the other scenarios the users have to travel 250 meters (SC3) and 300 meters (SC2) to the mobility hub. When comparing scenario 2 and 3, it becomes clear that scenario 3 offers more modes of transport within a shorter distance.

Table 14 - Comparison matrix: distance

	SC1	***SC2***	***SC3***
SC1	1,00	7,00	5,00
SC2	0,14	1,00	0,33
SC3	0,20	3,00	1,00

Vehicle costs

The vehicle costs are a difficult criterion to evaluate (see Table 15). It is possible that because of the higher number of hubs, scenario 1 leads to higher vehicle costs for the users. However, the provider may operate in a larger region and applies the same prices at every location. Therefore, it is assumed that all scenarios score equally. This criterion is reflected in the final result and with that, demonstrates its influence on the final score.

Table 15 - Comparison matrix: vehicle costs

	SC1	***SC2***	***SC3***
SC1	1,00	1,00	1,00
SC2	1,00	1,00	1,00
SC3	1,00	1,00	1,00

Availability of vehicles

As given in Table 16, scenario 2 scores best on availability compared to the other scenarios. This is because all the shared mobility is offered in the smallest number of hubs, which means that – with the same number of vehicles – the chance of finding a vehicle is the greatest. Scenario 3 scores moderately lower compared to scenario 2, because the number of hubs is higher which means less vehicles per hub. This scenario scores somewhat higher than scenario 1, because the number of hubs is smaller. Scenario 1 scores compared to scenario 2 and 3 lower because the number of vehicles per hub is significantly lower which means a lower availability per hub. However, when there are no vehicles available at one hub, another hub can be reached within a small distance. Therefore, it scores not (very) much lower compared to other scenarios.

Table 16 - Comparison matrix: availability

	SC1	***SC2***	***SC3***
SC1	1,00	0,25	0,33
SC2	4,00	1,00	3,00
SC3	3,00	0,33	1,00

State & (social) safety of the hub

When looking at the state and (social) safety of the mobility hubs, it can be noted that scenario 1 scores better compared to scenario 2 and 3. This is due to the high number of mobility hubs, which makes them spread out over the area and with that close to civilization. It should be noted that this is an estimation of the scenario, because the final location and layout of the area are not known and can largely influence the (social) safety of the hubs. Also, because of the smaller scale of the hubs it is assumed that the social cohesion improves, which will increase the state of the hubs, such as the neatness (Derksen et al., 2019a). Scenario 3 scores better compared to scenario 2 because the higher number of hubs, which leads to smaller hubs. Therefore, the state and (social) safety score better.

Table 17 - Comparison matrix: state & (social) safety

	SC1	***SC2***	***SC3***
SC1	1,00	4,00	2,00
SC2	0,25	1,00	0,33
SC3	0,50	3,00	1,00

Visibility of the hub

In Table 18, the visibility of the various scenarios is compared. As can be seen, scenario 1 has the highest ranking because of the large number of hubs. This makes them an important part of the scene in the Achtersluispolder. Scenario 3 scores moderately compared to scenario 1, because the number of hubs is lower than in scenario 1, which makes them less part of the scene in the Achtersluispolder. Finally, scenario 2 performs worst because of the lowest number of hubs. It should be noted that visibility also largely depends on the implementations of the mobility hubs, since various aspects can contribute to the visibility, such as colour and signboards. Also, digital visibility is important, such as visibility in navigation software, in search engines and on maps.

Table 18 - Comparison matrix: visibility of the hub

	SC1	***SC2***	***SC3***
SC1	1,00	5,00	3,00
SC2	0,20	1,00	0,33
SC3	0,33	3,00	1,00

Diversity in vehicles

Lastly, the diversity in vehicles is in essence equal for all scenarios, because the offered modes are the same. However, when looking at the diversity in modes per hub it can be noted that scenario 1 scores best compared to scenario 2 and 3, because all modes of transport are present at all hubs (see Table 19). Especially scenario 3 scores poorly, because only LEV's are offered at the small hubs. Scenario 2 scores moderately compared to scenario 1 because, although it does not offer the privately owned car, it does provide all modes of shared mobility. Scenario 2 performs slightly better compared to scenario 3, because it does offer all the modes of shared mobility.

Table 19 - Comparison matrix: diversity in vehicles

	SC1	***SC2***	***SC3***
SC1	1,00	4,00	8,00
SC2	0,25	1,00	3,00
SC3	0,13	0,33	1,00

When calculating the scores per scenario for each criterion, it appears that scenario 1 contributes with 55% to the final goal of a successful implementation of mobility hubs in the Achtersluispolder (see Figure 27). This means that scenario 1 is preferred over scenario 2 and 3, using these criteria and weights. When looking at the scores in more detail, it can be seen that scenario 1 scores better compared to the other two scenarios on the two most important criteria *ease of use* and *distance.* This makes scenario 1 the most preferred alternative using these criteria.

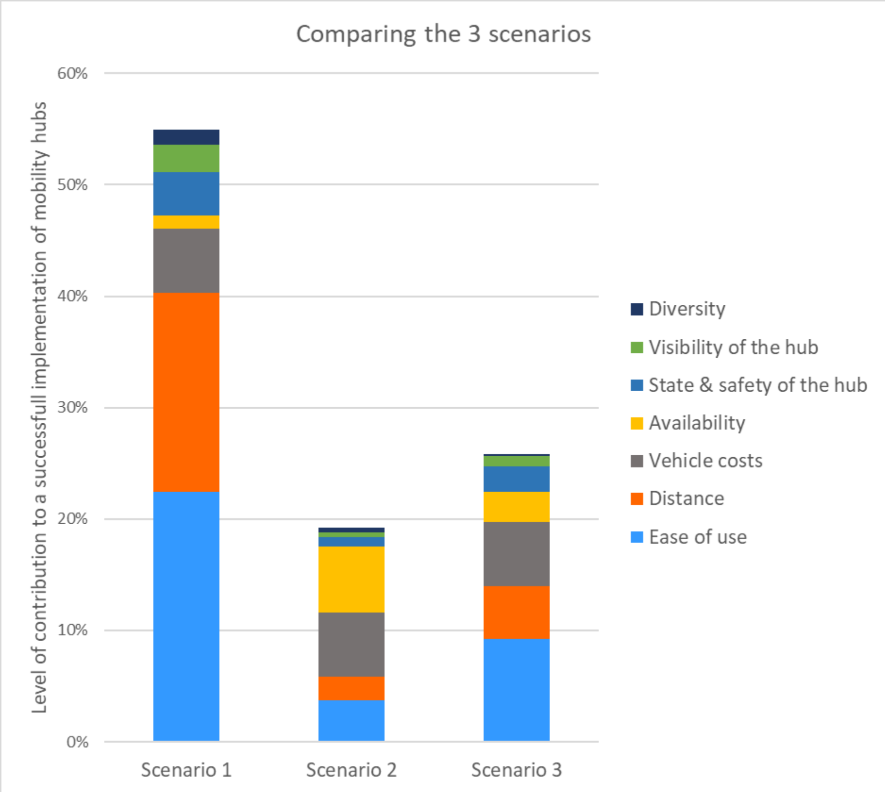

Figure 27 - Comparison of the scoring of the 3 scenarios

However, it can be noticed that these seven criteria are mainly important criteria to the users. It is very well possible that the other stakeholders have other priorities, which would result in a different outcome. Therefore, the interviews and if possible, other information, is used to give an estimated assessment of the three scenarios, in which also other criteria than the above mentioned seven are taken into account, in order to get a more comprehensive assessment.

When considering the interests of the municipality, it is important that the mobility strategy stimulates sustainable transport (see also Figure 24), which leads to less air pollution in the area and helps to reach the sustainable goals of the municipality of Zaanstad (2019). Scenario 3 scores best on that topic, because of the emphasis on active means of transport and public transport, which are more sustainable than (shared) cars. Also, the strategy should contribute to less traffic congestion in the area, compared to the situation where no action would be taken. One could say that interest is covered by all three scenarios, although scenario 3 actively discourages car usage (both shared and private), which can lead to less congestion. Another interest of the municipality is that the area is attractive to live, such that the residents are contented with living in the area and that the houses can be sold at good prices. This can be achieved by for example car-free streets and a lot of green in the area. Again scenario 3 would probably score best, since residents are actively stimulated to use other modes than cars. Scenario 2 would score second best, because the main parking garages are located at the main roads which means in theory that most of the cars will not enter the residential areas itself. Lastly, the municipality desires an affordable mobility strategy. Other reports suggest that property developers pay most of the costs, because it is no longer necessary that they build and pay the parking spaces (Burmanje et al., 2019; Derksen et al., 2019a; Boshouwers et al., 2018a). However, in the same reports it is also assumed that the municipality has to contribute financially to the construction and operating of the mobility hubs. Scenario 1 would probably score lowest on that point, because the large number of hubs involves higher costs. Scenario 3 would score moderately, because the small hubs for active modes of transport are relatively small and easy to build (see for example Figure 28). Scenario 2 involves the lowest number of locations – both parking garages as mobility hubs – which can lead to economies of scale.

Figure 28 - Example of a Hely hub with active modes (Belfadla, 2019)

When looking at the interests of the provider, a positive business case is the most important aspect. Therefore, the number of shared mobility users is important, which is preferably as high as possible. Another aspect is financial support. As indicated by the interviewed provider, financial support is needed to cover start-up losses. It could be argued that the higher the (potential) number of users, and with that the potential to replace private cars, the higher the willingness to financially support the mobility provider (e.g. subsidies). Based on the Technology Acceptance Model, it can be said that a higher number of users can be achieved by providing shared mobility which entails less effort than the private car. Scenario 1 offers shared mobility very close to the users, but the same applies to the private car. Scenario 2 offers all shared mobility closer to the user compared to the private car, which means that scenario 2 is probably preferred. Scenario 3 involves also shared mobility closer to the user compared to the private car, but applies only to the shared LEV's; shared cars are offered at the same locations as the private cars. Therefore, scenario 3 scores neutral. In addition to the earnings, also the costs are important to the provider. If it assumed that a higher number of hubs leads to more construction, operation and maintenance costs, scenario 1 scores worst, because of the high number of mobility hubs. Scenario 3 would score moderately and scenario 2 would score best. Summarising, it can be said that scenario 1 scores neutral, because it offers shared mobility very close to the user, but the same applies to the private car, and it involves high costs. Scenario 2 would score very good, because shared mobility is closer to the users than the private car, and the involved costs are the lowest. Last, scenario 3 would score slightly positive, because shared LEV's are closely located to the users and the involved costs are moderate.

Finally, the residents' perspective is mainly covered by the above performed MCDA, which means that alternative 1 is most favoured mainly because of the short distance to all means of transport and the small scale of the hubs. Scenario 3 is second best, mainly because of the acceptable range of mobility options. Scenario 2 is the least favoured, because of the larger distances to private cars. The result of the above analyses can be seen in Table 20. On the basis of this estimated rating, scenario 3 would score best.

Table 20 - Estimated rating of the scenarios by the various stakeholders

	Scenario 1	**Scenario 2**	**Scenario 3**
Rating municipality	-	+	++
Rating provider	+/-	++	+
Rating residents	++	-	+

7. Discussion and limitations

The concept of mobility hubs is a new phenomenon. As a result, it is difficult to find specific literature regarding mobility hubs. The studies that were examined are mainly master theses, which are not reviewed like articles from journals. Next to that, articles that were used to support the findings about mobility hubs, deal with certain shared modes, such as carsharing and bicycle sharing. Although these modes are part of mobility hubs, the whole is greater than the sum of its parts. Another consequence of the novelty of mobility hubs, was the difficulty of determining whether the interviewed experts are "real experts". As also noted during the interviews by one of the interviewees, there is not that much known already, which makes that there are not (many) "real" experts. This makes it important to use the information retrieved from the interviews together with other information.

In order to give recommendations on how mobility hubs could successfully be implemented, important hub criteria were determined. The research of Van Rooij (2020) was used to determine these aspects, as he determined fourteen important mobility hub criteria. However, Van Rooij did not explain what each characteristic exactly means. As a consequence, the meaning of some criteria had to be estimated. To give an example, hub costs was mentioned as one of the characteristics, but it did not become clear whether these costs were for the users or for the hub owner. To deal with this problem, some criteria were consequently explained during the interviews which makes that the experts used the same definitions when assigning points.

Furthermore, one of the characteristics of mobility hubs is whether it has a roundtrip or one-way model. When designing and calculating the spatial characteristics of the scenarios, it has been assumed that a roundtrip model would be applied in the case of the Achtersluispolder. This is a limitation, because one-way will probably ask for a different number of shared vehicles. Next to that, the number of parking spaces do not control for so-called "dual use" of parking spaces, which means that for example parking spaces of companies could be used outside working hours for residents to park their cars when they return from work outside the Achtersluispolder.

To indicate which scenario performed best, mainly the fourteen hub criteria mentioned by Van Rooij (2020) were used. However, there are other important aspects that are not covered by these criteria, such as spatial quality and financial aspects. By missing the financial aspect of the scenarios and with that the financial consequences for the future residents, the comparison between these scenarios is not complete and could be further improved. Related to that, it has been assumed that parking is always located inside an above-ground building, in order to gain as much space as possible, such that residents experience the benefits (Van der Linde et al., 2018b). Nevertheless, by assuming that parking is always located inside an above-ground building, the differences in building costs for other parking options was not taken into account, while there are considerable differences (Burmanje et al., 2019). This led to an MCDA that does not cover all aspects of mobility hubs. As a result, the performed MCDA is not the final answer on applying mobility hubs in the Achtersluispolder, but rather an instrument to gain insight in the performance of the various scenarios looking at specific criteria.

When evaluating MCDA methods in general, several limitations arised. First, when applying an MCDA, it is assumed that the preference for criteria are independent of each other; this is called preferential independence (Fishburn & Keeney, 1975). However, it can be noted that the used criterion *availability* is partly depending on *distance* and *visibility* depends on the *number of hubs* (see Assessing three scenarios, p.40). This has also been recognised as a generic shortcoming of MCDA (Fishburn & Keeney, 1975). Another limitation is that complex MCDA methods, in this case the AHP method, may be perceived as black-box models by people that are not familiar with it (Lai, Lundie, & Ashbolt, 2008). Lastly, the selection of a certain MCDA method is often restricted to user familiarity and/or simplicity (Lai et al., 2008). In this study, the AHP was applied mainly because it was explained at the university and the relative ease of use.

The weightings that were applied to the MCDA in this study have their limitations. First, only one provider was interviewed, which makes it difficult to determine what the view of shared mobility providers in general is. Second, since most of the interviewees are municipal experts and a ranking was applied, their opinion is implicitly more weighted compared to the other experts (see Figure 26). Last, the interviews were not intended as a stakeholder analysis. As a consequence, not the particular viewpoint of the stakeholders was found, but rather important hub criteria in general. However, when assessing the three scenarios, it became apparent that a stakeholder analysis would be a valuable addition to this research. Therefore, the awarded points per stakeholder group, i.e. municipal experts, Arcadis experts and the provider, were examined to get some insight in their interests. These results should however be interpreted with caution, since the interview questions were not aimed at analysing the interests of the stakeholders.

As explained above, there are drawbacks to using MCDA. The same applies to the AHP method. One of the limitations is that important information may be lost when good scores on some criteria compensate for bad scores on other criteria (Macharis, Springael, de Brucker, & Verbeke, 2004). Another limitation, especially in this study, is to determine the weights. In order to do this, the following question has to be answered: "How much more is option A contributing to a higher goal than option B?" If this question has not been formulated correctly, anomalies can occur (Macharis et al., 2004). In this study, the above question has not been asked to the stakeholders. Rather, their scoring of 100 points was used to apply the fundamental scale of Saaty (1990). Although the scoring gave an indication, it is not the same. Finally, the interpretation of the fundamental scale is not trivial and can make accurate comparisons difficult (Belton, 1986). This shows that "the final decision should not be the automatic result of an MCDA; it should be made by the decision-maker(s)" (Kujawski, 2003, p. 8).

Finally, the development and use of carsharing can also lead to unexpected negative developments. Research into free-floating shared cars in Berlin showed that these cars are used at the expense of walking, cycling and public transport. Next to that, the cars were almost as inefficient as privately owned cars and use almost the same amount of space: the cars drove only 62 minutes per day, while private cars drove 30 to 45 minutes per day (Harder, 2014, as cited in KiM, 2015).

8. Conclusion and recommendations

The aim of this study was to offer recommendations on how to apply the concept of mobility hubs in terms of location, criteria and users, in the context of the Achtersluispolder. The 1st research question was defined as: "Which characteristics of mobility hubs in terms of location, number, criteria and users, emerge from literature research, survey results and interviews?" During the interviews it was mentioned that location influences dominant mode choice; cars will probably be dominant at the edge of an area, close to a highway, while e-bikes and cargo bikes will be dominant in the centre of an area. Furthermore, two or three types of mobility hubs were distinguished: small neighbourhood hubs, Park & Ride locations and some experts mentioned a third type, which is the public transport node, although this type can also coincide with one of the two other types. A neighbourhood hub focuses on a small distance to the user, while a Park & Ride location focuses on capturing car traffic before it enters the area; a public transport node focuses on combining public transport with shared mobility, which results in a system that can be used for an entire journey.

Moreover, from interviews and literature review it became clear that a public transport connection can be of added value, but does depend on the purpose of the hub. A high-quality public transport connection offers more transportation options to the users, which can positively influence the use of mobility hubs. From literature research it became apparent that there is not a single manifestation of hubs, i.e. hubs can be small and large, there can be a large or small number of hubs and they can be located above-ground or underground; it depends on the context. Something that is stressed by all studied reports, is the need of flexibility. Since mobility hubs are a new phenomenon, it is important to be able to adjust the strategy and hubs in the future.

The characteristics of (potential) hub users were studied using literature review and survey results from the Hague. Influential characteristics are age, level of education, living in a high density area and car independence. When looking at age, it can be said that a younger age has a positive influence on the adoption of shared mobility. In addition to being younger, a higher level of education, i.e. having at least a bachelor's degree, shows a very strong influence on the adoption of shared mobility. The same applies to living in a highly urbanised area, among others because of the presence of (high) parking pressure. Lastly, being less car-minded positively influences the likelihood of using shared mobility. It is recommended to stimulate people with the above characteristics to settle in the Achtersluispolder.

The performed interviews and elicitation of Arcadis experts led to determining important hub criteria. When combining the data, the following criteria showed to be important, from high to low: ease of use, distance to the hub, vehicle costs, availability, state & (social) safety of the hub, visibility of the hub and diversity in vehicles. This answered the 2nd research question: "How do the hub criteria mentioned in research question 1 relate to each other?"

Research question 3 was phrased as: "How can the identified hub characteristics be applied to develop three scenarios for hubs in the future Achtersluispolder?" Using the input of the first and second research question, three scenarios were constructed. These scenarios were based on a combination of the Technology Acceptance Model (TAM) and the hub criterion *distance to the hub*. By doing this, an important hub criterion can be objectively used to vary within the scenarios. The combination led to three frameworks. First, when users experience more effort to reach a hub compared to reaching their private car, shared mobility is an additional service. Second, if the same amount of effort is experienced in order to reach a hub compared to a privately owned car, shared mobility becomes an interesting option. Last, when users experience more effort to reach their private car compared to reaching a hub, mobility hubs have the greatest chance to replace the private car. Since the goal of the municipality of Zaanstad is to reduce the use of private cars in the Achtersluispolder, the first option – mobility hubs as an additional service – was not used in one of the three scenarios.

Scenario 1 focuses on offering all modes of transport, both private and shared, within a distance of 150 meters. This results in 35 small hubs, spread across the Achtersluispolder. In this way, shared mobility is offered with equal effort compared to owning a private car. The second scenario actively stimulates shared mobility by introducing more effort to reach the private car than reaching the hubs. This results in 5 big parking garages and 13 smaller mobility hubs. Scenario 3 highly focuses on sustainable transport and car-free streets. That means there is a strong emphasis on walking, cycling and public transport usage. This is facilitated by 20 small hubs close to the users that offer shared e-bikes, (e-)cargo bikes and e-scooters and 9 bigger hubs at a larger distance that contain both private and shared cars.

When introducing mobility hubs, several boundary conditions have to be met. These conditions are again linked to the Technology Acceptance model, since they focus on increasing the effort of owning a private car compared to using shared mobility. One of the most important boundary conditions is lowering the parking standard. Next to that, it is important to introduce paid parking within the Achtersluispolder, such that inhabitants are stimulated to use other means of transport than the car when travelling within the area, such as a groceries trip. Also, the parking policy of the adjacent neighbourhoods have to be examined, and if necessary adjusted, in order to prevent people living in the Achtersluispolder from parking their cars in these neighbourhoods, because of lower parking pressure and/or lower parking prices.

The above mentioned scenarios were compared by applying a weighted MCDA, using the Analytic Hierarchy Process (AHP). In this way, a reproducible method was used to come to a weighted comparison. The seven important criteria that followed from answering research question 2 (ease of use, distance to the hub, vehicle costs, etc.) were translated into weights. Subsequently, the three scenarios were compared on each of the seven criteria. This resulted in a weighted comparison, in which scenario 1 contributed the most to achieving the goal of a successful implementation of mobility hubs in the Achtersluispolder. It should be noted that this MCDA mainly focuses on the user demands, while not explicitly considering the interests of the other stakeholders, which are the municipality of Zaanstad and the mobility hub provider. When considering the interests of these other stakeholders, scenario 3 scored better. This shows that the MCDA is an indication and can be used to get a better insight in important criteria. The final decision should be made by the decision-maker(s).

The answers of the discussed sub questions led to answering the main question: “How can the concept of mobility hubs (theoretically) successfully be implemented in the context of the Achtersluispolder?” The results suggest that a larger number of small hubs is the most suitable implementation, because of the ease of use, the small distance to the mobility hubs and the diversity in vehicles. It is important to realise that the presented scenarios are not the solution. Rather, they serve as a starting point from which the strategy for implementing mobility hubs in the Achtersluispolder can be determined. Within this strategy, it is recommended to develop each hub fitting the wishes and needs of the area it serves. If a neighbourhood needs a supermarket for example, locating it in or near a mobility hub can increase the attractiveness of both the supermarket and the mobility hub, and with that also the (social) safety of these hubs. Last, it is recommended to make the hubs fit in with the residents of a specific neighbourhood and vice versa. For example, an area with residents that have a lower car dependence – such as students and social housing – probably need a hub with a public transport connection and without many shared cars.

To conclude, it can be said that mobility hubs can contribute to a more sustainable way of travelling in the Achtersluispolder. Since mobility hubs are a new phenomenon, it is important to apply the concept in a flexible way, such that it can be adjusted to unexpected situations and future developments.

9. Recommendations for further research

To get a more comprehensive understanding of mobility hubs, further research is necessary. These studies should focus on actual usage and revealed preferences of users. At this moment, there is mainly research about what is expected and what is reasoned by experts, but it is important to see how this concept will work out in practice. In addition, at the time of writing various projects with mobility have been announced, such as Strandeiland and Merwedekanaalzone. To see the effects of mobility hubs in practice, these developments could be further studied and monitored.

Furthermore, it is recommended to perform an in-depth stakeholder analysis, which includes (future) residents, mobility providers, the municipality of Zaanstad and property developers. In that way, the interests are clear and can be taken into account when introducing mobility hubs in the future Achtersluispolder.

As mentioned in the discussion, the financial aspects of the scenarios have not been considered. Therefore, it is recommended to examine the financial aspects, looking at the costs in terms of construction, operation, maintenance and the involved costs if the hub has to be adapted in response to future developments. Furthermore, it is advised to consider how the costs are divided. An important question is: will all residents of the future Achtersluispolder pay for the mobility hub strategy, or only people that use it?

In this study, only the future residents of the Achtersluispolder have been considered. However, the future jobs that will be located in the area, could also use the mobility hubs. In that way, the number of vehicle movements within the area can be lowered and the means of transport can become more sustainable. Also, there may be additional opportunities in combining these two, for example by using the business parking spaces in the evening for residential parking (dual use). Further research could give more insight in these aspects.

As mentioned in the literature review section, there was no univocal connection found between the household composition and the adoption of carsharing or mobility hubs. Therefore, it is recommended that future studies examine the influence of household composition on the adoption of mobility hubs.

Finally, more research is necessary on the effects of one-way and roundtrip. The interviewed experts were divided about which model is preferred, so it is recommended to study what the effects are of one-way. In particular, it is interesting to know whether one-way leads to higher usage and what the costs are.

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Appendix A – Interview scheme

Document sent for interview

Note: the sent document was in Dutch, but has been translated to English to make it consistent with the rest of the report.

Research background	The municipality of Zaanstad wants to transform the Achtersluispolder (ASP) from a working area into a working/living area. This means that in 2040, 8500 jobs and 8500 households will be located in this area. Together with these jobs and households, also an increase in vehicle movements and an increase in the number of parking spaces is expected. Since the current mobility situation already faces some bottlenecks, it is important to determine a futureproof mobility strategy. The municipality of Zaanstad focuses on high-quality public transport (bus, tram and light rail) for the ASP and wants to give priority to cyclists and pedestrians. Starting point is the accessibility of the existing companies, which means that the area should remain (sufficiently) accessible by car.
Research objective	One of the possible solutions, is the so-called mobility hub. My research question focuses on working out this concept, with the main question formulated as: *How can the concept of mobility hubs (theoretically) successfully be implemented in the context of the Achtersluispolder?*
Mobility hub definition	A place where various (shared) modes of transport are available, such that users can easily use and switch between modes that best suits their mobility needs. A connection with public transport is possible but is not a requirement.
Interview objective	Determine the relevant characteristics of mobility hubs, in terms of location, number, (design) criteria and users.
Permission to record	I will interview various experts to get an overview of the relevant characteristics. Therefore, I would like to record this interview, such that I can transcribe and code the interview, which enables me to compare the answers of the various experts. <u>Do you give permission to record this interview?</u> This will be of course confidential (I will be the only one that will listen to the recording) and the transcription will be anonymised. The recording will be deleted after maximal 30 days.
Rights of interviewees	During the interview, you are free not to answer certain questions if you do not want to. Also, you can withdraw your answers up to fourteen days after the interview.
Duration of the interview	45 minutes (one interviewee) or 75 minutes (two interviewee).

Interview scheme

Note: the asked questions were in Dutch, but have been translated into English to make it consistent with the rest of the report.

Time	Subject	#	Question
	Introduction	1	Were you able to read the document that I sent to you?
	Introduction	2	Do you give permission to record this interview, as described in the document?

Before we start with the substantive questions, I am curious about your experience with shared mobility and mobility hubs. Therefore, I wonder:

	Other	3	To what extent do you have experience with shared mobility?
	Other	4	To what extent do you have experience with mobility hubs?

Show slides and provide explanation about the Achtersluispolder

One of the questions regarding mobility hubs, is the location. Different locations are likely to have different influences; a hub at the edge of an area will be different from a hub in the centre.

	Location	5	Wat kind of locations will be interesting for hubs, such as the hubs in the ASP?

One of the possible characteristics of a mobility hub can be the connection between hub and public transport.

	Location	6	Do you think that that a connection with public transport is important? ➔ If yes, how does this connection look like?

One of the possible modes of transport is the shared car. P2P and B2C cars are offered within shared mobility (definition P2P and B2C explained).

	Criteria	7	Which type of shared cars best matches the mobility hubs in the context of the ASP?

Next to the mobility functions of the hub, there are also the socio-economic possibilities. Think of parcel pick-up points or coffee bars.

	Criteria	8	What is your opinion regarding these services in a mobility hub?

The hubs in the Achtersluispolder will probably not (initially) be part of a regional or national network of hubs, which can lead to a roundtrip model rather than a one-way model. This means that users have to return the vehicle at the same location as where they have picked it up.

Criteria	9	Does this have an influence on the success of the mobility hubs in the ASP? ➔ If yes, what is the influence? ➔ If yes, how big is this influence?

To draw up a list of important design criteria and the relation among these criteria, I would like to know which of these characteristics are important.

Criteria	10	Which (design) criteria are important for a successful mobility hub?

Give a summary of the mentioned criteria.
A number of criteria is also known from literature, these are: ….

1. Distance to the hub
2. Diversity of vehicles
3. Sustainability of the vehicles
4. Availability of the vehicles
5. Sustainability of the hub
6. Visibility of the hub
7. State of the hub
8. Hub costs
9. Ease of use
10. Safety of the hub
11. Safety of the vehicles
12. State of the vehicles
13. Vehicle costs
14. Roundtrip model
15. Connection with PT

Criteria	11	As mentioned, I would like to know the relation among these criteria. Therefore, I want to ask you to divide 100 points among the criteria, where more points mean more of importance.

Closure	Thanks for participating! I will send the summary as soon as possible to verify if I summarised your answers correctly.

Appendix B – The Analytic Hierarchy Process

Explanation about the Analytic Hierarchy Process (AHP)

The AHP decomposes the problem into a hierarchy of criteria, by defining a main goal, criteria and alternatives. Then, the alternatives and criteria can be assessed by making pair-wise comparisons, which means that each criteria and alternative is compared with another criteria or alternative (Vargas, 2010). These comparisons are performed using the fundamental scale, where 1 indicates an equal importance of two alternatives/criteria and 9 indicates an extreme importance of one alternative/ criteria over the other (see Table B.1). Even values can be used when a compromise is needed, however using the odd numbers is preferred, such that there is a reasonable distinction (Vargas, 2010).

Table B.1 - The fundamental scale, based on (Saaty, 1990)

Intensity of importance	**Definition**
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance

To give a small impression of how this works in practice, an example is given in Table B.2. Criteria 1 is obviously equal important to criteria 1, which gives the number 1. Criteria 1 is compared to criteria 2 of very strong importance, which gives a 7 for criteria 1 and 1/7 for criteria 2 compared to criteria 1. More explanation about the AHP can be found in the original work of Saaty (1990) and in a comprehensive guide of Vargas (2010).

Table B.2 - Example of a comparison matrix

	Criteria 1	**Criteria 2**
Criteria 1	1	7
Criteria 2	$\frac{1}{7} = 0{,}14$	1

Applying the Analytic Hierarchy Process

Goal (level 1) Successful implementation of mobility hubs in the Achtersluispolder

Criteria (level 2) 7 most important criteria, which are: *ease of use, distance, vehicle costs, availability, state & (social) safety of vehicles, visibility of the hub* and *diversity*

Alternatives (level 3) Scenario (SC) 1, 2 and 3

The criteria are filled in a matrix and compared using the fundamental scale (Saaty, 1990). For example, *ease of use* is of strong importance (or strongly preferred, see (Vargas, 2010)) compared to *availability*. Another example: *distance* is of extremely importance (or extremely preferred, see (Vargas, 2010)) compared to *diversity*. The result is given in Table B.3.

Table B.3 - Comparison matrix for criteria

	Ease of use	Distance	Vehicle costs	Availability	State & safety of the hub	Visibility of the hub	Diversity
Ease of use	1,0	2,00	3,00	5,00	6,00	8,00	9,00
Distance	0,50	1,0	2,00	4,00	5,00	7,00	9,00
Vehicle costs	0,33	0,50	1,0	3,00	4,00	6,00	8,00
Availability	0,20	0,25	0,33	1,0	2,00	4,00	8,00
State & safety of the hub	0,17	0,20	0,25	0,50	1,0	3,00	7,00
Visibility of the hub	0,13	0,14	0,17	0,25	0,33	1,0	4,00
Diversity	0,11	0,11	0,13	0,13	0,14	0,25	1,0
Total	**2,44**	**4,20**	**6,88**	**13,88**	**18,48**	**29,25**	**46,00**

Subsequently, the matrix is normalised by dividing each element by the sum of the column. Example: vehicle costs (column 3): $\frac{3,00}{6,88} = 0,436$, $\frac{2,00}{6,88} = 0,291, \dots \frac{0,13}{6,88} = 0,018$. This is done for each column. The result is given in Table B.4.

Table B.4 - Normalised comparison matrix for criteria

	Ease of use	Distance	Vehicle costs	Availability	State & safety of the hub	Visibility of the hub	Diversity	Eigen-vector
Ease of use	0,410	0,476	0,436	0,360	0,325	0,274	0,196	**0,35**
Distance	0,205	0,238	0,291	0,288	0,271	0,239	0,196	**0,25**
Vehicle costs	0,137	0,119	0,145	0,216	0,216	0,205	0,174	**0,17**
Availability	0,082	0,059	0,048	0,072	0,108	0,137	0,174	**0,10**
State & safety of the hub	0,068	0,048	0,036	0,036	0,054	0,103	0,152	**0,07**
Visibility of the hub	0,051	0,034	0,024	0,018	0,018	0,034	0,087	**0,04**
Diversity	0,046	0,026	0,018	0,009	0,008	0,009	0,022	**0,02**

The total of the sum of each row results in the Eigenvector, which are the criteria weights. In order to simplify the calculation process, the approximation – instead of calculating the exact Eigenvector – is applied. This is done most of the time, resulting in a difference of less than 10% (Kostlan, 1991).

This Eigenvector represents the weight that the criteria have, relative to the total result of the goal (Vargas, 2010). This results in the following criteria weights:

Table B.5 - Criteria weights

Criteria	**Weights**
Ease of use	0,354
Distance	0,247
Vehicle costs	0,173
Availability	0,097

Table continues on the next page

State & safety of the hub	0,071
Visibility of the hub	0,038
Diversity	0,020

Next, the inconsistency index has to be determined, by first calculating the Maximum Eigenvalue λ_{max}. This is done by multiplying each criteria weight by the sum of the column in the comparison matrix and taking the sum of that, i.e.:

$$\lambda_{max} = 0{,}354 * 2{,}44 + 0{,}247 * 4{,}20 + 0{,}173 * 6{,}88 + 0{,}097 * 13{,}88 + 0{,}071 * 18{,}48 + 0{,}038 * 29{,}25 + 0{,}020 * 46 = 7{,}77$$

Subsequently, the Consistency Index (CI) can be calculated with n being the number of elements (in this case 7 criteria):

$$CI = \frac{\lambda_{\max} - n}{n-1} = \frac{7{,}77 - 7}{7-1} = 0{,}128$$

To verify whether the CI is adequate, the Consistency Ratio (CR) has to be calculated. The matrix will be considered consistent if the CR is smaller than 10%. For n=7, the RI equals 1,32 (Saaty, 2005). This results in:

$$CR = \frac{CI}{RI} = \frac{0{,}128}{1{,}32} = 0{,}097 < 0{,}10$$

This indicates that the weighting presented in the above is consistent.

The same has to be done for all 7 criteria. Since the procedure is very similar, no calculations will be given. The comparison matrices of the scenarios can be found in the main report (see Assessing three scenarios, p.40).

The comparison matrix of *ease of use* is normalised, by dividing each element by the sum of the columns. This results in the normalised matrix, see Table B.6.

Table B.6 - Normalised comparison matrix for ease of use

Normalised	**SC1**	**SC2**	**SC3**	**EIGENVECTOR**
SC1	0,65	0,56	0,69	**0,63**
SC2	0,13	0,11	0,08	**0,11**
SC3	0,22	0,33	0,23	**0,26**

This results in the following Maximum Eigenvalue:

$$\lambda_{max} = 3{,}055$$

The Consistency Index (CI) is calculated with n=3, since there are 3 scenarios.

$$CI = \frac{\lambda_{\max} - n}{n-1} = \frac{3{,}055 - 3}{3-1} = 0{,}0277$$

The matrix will be considered consistent if the CR is smaller than 10%. For n=3, the RI equals 0,58 (Saaty, 2005). This results in:

$$CR = \frac{CI}{RI} = \frac{0{,}0277}{0{,}58} = 0{,}048 < 0{,}10$$

The comparison matrix of *distance* is normalised, by dividing each element by the sum of the columns. This results in the normalised matrix, see Table B.7.

Table B.7 - Normalised comparison matrix for distance

Normalised	SC1	SC2	SC3	EIGENVECTOR
SC1	0,74	0,64	0,79	**0,72**
SC2	0,11	0,09	0,05	**0,08**
SC3	0,15	0,27	0,16	**0,19**

This results in the following Maximum Eigenvalue:

$$\lambda_{max} = 3{,}111$$

The Consistency Index (CI) is calculated with n=3, since there are 3 scenarios.

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{3{,}111 - 3}{3 - 1} = 0{,}0557$$

The matrix will be considered consistent if the CR is smaller than 10%. For n=3, the RI equals 0,58 (Saaty, 2005). This results in:

$$CR = \frac{CI}{RI} = \frac{0{,}0277}{0{,}58} = 0{,}096 < 0{,}10$$

The comparison matrix of *vehicle costs* is normalised, by dividing each element by the sum of the columns. Since the vehicle costs were considered equally important, the numbers are the same. This results in the normalised matrix, see Table B.8.

Table B.8 - Normalised comparison matrix for vehicle costs

Normalised	SC1	SC2	SC3	EIGENVECTOR
SC1	0,33	0,33	0,33	**0,33**
SC2	0,33	0,33	0,33	**0,33**
SC3	0,33	0,33	0,33	**0,33**

This results in the following Maximum Eigenvalue:

$$\lambda_{max} = 3{,}000$$

The Consistency Index (CI) is calculated with n=3, since there are 3 scenarios.

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{3{,}000 - 3}{3 - 1} = 0$$

The matrix will be considered consistent if the CR is smaller than 10%. For n=3, the RI equals 0,58 (Saaty, 2005). This results in:

$$CR = \frac{CI}{RI} = \frac{0}{0{,}58} = 0 < 0{,}10$$

The comparison matrix of *availability of vehicles* is normalised, by dividing each element by the sum of the columns. This results in the normalised matrix, see Table B.9.

Table B.9 - Normalised comparison matrix for availability of vehicles

Normalised	**SC1**	**SC2**	**SC3**	**EIGENVECTOR**
SC1	0,13	0,16	0,08	**0,12**
SC2	0,50	0,63	0,69	**0,61**
SC3	0,38	0,21	0,23	**0,27**

This results in the following Maximum Eigenvalue:

$$\lambda_{max} = 3{,}101$$

The Consistency Index (CI) is calculated with n=3, since there are 3 scenarios.

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{3{,}101 - 3}{3 - 1} = 0{,}0506$$

The matrix will be considered consistent if the CR is smaller than 10%. For n=3, the RI equals 0,58 (Saaty, 2005). This results in:

$$CR = \frac{CI}{RI} = \frac{0{,}0506}{0{,}58} = 0{,}087 < 0{,}10$$

The comparison matrix of *state & (social) safety* is normalised, by dividing each element by the sum of the columns. This results in the normalised matrix, see Table B.10.

Table B.10 - Normalised comparison matrix for state & (social) safety

Normalised	**SC1**	**SC2**	**SC3**	**EIGENVECTOR**
SC1	0,57	0,50	0,60	**0,56**
SC2	0,14	0,13	0,10	**0,12**
SC3	0,29	0,38	0,30	**0,32**

This results in the following Maximum Eigenvalue:

$$\lambda_{max} = 3{,}023$$

The Consistency Index (CI) is calculated with n=3, since there are 3 scenarios.

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{3{,}023 - 3}{3 - 1} = 0{,}0117$$

The matrix will be considered consistent if the CR is smaller than 10%. For n=3, the RI equals 0,58 (Saaty, 2005). This results in:

$$CR = \frac{CI}{RI} = \frac{0{,}0117}{0{,}58} = 0{,}020 < 0{,}10$$

The comparison matrix of *visibility* is normalised, by dividing each element by the sum of the columns. This results in the normalised matrix, see Table B.11.

Table B.11 - Normalised comparison matrix for visibility

Normalised	SC1	SC2	SC3	EIGENVECTOR
SC1	0,65	0,56	0,69	**0,63**
SC2	0,13	0,11	0,08	**0,11**
SC3	0,22	0,33	0,23	**0,26**

This results in the following Maximum Eigenvalue:

$$\lambda_{max} = 3{,}055$$

The Consistency Index (CI) is calculated with n=3, since there are 3 scenarios.

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{3{,}055 - 3}{3 - 1} = 0{,}0277$$

The matrix will be considered consistent if the CR is smaller than 10%. For n=3, the RI equals 0,58 (Saaty, 2005). This results in:

$$CR = \frac{CI}{RI} = \frac{0{,}0277}{0{,}58} = 0{,}0480 < 0{,}10$$

The comparison matrix of *diversity* is normalised, by dividing each element by the sum of the columns. This results in the normalised matrix, see Table B.12.

Table B.12 - Normalised comparison matrix for diversity

Normalised	SC1	SC2	SC3	EIGENVECTOR
SC1	0,73	0,75	0,67	**0,71**
SC2	0,18	0,19	0,25	**0,21**
SC3	0,09	0,06	0,08	**0,08**

This results in the following Maximum Eigenvalue:

$$\lambda_{max} = 3{,}031$$

The Consistency Index (CI) is calculated with n=3, since there are 3 scenarios.

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{3{,}031 - 3}{3 - 1} = 0{,}0153$$

The matrix will be considered consistent if the CR is smaller than 10%. For n=3, the RI equals 0,58 (Saaty, 2005). This results in:

$$CR = \frac{CI}{RI} = \frac{0{,}0277}{0{,}58} = 0{,}026 < 0{,}10$$

By combining the weights of the criteria with the score per scenario for each criterion, the final result is found. See Table 13, 14, 15 on the next page.

Table B.13 - Final priority evaluation of scenario 1

Scenario 1			
Criteria	Criteria weight	Alternative score	Product
Ease of use	0,35	0,63	22%
Distance	0,25	0,72	18%
Vehicle costs	0,17	0,33	6%
Availability	0,10	0,12	1%
State & safety of the hub	0,07	0,56	4%
Visibility of the hub	0,04	0,63	2%
Diversity	0,02	0,71	1%
		TOTAL	55%

Table B.14 - Final priority evaluation of scenario 2

Scenario 2			
Criteria	Criteria weight	Alternative score	Product
Ease of use	0,35	0,11	4%
Distance	0,25	0,08	2%
Vehicle costs	0,17	0,33	6%
Availability	0,10	0,61	6%
State & safety of the hub	0,07	0,12	1%
Visibility of the hub	0,04	0,11	0%
Diversity	0,02	0,21	0%
		TOTAL	19%

Table B.15 - Final priority evaluation of scenario 3

Scenario 3			
Criteria	Criteria weight	Alternative score	Product
Ease of use	0,35	0,26	9%
Distance	0,25	0,19	5%
Vehicle costs	0,17	0,33	6%
Availability	0,10	0,27	3%
State & safety of the hub	0,07	0,32	2%
Visibility of the hub	0,04	0,26	1%
Diversity	0,02	0,08	0%
		TOTAL	26%