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By

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PREFACE

Committing myself to writing a thesis during a pandemic is probably one of the most challenging things I have done. I would not have gotten this far without the guidance of my first supervisor Jan Anne Annema, who has constantly provided me with valuable and constructive feedback and motivated me to keep going. I would therefore like to express my gratitude for the guidance during all the sessions.

I also want to thank my other supervisors, Minze Walvius and Niels van Oort, who have also provided me with valuable support along the way.

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EXECUTIVE SUMMARY

Cities and regions with access to water infrastructure are actively rethinking the possibilities of expanding the public inland waterway transport, especially since road congestion and pollution are still a reoccurring issue. Their aim is to make water transport more attractive for travelers by allowing the introduction of sustainable water modes to increase the use of the already existing water infrastructure instead of extending the road networks.

In parallel with the common used large scheduled passenger ships, supporting on-demand water transport could be offered on a smaller scale in order to cope with fluctuating off-peak demand or to serve a specific target group, such as tourists. One way to set this up is by using on-demand water-taxis, such as Seabubbles. Seabubbles are small zero-emission (hydrogen) hydrofoil ships that can transport four to fourteen passengers depending on the type. The deployment of Seabubbles in water transport can be compared to Uber-taxis that are used in road transport. Since waterborne transport does not usually provide door-to-door transportation, the main challenges of introducing on-demand Seabubbles lie in their safe and practical integration into the surrounding urban area and transport network. The water hubs where the Seabubbles dock should seamlessly connect the waterfront with the landfront and therefore play an important role in connecting the water transportation system with the road transportation system.

A conducted literature study on what multi-modal water hubs could be used for small hydrogen water transport modes revealed a research gap: No scientific research could be found on how to use relevant decision criteria to differentiate between water hub types so that a feasible water hub for small on-demand hydrogen transport modes could be selected. This research aimed to fulfill that gap by answering the following research question:

Which potential multi-modal water hubs are most feasible for connecting on-demand hydrogen fueled Seabubble water-taxis on the water side with road transport on the land side?

The research question is addressed by following a 6-step methodology plan, using the following methods: *A desk research, a case study and a Best-Worst method to rank potential water hubs.*

The desk research where secondary sources were researched was necessary to identify relevant decision criteria that would allow differentiation between multi-modal water hubs. In addition, it was necessary to narrow down the possible types of water hubs that could be used in an urban water transport network, since there are many options for water hubs. In order to scope the theoretical research, the Political Economy Model was used. From this theoretical framework, only the social and technical feasibility of potential water hubs were researched. An important departure point that was used for the theoretical research was the mobility hub concept. From this concept it was possible to determine relevant decision criteria and narrow down the potential water hub types for Seabubbles.

The desk research has resulted in two key results. The first result was an overview of 19 relevant decision criteria that could be used to differentiate between multi-modal hub types. The distinctions are possible because different criteria may be considered important for each individual hub type. These decision criteria can also be used to distinguish between potential multi-modal water hub types, since water hubs also fall into the category of multi-modal

hubs. The identified relevant decision criteria for this study covered the needs of travelers in three different key areas of multi-modal water hubs, namely the Access/Egress Landside zone (8 criteria), the Access/Egress Waterfront zone (3 criteria), and the Facilities & Retail zone (8 criteria).

The second major result of the desk research was the reduction of the large number of possible multi-modal water hubs. By using the mobility hub concept as a starting point, the number of feasible hub types could be reduced to six potential multi-modal water hubs that could be used for Seabubbles, namely:

- Large interchange - City Centre Mobility hubs
- Medium Interchange- Transport Corridor/Linking hubs
- Business parks/New housing development hubs
- Village hubs/small market towns hubs
- Suburb hubs
- Tourism hubs

The next method that was used to investigate relevant decision criteria for potential multi-modal water hubs for Seabubbles was the conduction of a case study. A potential location for a water hub in Alblasserdam in the Drechtsteden region in the Netherlands was used to make the research more tangible and provide it with some context.

Semi-constructed interviews were held with 3 Experts, 4 Industry Interests and 4 Non-Business interests to address the case study. The aim of the interviews was twofold. The first objective was to find out if the interviewees would bring up some of the decision criteria that emerged from the desk research. This way the relevance of the found criteria for the case study could be explored. The second objective was to come up with additional relevant decision criteria for the key areas that could not be derived from the theoretical desk studies.

One of the key findings was that there was indeed almost a complete overlap, since 17 of the19 of the decision criteria that were derived from the desk research were mentioned by the interviewees. The Experts were especially focused on the technical decision criteria for the Access/Egress zones. The Industry interests were interested in all zones of the Water hub and almost tapped all derived desk research criteria. The Non-Business Interests were mainly interested in the decision criteria related to the land side of the water hub.

Another result that emerged from the interviews consisted of five additional decision criteria for the Access/Egress Water side zone. The Experts and Industry interest brought these additional decision criteria up. The Non-Business Interests were mainly interested in making sure that the land transport connections, which were already derived from the desk research, would be included. These derived decision criteria from the interviews were all related to the introduction of on-demand hydrogen water-modes in the Drechtsteden region.

Together, the desk research and interviews resulted in 24 decision criteria, of which eight were for the Access/Egress Landside Zone; eight were for the Access/Egress Waterfront zone, and eight for the Facilities & Retail zone. These decision criteria can be used to select the most feasible water hub for the case study location. A Multi-Criteria Decision Analysis (MCDA) using pairwise comparison is the most practical method for this study to evaluate the found decision criteria and select a potential water hub. The selected MCDA is the Best-Worst method. This method can be used to rank the potential multi-modal water hubs for the case study based on the preferred decision criteria for the location. However, the main reason for selecting the Best-Worst Method is the desire to select the most important or "best" decision criteria associated with a particular location so that the best fitting water hub can be selected for that area, without really eliminating the other alternatives.

The first step was to have the six multi-modal water hubs scored on each of the 24 decision criteria, using the desk research and interviews as sources. By scoring each of the hub types on the decision criteria as vital (score=3), desirable (score=2), or optional (score=1), the respective hub is assigned a preference level for the decision criteria. The scores are derived from the mobility hub guidelines and real case studies that were used in the desk research. If no score could be assigned due to lack of references, a score was derived based on a heuristic approach using analytical thinking.

The most important decision criteria for each key area could be determined based on the extent to which they differed in their scoring levels across water hubs:

- The main criteria for the Access/Egress Land Side zone are:
    - >1 Shared mobility options to be returned to hub and
    - >1 Shared mobility options not to be returned to hub
- The main criteria for the Access/Egress Water Side zone are:
    - Staff support
    - On-demand access to waiting area
    - Dock sharing with other water transport modes
- The main criterion for the Facilities & Retail zone is:
    - Real-time travel data

The other criteria have assigned similar preference scores to four or more hubs, and were therefore less distinctive. The decision criterion, on-site bicycle parking, turned out to be even completely irrelevant for the study, since it had the same score levels for all hubs.

Despite the fact that there were only three usable responses to the surveys to perform the Best-Worst method, it appeared that the three different inputs from the actors resulted in weights that were fairly close to each other, although the Non-business Interest differed from the others on some decision criteria. The Industry expert and the Expert followed almost the same trend in the weights for the decision criteria in all key areas, where the Non-Business Interest had some peaking weights in each key area.

The outcome of the Best-Worst Method was a Business park hub for Alblasserdam for all surveys, which was somewhat expected, because it is located in an industrial area with many business people. The second in line was the Tourist Hub, which is also applicable to the area due to the nearby tourist attraction Kinderdijk. The set expectation and the resulting output allow for some validation of the model. However, a very remarkable thing about the results is that all hubs are ranked exact the same for all actors. The resulting ranking of the multi-hubs was as follows for all actors:

1. Business Park
2. Tourist hub
3. Large Interchange
4. Medium Interchange
5. Village hub
6. Suburb hub

From this it can be concluded that all surveyed actors seem to be on the same page when it comes to the general consideration for a potential hub in Alblasserdam. This is what the BWM is known for, to arrive at a ‘best fit’ with very little information.

This study aimed to help fill the research gap by proposing a solution whereby, based on the assigned importance level of specific decision criteria, a potential social and technical feasible multi-modal water hub type can be selected for a potential hub location. By allowing stakeholders to pairwise compare a set of decision criteria through the Best-Worst method to arrive at a "best" fitting potential water hub, for the case study, it can be implied that the aim has been achieved.

Although the model seemed to work well for the case study in Alblasserdam, there are a few side notes that need to be taken into account as well. The first very important remark is that I did not receive enough surveys to be able to validate the research method sufficiently on reliability and applicability. Nevertheless, the model did meet the expectations and showed well what type of hubs fit best for the case study location. The reason behind so few survey responses is most likely due to the fact that initiatives such as the Region Deal (regional funding projects) were running in the Drechtsteden Region during the research period of this thesis. By participating in this research, interviewees feared expressing an unintended preference for Seabubbles. It would probably have been helpful to this study if it had not been specifically linked to the Seabubbles and if instead the potential water hubs for general hydrogen water-taxis were examined.

Another important aspect to realize is that the whole method is based on subjective input, which is common with an MCDA. The derivation of the decision criteria, the hub scoring system, survey inputs and thus the resulting results are based on desk research and the views of active stakeholders from the case study, making the perspective of the model one-sided and subjective. This makes that the proposed model is not comprehensive and only intended to help determine a first impression of which potential water hub typology is appropriate for a site. The subjective element in the model does not mean that the model should be rejected, but only indicates that it is probably only applicable in the Drechtsteden region. Since a network of hubs would need to be established in the Drechtsteden region to enable the adoption of Seabubbles, the proposed model certainly remains relevant. Besides, all input can of course also be adjusted to new circumstances. The approach and basis of the model can however still be used as a starting point for other areas.

Lastly, the mobility hub is currently only conceptually implemented and that does not imply that it is actually technically or socially feasible on the longer term. The mobility hub concept is still in the development phase and might as well prove unsuccessful in the future. However, given the investments being made in similar projects, which could include Seabubble's water hubs as well, it seems that governments and the private sector do believe it is a viable concept, provided the operators are given a financial push to get things started.

The recommendations for future research are as follows:

- In order to frame the scope of the research, the Political Economy Framework was used to investigate the feasibility of water hubs that support the deployment of on-demand Seabubbles. However, only parts of the social feasibility and technical feasibility are researched within this study. It is recommended to also examine the other parts of the framework, such as the political feasibility to complete all feasibility levels for the potential multi-modal water hubs. The political feasibility dives deeper into the role of governmental entities when it comes to the adoption of new transport modes.
- Because of the sensitivity to bias in the BWM, it is therefore recommended to conduct a sensitivity analysis by applying additional quantitative methods other than the

Linear Max approach and/or the weighted Sum-Product and then compare the results with the current model to test the robustness of the model.

- Since this study can also be used for general implementation of hydrogen on-demand modes, it may not be necessary to link further research to a commercial party, such as Seabubble. Since the implementation of new transport modes is a sensitive topic among politicians and other stakeholders, it may be better for future research to take a more objective approach. Unfortunately, this research suffered from the politically sensitive climate, which resulted in an insufficient response rate as far as the case study was concerned.
- Only three respondents participated in the MCDA, which increases the risk of incredibility and unreliability. More surveys should be distributed among relevant actors to test the model on reliability.
- Further it is recommended to use the model for multiple test case studies and discover if the model is still reliable when other environmental contexts are used.
- It is recommended to perform a stakeholder analysis, since many actors are involved with water hubs that need to support an innovative transport mode. By investigating the needs of each stakeholder, interest conflicts can be identified at the beginning of the process. There are different layers involved of governmental institutions, businesses, interest groups, end-users, etc.
- Customer journeys are also recommended for each potential water hub location, as the end user may or may not use the hub. It is very important to investigate whether there is a need for a hub in an area, before it is located. It is also good to recognize what function a hub will fulfill so that a better estimate can be made of the decision criteria that will be needed.
- This research was mainly concerned with a non-monetary evaluation method based on desired decision criteria for potential water hubs. Since many mobility hubs need to be subsidized in order to be aired, and water hubs cost even more than land hubs, a Cost- Benefit Analysis is recommended to get insight in the expected investing costs.

The recommendations for interviewed actors groups are as follows:

Experts

- The experts have the expertise and knowledge levels on transport over water and they should be consulted when it comes to safety and technical solutions. This is especially the case for the experts that are already involved in passenger transport, such as the Waterbus expert.

Industry Interests

- Despite the fact that all interviewees expressed positive views on the deployment of Seabubbles in the Drechtsteden region to expand the existing transport network, a number of reservations were also expressed. Because a water hub facilitates the transition between land and water transport, there are many stakeholders involved with conflicting interests on the land side and on the water side. Therefore, it is important that the views of all parties are aligned as much as possible by selecting a single party who will lead and roll out the initiative, so that an overview is maintained. The implementing party can take on this task, but must make proper arrangements for this with all parties involved. Determining who these parties are is also a recommendation for future research.

- Another point that should be looked in closely is the investor attention once the "hype" surrounding the introduction of hydrogen-powered Seabubbles dies down. It is important that the involved industry actors, such as Advier and Seabubbes, need to take advantage of the hype surrounding the innovation especially in the first few years to attract tourists and other leisure activities in order to keep the investors' attention, which also includes governmental entities. It will take some time for the Seabubble to be fully accepted and integrated into the water transport network.
- It is also important for industry interests to conduct a comprehensive study of customer travel by origin and destination to determine traveler needs and also to determine potential hub locations. The model resulting from this research can then be used to provide insight into hub types that can facilitate hub locations.

Non-Business Interests

- While politicians are most enthusiastic about the deployment of innovative water modes such as Seabubbles because of the expected "city branding" for the entire region, they are somewhat reluctant to invest in a new mode of transportation that has not yet been proven to work. Decision-makers are now approaching the initiative primarily from a facilitator role rather than as an investor, which can make it difficult to raise enough money to finance the Seabubbles and network of water hubs. Since the Seabubble can be part of the mobility hub concept, it may be a good idea to introduce the Seabubbles as a similar pilot project and to label and subsidize it as such.
- If the Seabubble concept is developed properly and a network of multi-modal water hubs can be implemented, it could make a significant contribution to the image of the region, but above all serve as an example for other cities and regions to start similar sustainable concepts.
- The introduction of Seabubbles involves high investment costs and the system will not work if there is no network of strategically placed water hubs. The strength of a supportive on-demand water transport system lies primarily in the ability to dock at as many places as possible that would otherwise be difficult to reach when using the common transport modes. This means identifying in advance potential hub locations and necessary decision criteria that may be important for the user groups in the area. This study can serve as a tool to help with selecting socially and technical feasible water hubs for potential hub locations.

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1 INTRODUCTION

The internet era and the increasing use of big data have already shown the potential of shared on-demand transport modes. In recent years, more and more various on-demand road modalities have emerged in larger cities in the Netherlands to meet the transport demand of travelers in a flexible and sustainable way. On-demand transport modes as mentioned in this report are a form of shared private or public transport, with fixed or dynamically allocated routes and schedules (Coutinho et al., 2020). The on-demand transport possibilities can vary between taxi-services (e.g. Uber), e-scooters, e-bikes and other rental services. The convenience of on-demand shared mobility includes the disappearance of owning a transport mode and the associated disadvantages, such as maintenance costs and storage.

The concept of offering on-demand road transport to improve the flexibility and comfort of travelers can also be applied to water transport networks in areas where road congestion is an issue. The existing scheduled water transport lines can be expanded with a small-scale underlying network where sustainable on-demand water modes serve fluctuating demand. In this way the road traffic network can be further relieved and the existing water transport network can be integrated more in the overall transport network. The water hubs that need to connect on-demand water modes with road transport will play a major role in the success or failure of the on-demand water transport concept.

1.1 On-demand water transport

Cities and regions with access to water infrastructure are actively rethinking the possibilities of expanding the public inland waterway transport, especially since road congestion is still a reoccurring issue (ProvincieZuid-Holland, 2020). Their aim is to make water transport more attractive for travelers to increase the use of the already existing water infrastructure instead of extending road networks.

Despite the fact that waterborne public passenger transport is highly encouraged and placed on the agenda by governments, including the Dutch government (Klimaatakkoord.nl, 2019), little scientific research has been conducted to investigate the possibilities of urban waterborne transportation*(see section 2.5 for more details about this knowledge gap found)*. When looking for on-demand water transport solutions and what feasible water hubs should be supporting this concept it will appear that there hasn't been performed any specific research at all.

Water modes already have the advantage of being non-traditional transport modes, which are known to generate latent demand as these modes are popular and beneficial due to the travel experience itself regardless of the destination (Mokhtarian & Salomon, 2001).

Although governmental entities want to increase use of the water infrastructure, they also feel the pressure of the effects that climate change will bring on the long term if they would allow more vessels that run on traditional fossil fuels. The SO2 and NOx emissions that are emitted by European ships are expected to surpass the safety limit by 2030 if no action is taken (Gagatsi, Estrup, & Halatsis, 2016). In order to stay within the safety limits and in line with the Dutch Climate Agreement, measures are needed to make freight and passenger transport more sustainable (Klimaatakkoord.nl, 2019). This is why implementation of non-fossil fueled transport modalities is subsidized and promoted in urban and regional plans (Rogelj et al., 2016).

The increasing interest in zero-emission sailing has led various innovative parties to experiment with the construction of electrically powered passenger boats for mainly recreational use (Butler, 2020). The few companies that aim for sustainable public water transport modes mainly focus on design of larger electric ferries (Damen, 2020; Murray, 2020; Wyrzykowski, 2020).

Figure 1: Left: Full electric Damen Road Ferry 6819, (Damen, 2020), Right: Electric Seabubble, (Lilly, 2019)

Although on-demand road transport modes have gained popularity in recent years, the deployment of small on-demand waterborne public transport has hardly been researched or applied. A specific party that consciously strives to use sustainable boats as commercial on-demand water-taxis is Seabubbles (Seabubbles.nl, 2019). Seabubbles are small zero-emission hydrofoil ships that can transport four to fourteen passengers depending on the type. The deployment of Seabubbles in water transport can be compared to Uber-taxis that are used in road transport. The success of services like Uber lies in the increased connectivity between origin and destination for the traveler. The water hubs that need to connect on-demand boats with landside transport will play a major role in the success or failure of the on-demand water transport concept. It is therefore important that decisive criteria need to be determined and assessed to examine the feasibility of such water hubs. The Seabubble supports the concept for an on-demand water transport network, making it suitable for use as an applied example to develop the criteria for the multi-modal water hubs.

1.2 Problem definition: multi-modal water hub for on-demand Seabubbles

The main challenges of implementing on-demand Seabubbles lie in their safe and practical integration into the surrounding urban (transport) network. The water hubs where the Seabubbles moor have to connect the water side to the land side and play therefore a major role in connecting the transport systems on both sides. In addition to these challenges one must also take into account that a water hub acts as a front door to the visited region.

Most water hubs that are used for conventional public water transport, such as the Waterbus docks in Rotterdam-Drechtsteden region act mainly as transfer points between the water side and the land side and offer minimal services. Conventional water hubs are therefor in general comparable to bus stops (Waterbus, 2020). Their main focus is on transferring passengers in a very limited time period adding a minimum of extra value to the travel experiences.

On the other side, when looking at other types of public transport nodes, e.g. multi-modal hubs such as airports or NS train stations, the hubs are designed to increase the user experiences during traveling. By offering on-site services, shops and eateries and good connection with other transport modes, NS aims to reduce the inconvenience of waiting times between mode transfers and create a location where the user experience is centralized (NS, 2020).

Figure 2: Waterbus stop Merwekade in Dordrecht, the Netherlands (Waterbus, 2020)

As will follow from the literature research in Chapter 2, there has been no relevant scientific research on implementing non-fossil on-demand water modes and what types of water hubs should facilitate them. However, given the scope of this study, the focus will be on the water hubs needed to enable the implementation of on-demand water modes. Thus, the feasibility of on-demand water modes, such as Seabubbles themselves will not be examined. As a result, this study will only be devoted to determining the feasibility of potential multi-modal water hubs that will have to support a potential implementation of Seabubbles.

This research will mainly focus on the water network area in the Netherlands, since the water infrastructure is already in place and the Netherlands has already made good progress in implementing innovative transport methods. An applied case study will be conducted for a potential water hub in Alblasserdam, located in the Drechtsteden region in the Netherlands, to make this research tangible.

1.3 Research Questions

To address the knowledge gap that emerges from the literature study in Chapter 2, a research question and supporting sub-questions are formulated:

Which potential multi-modal water hubs are most feasible for connecting on-demand hydrogen fueled Seabubble water-taxis on the water side with road transport on the land side?

<u>Research sub-questions</u>

1. *What is the perceived effectiveness of multi-modal water hubs for hydrogen on-demand Seabubbles?*
2. *What are the perceived problems of multi-modal water hubs for hydrogen on-demand Seabubbles?*

3. *What decision criteria should be considered to distinguish between potential multi-modal hubs?*
4. *What multi-modal hub typologies can be used for the selection of potential water hubs for Seabubbles?*
5. *What decision criteria should be used to distinguish between potential multi-modal hub types for Seabubbles?*
6. *What type of multi-modal water hub would potentially be the best fit for implementing on-demand Seabubbles for the case study?*

The research question stems from the scientific gap identified in the literature review in Chapter 2.

The applied methodology that is used to address the research gap and to answer the research questions will be discussed in Chapter 3.

A technical framework will be introduced in Chapter 4 to scope the research and to shed a light on the social and technical feasibility of multi-modal water hubs and associated decision criteria from a theoretical perspective.

The case study, involving the deployment of Seabubbles in the Drechtsteden region with a potential water hub in Alblasserdam, will be presented in Chapter 5.

In Chapter 6 the results of the interviews with relevant experts, industry interests and non-business interests are discussed and decision criteria are determined that are suitable for the deployment of Seabubbles.

Chapter 7 presents the results of the evaluation of the surveys that are related to the case study. The used evaluation method is an MCDA , the Best-Worst method by Rezaei (2015). The results will be followed by a discussion in Chapter 8, where the findings from the study are discussed and evaluated.

Lastly, the conclusions and recommendations for further research are discussed in Chapter 9.

2 LITERATURE STUDY

This chapter examines the problem outlined in the introduction, proposing the need for water hubs required for the introduction of on-demand hydrogen modes.
A literature study based on scientific articles is presented to show the research that has been done so far on the reasons behind the use of on-demand water transport and the role of multi-modal (water) docks. Based on this exploration a research gap is identified, which will act as a thread through the rest of this report. The main sources for these references were found via the following online search engines: ScienceDirect, Google/ Google Scholar, Elsevier, Scopus, Web of Science and WorldCat Discovery.

The references where found by using mainly combinations of the following keywords (but not limited to): *Water, transport, waterborne, inland waterway, IWT, dock, hub, mode, multi-modal, passenger transport, public transport, transfer, trip, hydrogen, refueling, zero-emission, non-fossil, electric, water-taxi, ferry, vessel, ship, on-demand, decision criteria, types, sustainability, connectivity*

If relevant references were found, forward and backward snowballing tactics where used to find more relevant articles that would otherwise not be found using merely keywords. For this literature study, 29 relevant scientific papers were selected that could be used.

2.1 Hydrogen water-taxi

Multiple studies have been conducted to explore the reasons behind the implementation of water transport in cities (Soltani, Tanko, Burke, & Farid, 2015; Thompson, Burroughs, & Smythe, 2006; Tsai, Mulley, Burke, & Yen, 2017; Weisbrod & Lawson, 2003). These studies show that, in addition to persuading commuters to use public transport, governments and local stakeholders also pursue economic reasons that are key elements in the decision making. There has also been a noticed land value increase around urban ferry terminals. Waterfront locations that are considered pauperized may receive a boost with the construction of water hubs. Water transport also plays a role in tourism promotion and city branding (Łapko & Panasiuk, 2019).

In addition to the need of expanding the water transportation network to achieve a modal shift from road to water, the implementation of sustainable water modes is also a way to advocate the use of renewal fuels and showcase the current state of development in the research and application of fuels such as hydrogen in water transportation.

Hydrogen as an energy source is gaining popularity in recent years as it can provide in a green solution for transportation. Another benefit is that hydrogen transport modes can be refueled in less than 10 minutes, which makes hydrogen a very attractive fuel for larger vehicles such as trucks and ships (Rivard, Trudeau, & Zaghib, 2019). In public transportation, recharging time is an important decision factor because the transport modes need to be able to be back in operation as quickly as possible. Although electric vehicles are also considered a good alternative in transportation, the long charging times and large batteries can be a huge bottle neck for application.

Despite the fact that there is a lot of research going on for application of hydrogen as a fuel, there are not many projects going on about application in small-scale water transportation services. There is currently a hydrogen-water taxi being developed by the SWIM consortium (consisting of Enviu, Watertaxi Rotterdam, Flying Fish and ZEPP.solutions) as part of a zero-emission shipping program, THRUST (Enviu, 2020). Within this project they are also working on a green hydrogen refueling station for the water-taxis, since there is no solution for that yet either.

Waterborne transport that is common in public transport is mostly fixed schedule based and offered in the form of 'cross river' services (Tanko, Cheemarkurthy, Hall Kihl, & Garme, 2019). In this situation a ferry moves between two points. Another frequently used ferry service is where multiple water hubs are visited in a single ferry route. Both types of transportation focus on reducing the time spent at terminals, which is why the ferries often are double ended and the docks are just plain boarding and disembarking locations (Cheemakurthy, Tanko, & Garme, 2017). Ferry services that are using fixed timetables have to deal with an uneven passenger load factor at different times of the day. Outside peak hours there may be very low demand for transport, but the ferry will still have to continue its route. An opportunity could be to investigate if supporting small hydrogen fueled on-demand water-taxis, such as the Seabubbles (Seabubbles.nl, 2019), can support fixed ferry services outside peak hours. The water-taxis would only sail on-demand and otherwise not. By adding a GPS tracking system, similar to on-demand road transportation, travelers can track their boat from the time they order the service to the end of their trip. This type of tech mobility doesn't exist yet in waterborne transport. When using the search engines as mentioned at the beginning of this literature study, no research can be found on small hydrogen fueled on-demand vessels that can support fixed ferry services.

2.2 Multi-modal water hubs

Any public waterborne transit service connects two different land areas, so the main purpose of using a water transit service is to cross a water barrier. The water hubs can therefore be seen as multi-modal interchange nodes, where the transition between water and land is realized. The function of an interchange node is to reduce the distance between transport modes. Usually in urban areas there is only a scarce space available to enable the interchanges (Monzón, Hernández, & Di Ciommo, 2016).

Multi-modal water hubs in passenger transport generally have the same characteristics as any other type of multi-modal land nodes in terms of objectives and integration consideration (Butler, 2020). However, they differ from land hubs in their significant waterfront. Before multi-modal hubs are explored more in depth, the definitions of a multi-modal trip and dock need to be captured since much terminology is used interchangeably in literature. Murray (2020) defines a multi-modal trip as follows: "*A multi-modal trip consists of either combinations of multiple public transport modes or combinations of public transport and private modes*". Thus, a multi-modal hub acts in essence as a stopover to enable a multi-modal trip by offering multiple transport modes to travelers (Bolkovska & Petuhova, 2017). In case of a multi-modal hub, water transport modes are part of the offered transport modalities.

The location and surrounding infrastructure of a water hub is of great importance for a good connection to the land transport network (Cheemakurthy et al., 2017). Since water transport requires you to travel another first and last mile, as you sail from shore to shore, it is common to travel this first and last mile by means of e.g. bicycle, car or public transport. An easy and existing transition from water hub to bicycle, parking or bus station is therefore essential (Soltani et al., 2015). According to the study by Soltani et al. (2015), connecting waterborne transport to existing public transport networks is a key element when it comes to increasing the success rate of water transit services.

Although links to public transport modes and private modes are generally considered success factors to a waterway's transport network, on-demand mobility options may also be considered, as they are emerging and have become indispensable in recent years (Henderson, 2018). Private modes are more often replaced by on-demand e-bikes, e-scooters, cars etc. Road services like Uber and Lift were GPS services are used for transporting passengers is widely used. These car services are connected to potential travelers via mobile phone apps. The convenience of cashless payment and driver ratings add to the customer experience as well. Although these on-demand modes can be highly successful in dense urban areas due to frequent use, they can also be less successful in less dense areas (Currie & Fournier, 2020). High investment costs and the fact that more people own their own private modes the further they live from urban areas can make on-demand transportation fail in certain areas.

2.3 Water hub types

As for the type of a water hub, there are many options that can be applied. Most cities use some kind of fixed docks to facilitate their ferry services. However, in Rotterdam and Hamburg floating wharfs are used. By using floating docks, the water transport network can easily adapt to changes within the land transport network because the wharfs can be towed to a different location (Cheemakurthy et al., 2017).

Thompson et al. (2006) argue that ferry services without ‘expensive’ fixed water hubs do not attract as much attention to development and integration as e.g. rail stations. Inexpensive docks that don't offer additional facilities demonstrate the flexibility of displacement of the ferry services to other locations. This can deter parties from making large investments or making adjustments to the transport network. It is therefore important to look at existing public transport networks if economic flexible docks are also considered.

Often can be seen by the size of the terminal how important the terminal is (Rodrigue, Comtois, & Slack, 2016). Although there are many different variations and sizes of interchange hubs, they are usually reduced roughly into four categories: minimalistic, small, medium, and large terminals (Aono, 2019; ComoUK, 2020; Metrolinx, 2011).

2.4 Decision criteria for multi-modal water hubs

When it comes to interchange nodes, a number of important decision criteria have been studied in the literature that influence travel behavior (Cheemakurthy et al., 2017; Di Ciommo, Vassallo, & Oliver, 2009; Hoogendoorn-Lanser, Van Nes, & Hoogendoorn, 2006; Monzón et al., 2016; Van Hagen, 2011). The advantages of interchanges are mainly related to time savings, better use of waiting times, urban integration, and improvement of operational business models (Di Ciommo et al., 2009). According to Monzón et al. (2016), comfort, easy access, reliability of service, attractive frequencies of services and intermodal integration are the most important characteristics related to the service quality. In addition, the availability of information on travel times and alternate routes is critical to seamless door-to-door mobility.

When people need to travel, their choice for a transport mode is dependent on what they think provides the best quality considering time, money and effort. (Van Hagen, 2011). The first factor is time, which includes waiting and walking times. An important aspect that has been identified to reduce transfer times and to make a success of water transport services is the linkage with existing public transport networks or other forms of mobility (Soltani et al., 2015). Water hubs also should be designed in such way that they reduce the loading and unloading time of passengers (Cheemakurthy et al., 2017). Secondly, the costs of parking and public transport tickets can be a threshold to use multi-modal transport. The third factor is the physical effort that may add to inconvenience of travellers. A study of (Laatikainen, Piiroinen, Lehtinen, & Kyttä, 2017) shows that the average walking distance to water hubs is in general more than the acceptable walking distance of 300-400 meters for public transport.

Extending the three budgets, time, money and effort, Van Hagen (2011) has developed the pyramid of customer needs for the Dutch railway service NS (see Figure 3). When designing a station, the needs outlined in the pyramid must be considered. The bottom block represent Safety and Reliability, which are considered basic needs. The other needs are in order of importance: speed, ease, comfort and experience. From this research it shows that when travellers move through the station, speed and ease are becoming very important. However, if travellers need to stay at a station, then comfort and experience become key elements.

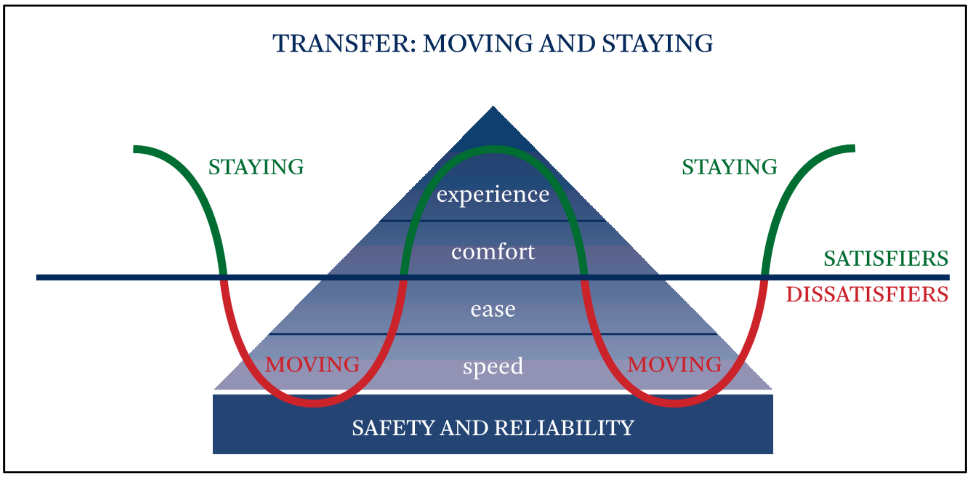

Figure 3: Pyramid of customer needs - Quality dimensions in order of importance (Van Hagen, 2011)

More recent studies from (Cheemakurthy et al., 2017; Tanko et al., 2019) indicate that extra options and facilities such as seating, shelter, ticket machine availability, real-time information systems and disability access are highly valued by travellers but are lacking in most water terminals to save on (maintenance) costs. Water hubs that are visited by high numbers of tourists, such as cruise terminals do however experience economic benefits from facilities available in water hubs (McCarthy & Romein, 2012). Although cruise terminals serve different kind of tourist visitors, the leisure based aspect remains present in the number of touristic travelers that are using urban water hubs. However, it is also important to realize that different types of water hubs are used for different types of routes and therefore the design may be limited to more basic facilities. Longer distances may require more recreational and toilet facilities, while for shorter routes the main emphasis will be on shortening the time spent on the water hubs (Cheemakurthy et al., 2017).

Travel patterns and preferences change over time and the increased leisure-based travel has resulted in travel time being valued more as a positive activity (Banister, 2008). If water transport is evaluated from a user perspective and compared to conventional road/rail transport, benefits that may add value to the sailing experience are increased ride comfort, additional on board space and scenic factors (Tanko et al., 2019). Heinze (2000) hypothesizes that leisure-based travel is a way to compensate for a low quality of life. By doing something completely different, such as traveling with a water mode people attempt to escape their daily reality. This effect can be enhanced by offering experiences with new technology, such as non-fossil running vessels or e-bikes.

2.5 Research gap

Based on the literature study a research gap can be identified. Waterborne transport and the relevance of transfer hubs are widely discussed in literature. However, the research is mainly focused on the conventional fossil fuel driven and electric vessel operations. As hydrogen-powered vessels may be a more sustainable and economical choice in the future, they can enable sustainable support of the regulated water transport network.

In addition, urban water hubs are functioning as simple transfer points for passengers, without extra facilities. On-demand water transport may allow a sustainable addition to the scheduled water transport network. As already mentioned in the Introduction in Chapter 1, governmental entities want to increase use of the water infrastructure and they also feel the pressure of the effects that climate change will bring on the long term if they would allow more vessels that run on traditional fossil fuels. This literature study revealed that no relevant scientific research could be found on what decision criteria should be considered to differentiate between potential water hub types so that a proper selection of a water hub for small on-demand hydrogen transport modes can be made. This research aims to fulfill that gap.

3 METHODOLOGY

In the Literature Study scientific research was conducted to define the research gap as presented in Section 2.5. The research gap showcases that no relevant research is found on the requirements of potential multi-modal water hubs that need to facilitate the implementation of on-demand water modes such as the Seabubbles. This section outlines the methodology used to answer the research questions in Section 1.3 and thus fill the gap in the study, see Table 1 for the methodology steps that are used to answer the questions

Table 1: Methodology steps for this study

METHODOLOGY STEPS		Adressed (Sub-)RQ	Chapter
PART I: Desk Research – Secondary literature sources (Mobility Hub Guidelines)			
Step 1	Determine perceived effectiveness/ problems of multi-modal water docks	Sub-RQ 1,2	Chapter 4
Step 2	Use practical (governmental) guidelines to determine relevant decision criteria for potential water docks for small on-demand water modes	Sub-RQ 3	Chapter 4
Step 3	Use practical (governmental) guidelines to determine potential water docks for on-demand water modes	Sub-RQ 4	Chapter 4
PART II: Case Study – Potential water dock for Seabubbles in Alblasserdam (Interviews)			
Step 4	Use interviews with Experts / non-business interests to determine relevant decision criteria for multi-modal water docks for Seabubbles	Sub-RQ 5	Chapter 5, 6
PART III: Case Study – Evaluation of Decision Criteria (Surveys)			
Step 5	Use BWM method to evaluate decision criteria against water dock types to select the best fitting potential water dock for the case study	Sub-RQ 6	Chapter 7
PART IV: Wrap-Up – Discussion, Conclusion & Recommendation			
Step 6	Discuss the findings and results		Chapter 8
Step 7	Reach to conclusions and address the main Research Question. Arriving at recommendations for stakeholders and future research.	RQ	Chapter 9

Since little scientific research has been done on the topic of water hubs to facilitate small hydrogen modes on demand, additional desk research from secondary sources was needed to theoretically pin down the topic and define relevant decision criteria. Also, the introduction of an innovative transport mode such as Seabubbles is best made tangible through the use of a case study. Interviewing relevant actors allowed a picture of expectations to be formed and relevant decision criteria for water hubs for Seabubbles to be identified. The water hubs that emerged from the desk research and interviews could be evaluated using the Best-Worst method of Rezaei (2015).The end result was a ranking of different potential dock types for the case study, which then revealed which water hub is the best fit for the location. The ultimate goal of this research was that the derived model could be used to determine a best-fit potential water hub for other locations as well. This end result also immediately answers the research question.

3.1 Part I: Desk research

It is important to address the research gap and research question from a theoretical perspective to form a solid base for the case study. Since no relevant scientific research has been found in the literature study conducted in Chapter 2 on what water hub types can support small water modes, additional desk research was performed to determine which dock types and decision criteria are suitable for Seabubbles from a theoretical perspective. Framed by the Political Economy Framework of Feitelson and Salomon (2004) (in chapter 4 the explanation why this framework was chosen can be found), secondary sources are consulted to examine guidelines and decision criteria that can be used to determine water hub types for the Seabubbles. The first part is the most comprehensive, as it includes four research sub-questions to examine the social and technical feasibility of potential water hubs and also examines decision criteria from a theoretical perspective.

Relevant decision criteria and potential multi-model hub types for achieving social and eco-technical feasibility were derived from the so-called mobility hubs concept for the Access/Egress land zones and Facilities & Retail Zones. A mobility hub is a defined area where multiple modes come together to serve travelers from a central location. The concept can be expanded with additional facilities depending on the hub type. By using this secondary research, relevant potential dock typologies for Seabubbles could be determined based on the urban area in which they are located.

3.2 Part II: Case Study

Chapter 4 presents a case study for a potential water hub in Alblasserdam, which is located in the Drechtsteden region of the Netherlands. This location is well suited for a case study, as it has already been announced by the region that small water-taxis may be used in the area to provide transportation for tourists and commuters. The choice for a case study is almost self-evident, because no relevant literature has been found in Chapter 2 on the research topic and a case study method is ideally suited to make a transport innovation tangible. The case study for a potential multi-modal water hub that supports Seabubbles in Alblasserdam will run like a thread through the next chapters to provide the reader with context.

The waterfront access and egress zone was not adequately served by the mobility hub concept from the desk research in Part I, so additional decision criteria had to be derived from conducted interviews for a real life case study. Semi-constructed interviews were held with local and regional officials and industry experts to define what decision criteria related to mode choice, operational function and end-user facilities are important for implementation of Seabubbles in the area. This will also answer research sub-question 5.

Although a case study can make an innovation tangible, one must keep in mind that the decision criteria that result from the case study and interviews may not be generally applicable to other waterways or environments that have different characteristics than the Drechtsteden region. In the discussion of this research (Chapter 7) the generalizability of the results will be discussed.

3.2.1 Interviews

Qualitative research, such as conducting interviews and/or surveys, was needed to achieve a deeper understanding of people's experiences, perceptions, behaviors and processes, and the meanings they attach to them (Moser & Korstjens, 2018).

To dive deeper into the case study and examine the opportunities and challenges of potential water hubs for Seabubbles in the Drechtsteden region, interviews were conducted with relevant actors. The interviews also provided in additional decision criteria for water hubs that could not be retrieved from the theoretical research, but are relevant to deploying Seabubbles.

The interviews were conducted with water transport experts, industry interests and, local and regional decision makers. A variety of views and decision criteria emerged from the diversity of the sample, since all actors have different interests. Experts and business interests tend to be more concerned with technical and economic issues of deploying Seabubbles, while non-business groups focus on the social impact the innovation will have.

The experts, industry interests' and non-industry interests, who were approached, and responded to the request for an interview, are listed below in this subsection[1]. More parties were approached, but unfortunately they couldn't participate in this study. Most interviewees wished to remain anonymous to avoid conflicts of interest, and therefore the results of the interviews were aggregated at the actor level rather than at the personal level.

<u>Experts</u>

Experts are relevant parties that have experience in passenger transport over water. They possess the knowledge and insights involved in a waterborne transportation network. Since introducing on-demand Seabubbles will complement water transportation lines, the parties offering waterborne transport or closely involved in it should were surveyed to review their points of view. Their input was critical to the technical feasibility. The organizations that have participated in this study are as follows:

- *Aquabus B.V (1 participant):* If the Seabubbles are introduced in the Drechtsteden region, they will support the thick water transport line Waterbus, so it is important to understand how this transport service experiences an additional service.
- *Port of Rotterdam (2 participants):* Many cargo ships use the rivers to reach the sea or other ports, so it is important to understand how the harbor authority experiences more traffic by small boats on the rivers.

<u>Industry Interests</u>

Companies or Transport & Logistics associations can benefit from a transport innovation from a social and economic point of view. By introducing a sustainable innovation, brand awareness and economic benefits can be realized for the parties involved and the environment. These parties initiate innovations and are also involved in creating awareness about the subject. Therefore, they can have a major impact on how people think about an innovation and influence its social feasibility. The organizations that have participated in this study as industry interests are as follows:

- *Advier (2 participants):* This innovative company will be a potential operator of Seabubbles and the associated water hubs in the Netherlands. It is interesting to see how this company sees the implementation of the Seabubbles from an economic and sustainable point of view.
- *Economic Development Board (2 participants):* This is an advisory committee of the Drechtsteden region. They advise on the socio-economic development of the region

[1] All interviewees (except from Advier) made it clear that they have no specific preference for Seabubbles compared to other water modalities to be deployed in the Drechtsteden area. They consider Seabubbles as one of the interesting examples that can be used for the case study in Alblasserdam to make this study tangible.

with a strong focus on innovation, regional profiling and network building. They benefit from higher employment rates and economic progress of the area.

Non-Industry Interests

Politicians are sensitive for social feasibility, since they take voter preferences into account. Politicians are looking for ways to develop their areas in a sustainable way while contributing to society. Political perceptions may also be influenced by experiences with similar projects or systems elsewhere. Policy makers will be the ultimate decision makers and are therefore a key element of social feasibility. The governmental organizations that have participated in this study are as follows:

- *Municipality of Alblasserdam (3 participants):* The interviewed policymakers of this municipality (two councilors and one support officer) will ultimately be involved in the decision making process on whether the Seabubbles add enough value to the city's mission and visions and whether or not a water hub will be built in the area. Their opinions and views are important for the case study. The interviewees are also closely involved as part of the Drechtsteden region, so they also spoke on behalf of the region.
- *Drechtsteden region (1 participant):* The Drechtsteden region consists of several cities working together on the development of the region by developing strategies for a sustainable region-wide approach to tackle various issues on the political agenda. This includes transportation in the region. Alblasserdam is one of the cities that are part of the Drechtsteden region. The interviewee that shed a light from a different point of view than the municipality of Alblasserdam and mainly from the interest for the Drechtsteden region is a councilor from the municipality of Sliedrecht.

3.3 Part III: Evaluation of Decision Criteria: Best-Worst Method

The results from the literature study, secondary literature sources and interviews were used to determine water hub typologies for Seabubbles and a selection of three key areas related to these water hubs, being the Access/Agress Zone-Land side, Access/Agress Zone-Water side and Retail & Facilities Zone. Each individual key area was assigned eight important decision criteria. The choice for eight criteria is to stay within the maximum decision criteria range of the used BWM evaluation method, which will be explained in the next section. Every water hub type scores differently on the same selection of decision criteria, because the urban environment and function of the dock determine different needs of the users.

The found guidelines in the desk research were used to arrive at a scoring system to determine how important each of the decision criteria found is for the different types of hubs, with the point system consisting of optional (1), recommended (2) and vital (3). The guidelines by ComoUK (2020) and Urban Design LA (2021) were the main sources used to arrive at this scoring system, because they already use a similar scoring system for decision criteria. The higher the importance of a criterion for a hub, the higher the score for that criterion will be assigned to the dock type. For the derived waterfront criteria that emerged from the interviews, the scoring was based on analytical thinking by using on-demand taxi and scheduled ferry services as a starting point, as this combination is the most representative of on-demand Seabubbles.

After the appropriate dock types for Sea Bubbles have been determined and scored against each found decision criterion, an evaluation method to rank the water hub types was selected. By choosing a proper evaluation method where the importance of each decision criterion compared to other criteria can be determined for each specific water hub, the best fitting dock types can be selected for each individual location. Since we have a set of decision criteria that need to be evaluated against each other to decide upon the most important criteria for each certain location, the most practical evaluation method would be to assess these decision criteria with a Multi-Criteria Decision Analysis (MCDA) where pairwise comparison is used.

An upcoming MCDA method which can be used for this purpose is the Best-Worst Method (BWM) (Rezaei, 2015). The BWM method is based on pair wise comparisons of decision criteria, and requires fewer comparisons in comparison to the widely used AHP method (Ishizaka and Nemery, 2013). Although less data is needed in BWM, the results are also more reliable. The reliability of the results is measured with an inconsistency index. The most important part of BWM is comparing all available criteria with the most and least important criterion. By pointing out the best and worst criterion, assigning weights to other criteria is an easier task.

The main reason for selecting the Best-Worst method for this study is the desire to select the most important or "best" potential water hub associated with a particular location so that the right target group can be addressed in a certain area. Besides, the Best-Worst method appears to result in a fast and reliable evaluation, which is very suitable for this research because of the limited time period. An added benefit is that the method does not require many input decision criteria, which also adds to the convenience compared to the AHP method.

Evaluation Approach

Within this study of choosing the most feasible water hub for Seabubbles, three key areas were identified, where each key area was assigned 8 decision criteria. The key areas are the Access/Agress Zone-Land side, Access/Agress Zone-Water side and Retail & Facilities Zone.

Rezaei's 5-step plan assumes one single set of decision criteria with one weighting set, making it a too simplified approach. To achieve a proper evaluation of the decision criteria in this study with the BWM, the 5-steps plan proposed by Rezaei (2015) on the ranking of a set of decision criteria is slightly adapted and more steps are added, see Table 2. The optimal weights for each decision criterion can then be calculated for each actor in the last step by using the solver software "BWM-Solver.xlsx"[2].

Table 2: Adapted 5-step plan of BWM to rank a set of key areas with sub-sets of decision criteria

Step 1	Determine a set (c1, c2, ..., cn) of n key areas.
Step 2	Determine the most important (best) and least important (worst) key areas.
Step 3	Determine the preference of the best key area over all the other key areas using a number between 1 and 9. The number 1 means that the best key area is equal important to the other areas and the number 9 indicates that the best key area is extremely more important than the other areas.
Step 4	Determine the preference of all the key areas over the worst key area using a number between 1 and 9. The number 1 shows an equal importance of both key areas. Number 9 means that a key area is extremely more important than the least important key area.
Step 5	For each key area: Determine a set (c1, c2, ..., cn) of n decision criteria.
Step 6	For each decision criteria set: Determine the most important (best) and least important (worst) decision criteria.
Step 7	For each decision criteria set: Determine the preference of the best decision criterion over all the other decision criteria using a number

[2] The BWM solver.xls software by Rezaei is retrievable from https://bestworstmethod.com/software/

	between 1 and 9. The number 1 means that the best decision criterion is equal important to the other decision criteria and the number 9 indicates that the best decision criterion is extremely more important than the other decision criteria.
Step 8	For each decision criteria set: Determine the preference of all the decision criteria over the worst decision criterion using a number between 1 and 9. The number 1 shows an equal importance of both decision criteria. Number 9 means that a decision criterion is extremely more important than the least important decision criterion.
Step 9	For each key area set & decision criteria set: Find the optimal weights for each criterion by solving the linear problem that arises. The BWM-Solver.xls software[1] can be used to perform the calculations. The solver also calculates the ξ, which forms an indicator for the reliability of the rankings.
Step 10	For each key area set & decision criteria set: Multiply the weight obtained for each decision criterion by the weight of its key area to get the "global" weight of the decision criteria. The sum of the global weights of all the 24 decision criteria becomes 1.0.

The reliability of the rankings is represented by ξ. The higher the value of ξ the higher the consistency index (see Table 3) and the less reliable the pairwise comparisons are. The max ξ allowed is dependent on the number of scaling levels used for the pairwise comparisons, which can vary from 1-9. In this study 9 levels are used to rank the criteria, since that is common practice with the BWM.

Table 3: Consistency Index (CI) table (Rezaei, 2015)

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency index (max ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

The Consistency Ratio can be calculated by dividing the found ξ by the consistency index belonging to the number of scaling levels used. The smaller the Consistency Ratio is compared to the Consistency Index, the higher the consistency of the rankings is.

In Table 4 the thresholds for Consistency Ratios are shown. For this study three key areas with each 8 decision criteria are used for the evaluation. It can be seen from the table that for a set of decision criteria consisting of 8 criteria where the maximum scale value used in the pairwise comparison system is 9, the threshold is 0.4587. This means that for the sets of decision criteria used in this study, all CR values lower than this value are acceptable. However, since the key areas must also be subjected to pairwise comparisons, they have a different threshold value. For the set of key areas, consisting of 3 criteria and with the maximum scale value 9, the threshold value is 0.2122.

If the method is applied correctly and the rankings are consistent, the most optimal water hubs can be determined by using a weighted calculation method over the normalized scores of all water hub and the weights of the decision criteria. The choice for normalization of scores for alternatives and the choice for a weighted calculation method are based on preference and therefore usually chosen based on common practice. In this study the scores of water hubs are normalized by using the Linear Max approach and for the weighted calculation method the weighted sum-product is used (Rezaei, 2020). Here it appears that there is a lot of freedom in choice for quantitative models, which can all have different outcomes when applied. There is a risk that this freedom will lead to a biased selection of the models that show the most preferred outcomes. Applying the BWM to evaluate the potential water hubs for the case study location in Alblasserdam resulted in a ranking of the six potential water hubs. The best fitting potential water hub for the case study location, a tourist hub, could be derived from the model.

Table 4: Consistency Ratio thresholds (Liang, Brunelli, & Rezaei, 2020)

	Criteria						
Scales	3	4	5	6	7	8	9
3	0.2087	0.2087	0.2087	0.2087	0.2087	0.2087	0.2087
4	0.1581	0.2352	0.2738	0.2928	0.3102	0.3154	0.3273
5	0.2111	0.2848	0.3019	0.3309	0.3479	0.3611	0.3741
6	0.2164	0.2922	0.3565	0.3924	0.4061	0.4168	0.4225
7	0.2090	0.3313	0.3734	0.3931	0.4035	0.4108	0.4298
8	0.2267	0.3409	0.4029	0.4230	0.4379	0.4543	0.4599
9	0.2122	0.3653	0.4055	0.4225	0.4445	0.4587	0.4747

3.3.1 Surveys

In order to complete the steps in Table 2, a survey was developed that could be presented to respondents. The survey can be found in Appendix B. In the survey, participants were first asked to fill in from which actor role (expert, industry interest or non-industry interest) they were filling in the survey for the case study, and then they were asked to make pairwise comparisons for the key areas and the three sets of decision criteria related to these key areas. Together with the survey a case study description as described in Chapter 5, was provided to the participants as well.

For this study, a total of ten decision making actors were approached (using the interviewees from Section 3.2.1), including two actors from each actor level to determine if there are significant differences in the outcomes for a feasible hub location for Alblasserdam. The reason behind the preference for surveying two actors per actor level, rather than just one, is to check for inconsistencies in outcomes within the actor levels. Opinions on the weights of criteria might vary between actors, depending on the preferences of the individuals or group they belong to. By surveying experts and industry interest, next to the actual decision makers, the politicians, it can be clarified whether all actors are aligned and have the same decision criteria in mind that leads to a feasible for the potential hub location. If there are significant discrepancies in the outcomes, it can be useful for them to get together and discuss the differences. Unfortunately, only three respondents returned a complete and usable survey, one participant from the Economic Development Board, one participant from the Drechtsteden region and one Expert. The rest of the interviewees did not (fully) complete the survey and/or did not respond to additional requests, so their input could not be incorporated into this study.

3.4 Part IV: Wrap-Up: Discussion, Conclusion and Recommendation

The final section of this study is not really part of the methodology, but rather discussing the results. The end result of the study is a ranking of potential dock types for the case study, which reveal which water hub is the best fit for the case study location. The goal of this research was that the derived model could also be used to determine a best-fit potential water hub for other locations for Seabubbles. This end result also immediately answers the research question. In the Discussion, the validity and usability of the applied methods were addressed. The Conclusion summarizes the main findings and also addressed the research question. The final section is the Recommendations section, which provides some recommendations for future research and for the actors involved.

4 DESK RESEARCH

From the scientific research conducted in the Literature study in Chapter 2 it appeared that there is insufficient scientific research to categorize urban water hub types on relevant decision criteria. Although a list of decision criteria could be derived from the literature study, see Table 5, it is not clear which decision criteria are essential and which are desirable. Moreover, there is also no attribution to areas on the specific water hubs, as they are mainly referred to in a very general setting as being important.

Table 5: Decision criteria that emerged from the literature study in chapter 2

Decision criteria for water hubs	
User Experience: Value for money (in time, money and effort)	On-demand access Time savings Better use of waiting times Comfort Easy access Reliability of service Attractive frequencies of services Total cost journey Door-to-door mobility Passenger flow efficiency Seating Shelter Ticket machine availability Real-time information systems Disability access Toilets
Environmental integration	Urban integration Connection with existing transport network
Operational	Fixed docks Refueling time of boats Investment costs
Mode Choice	Bicycle parking for private cycles Car parking Public transport options Ride sharing via apps (e-bikes, e-scooters, e-cars, etc.) Ease of transfer to other modes

This means that it is important to conduct additional theoretical research by using secondary sources that do allocate the decision criteria to specific areas at a hub. Besides, additional research is also necessary to reduce the amount of potential feasible multi-modal water hub types for Seabubbles.

In this chapter the additional desk research where secondary sources are used will be conducted. However, in order to scope the topic well so that it falls within the timeframe of this research, a theoretical framework will be selected to guide with scoping the research topic and give guidance in answering the research sub-questions.

4.1 Theoretical Frameworks

Innovation theories were deemed useful to investigate the dynamics of success and failure on implementing an innovative transport product or service. In this chapter some innovation theories are presented that are suitable to help in researching the feasibility of on-demand hydrogen Seabubbles and decision criteria for water hubs. The most applicable theoretical framework will be explained to guide through the entire study.

Frambach and Schillewaert (2002) introduced a framework that focuses on the role of the organizational party who is supposed to bring a product or service in such way that an innovation will be adopted by users. The theory states that attitudes of potential users can change and be influenced. However, with the implementation of hydrogen water modes, many stakeholders are involved that may have different (political) interests. It is a high risk to invest in the implementation of hydrogen vessels and rely on changed behavior of end users.

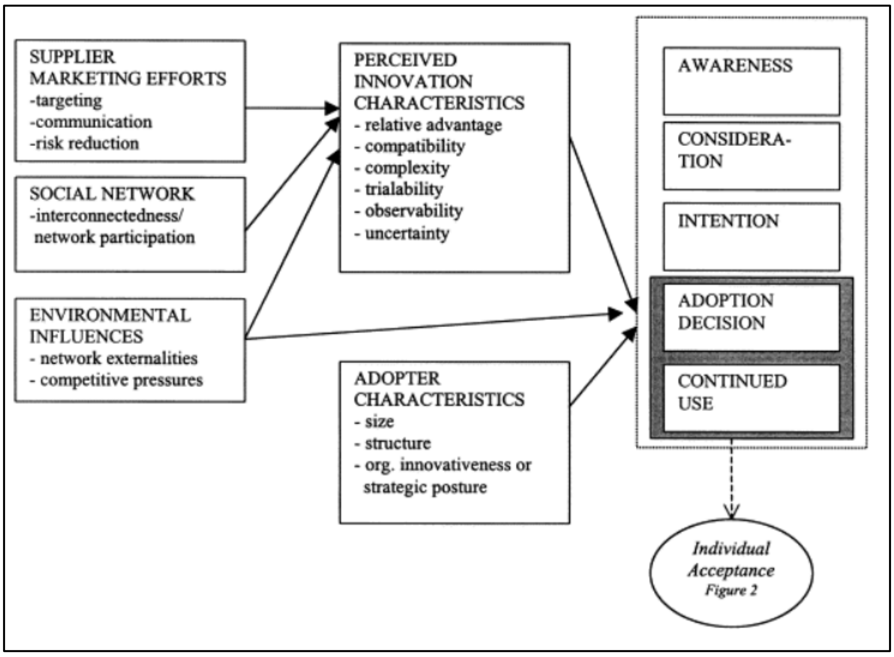

Figure 4: A conceptual framework of organizational innovation adoption (Frambach & Schillewaert, 2002).

(Nechully, Pokhriyal, & Thomas, 2017) have performed a literature study on theories related to innovation adoption that have been presented between the years 2000-2018. Although the research provides an extended overview of 61 frameworks that can be used to assess innovations, the review did not delve deeper into the implementation aspect of the theories. However, one theory that is widely discussed with regard to the adoption of transport innovations is the Technology Acceptance Model (TAM) (Marangunić & Granić, 2015; Nechully et al., 2017). This framework focuses on the user requirements of an innovation and has been extended and adapted over the years. Based on the social acceptance, the adoption of implementing hydrogen Seabubbles could be considered. The decision criteria that are important are from an end user perspective, such as safety, experience and reliability of the system. Although the theory forms a solid base from a social perspective, this framework fails to assess other important requirements that affect implementing on-demand water transport modes, e.g. techno-economic and political requirements. Seabubbles have to be facilitated by customized water hubs, which involve investments and regulations. This makes assessment of these fields also important.

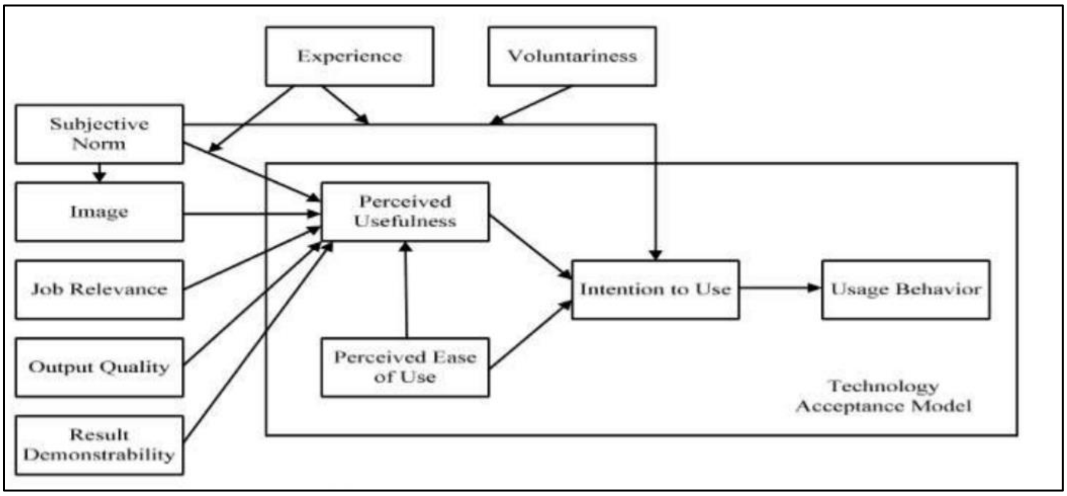

Figure 5: Technology Acceptance Model (TAM2) (Nechully et al., 2017).

A framework that does address these missing techno-economic and political requirements in TAM is the Political Economy Model by Feitelson and Salomon (2004). As shown in Figure 6, this framework covers more areas than TAM and is based on the perception that an innovation will only be implemented if it is seen as technically, economically, socially and politically feasible. By introducing a whole new water transport mode in public transport, all feasibilities should be considered. The feasibility levels are inter-connected and need to be pursued in order to find out if a successful adoption is possible. Feitelson and Salomon (2004) also remark that innovations aren't always generated out of necessity, but they may have an entrepreneurial or policy related origin. Motives for innovation adoption can be economic gains or the pursuit of political interests. This may also be the case when Seabubbles are considered, as governments and organizations may hype sustainability concepts.

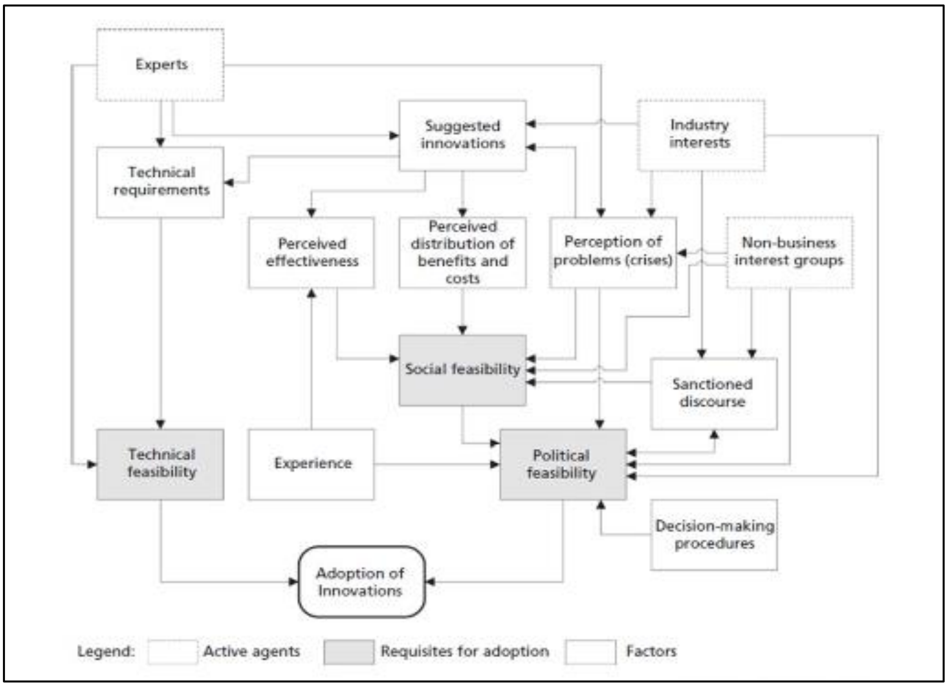

Figure 6: The Political Economy Model for transport innovations (Feitelson & Salomon, 2004).

4.2 Political Economy Framework

The theoretical framework that is selected to guide through the theoretical research is the Political Economy Framework as proposed by Feitelson and Salomon (2004). The motivation behind this choice is that Feitelson and Salomon (2004) cover the evaluation of more feasibility fields compared to other researched frameworks. An overall feasibility approach is especially important in adoption of transport innovations, such as the deployment of on-demand Seabubbles, since many of the involved stakeholders may each have different interests. The framework suggests that an innovation will only be adopted if it satisfies all feasibility levels, which means technically, economically, socially and politically.

The framework also suggests that a transport innovation can be investigated by performing a combination of a case study in practice and desk research, which is exactly what was intended within this study.

The original framework of Feitelson and Salomon (2004) consists of three main feasibility factors that lead to the adoption of an innovation. Within this study the social and technical feasibility of potential water hubs are examined.

However, from a social feasibility perspective, the perceived distribution of benefits and costs are also not examined, as a cost-benefit analysis of a feasible water hub for Seabubbles by itself would fit into an entire thesis. The same is the case with Sanctioned Discourse, as this would require an extensive stakeholder analysis to determine the views of the visions and opinions of all involved stakeholders. There are too many stakeholders involved in the introduction of an innovative waterborne transport mode, because we are dealing with both, interests on the water side, but also on the land side. These subjects are therefore recommended for future research as well. In order to keep the research scope of this thesis feasible within the limited period of time, the political feasibility is not investigated into depth and will be recommended for future research. The research concerning political feasibility can be very extensive, since governmental involvement in infrastructural innovations such as a multi-modal water hub may concern many layers within the government. Relevant stakeholders may include local, regional and nationwide governmental stakeholders and additional non-profit organizations, such as lobby groups.

The adapted structure of the framework that is used as guidance through this thesis is shown in Figure 7.

The technical, social and political feasibility factors are represented by the colored blocks in the figure. The other blocks represent the requisites that lead to the feasibility factors. For each requisite it is decided what research questions from section 1.3.2 it relates to. The arrows show in what direction the requisites are of importance. The dotted lines represent the desk research and active agents that are needed to provide the innovation with context and content.

Within this study, the potential adoption of on-demand Seabubbles is completely disregarded and not examined. Whether the implementation of the Seabubbles is feasible requires intensive customer research focusing on origins and destinations and customer preferences. This study is intended only to clarify what feasible potential water hubs would be best supporting potential adoption of the Seabubble if it were to be implemented.

The research gap will be addressed from a theoretical perspective by framing the research questions into parts of the Political Economy model. Views and concepts from scientific literature, secondary sources and interviews with actors as shown in the framework will be used where necessary to assist with the discussed theory. Each requisite that leads to social and technical feasibility of potential water hubs will be outlined in the next sections in this Chapter.

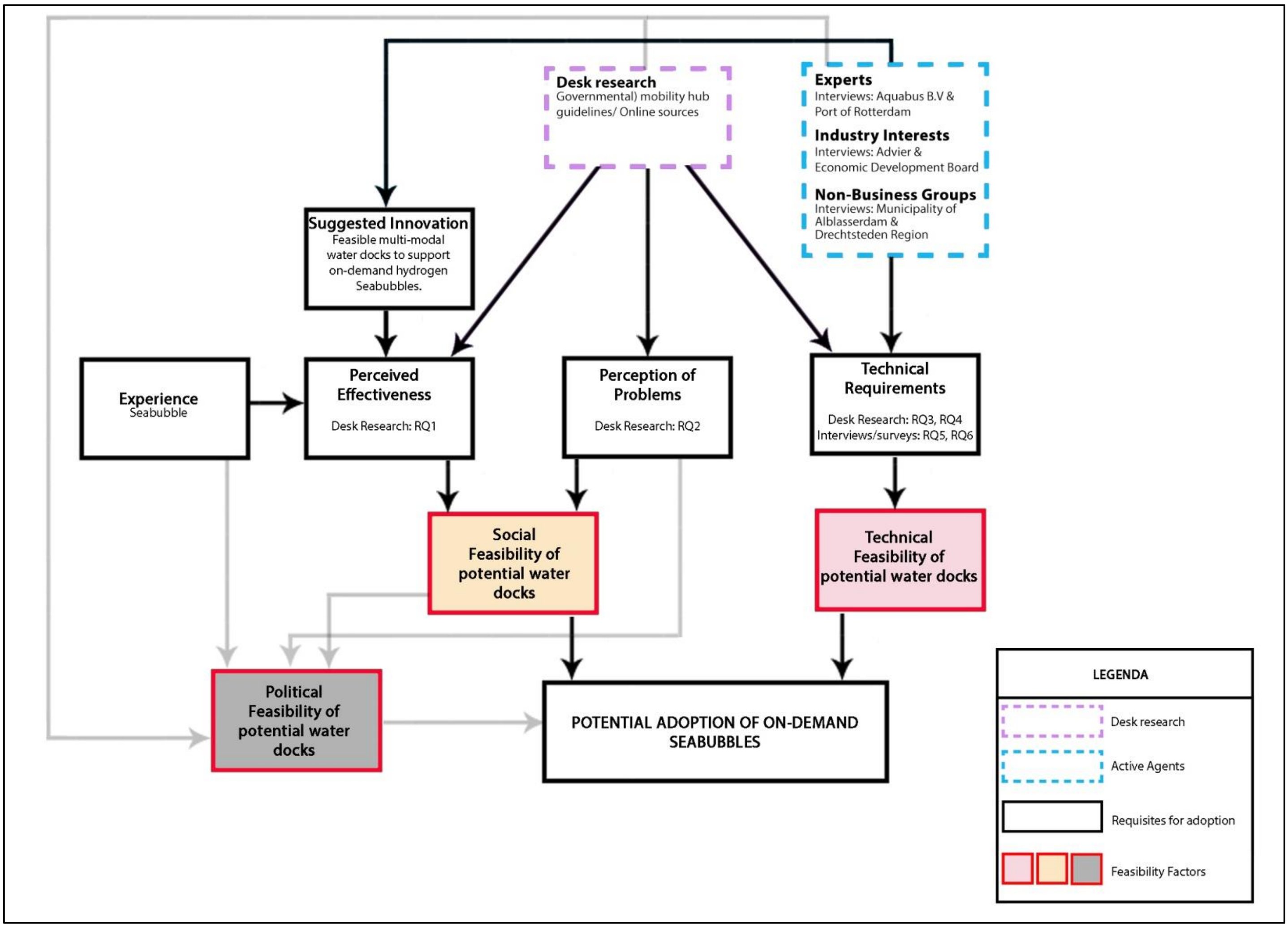

Figure 7: Adapted version of the Political Economy Model

In order to keep the research scope of this thesis feasible within the limited period of time, the political feasibility is not investigated into depth and will be recommended for future research. The part of the framework that is disregarded is printed grey in the figure. The research will instead focus on the social and technical feasibility of water hubs.

As can be seen in the framework the input for the requisites for adoption is provided by active agents. Due to the innovative nature of determining water hub types for on-demand hydrogen Seabubbles, interviews will not provide enough input to determine the social and technical feasibility. This is why additional desk research is needed to frame the subject and fill the gaps where necessary. This will be especially evident when determining relevant decision criteria for landside and facilities zones. The interviews will also not be able to contribute sufficiently to the determination of general usable water hub types, because the interviewees are looking at a specific location. Therefore the desk research will be used to address this part. However, the interviews are of great interest to important decision criteria that are needed on the water side of the water hubs.

The following Chapter addresses each of the required blocks to answer the sub-research questions and determine the conditions for potential water hubs.

4.2.1 Perceived effectiveness

The use of inland waterway transport (IWT) for passenger transport is not a new phenomenon and has been practiced in the Netherlands for centuries. Already in medieval times, Dutch engineers constructed inter-city canals to offer public transport by connecting Bruges, The Hague, Leiden and Delft (Crompton, 2004). At that time this was the fastest way to move from one city to another. The introduction of the private car and the construction of road and rail networks in the last century, have resulted in a modal shift from water to road transport. The immense increase in private car ownership has resulted in major congestion problems, air pollution, noise hindrance, health risks and parking problems (Manders, Cox, Wieczorek, & Verbong, 2020; Nocera, Pungillo, & Bruzzone, 2020). The expansion of water transit services will desirably result in a substantial modal shift from road to water transportation in the regions where water transit is possible so that these negative effects will be reduced. The implementation of sustainable on-demand water taxis offers opportunities for redesigning water-borne services to strengthen the strategic connection between land and water transit services, so that less people are going to use private modes if they perceive increased connectivity benefits (Waterbus, 2018).

A well-integrated water hub in the transport network can play a crucial role in connecting various hotspots within an urban area or region. Unfortunately, the typologies of urban water hubs in passenger transportation are a much understudied topic, so it is not known which type of water hub performs best in which environment.

In addition, there is a huge variety of terminology to designate water hubs. Some of the terms that were used interchangeably to indicate water hubs are: port, dock, wharf, yard, terminal, jetty, hub, pier, landing and mooring. These terms do have a lot of overlap with cargo ports, which on the other hand have been well researched. Due to the abundance of information on cargo ports, it was difficult to find relevant literature on passenger-only docks. Another reason for this may be that water hubs usually play a dual role in covering investment costs, where they serve as both, cargo and passenger port (Jugović, Mezak, & Lončar, 2006). Although there is tremendous diversity in water hub types, no research could be found that classified urban docks into clear typologies. Sometimes hubs are classified as small, medium or large based on the passenger flows, but it differs per research paper what passenger flows are assigned to a small or large dock (Cheemakurthy et al., 2017; Monzón et al., 2016).

Mobility hubs

Although no specific typologies or guidelines for water hubs could be found, a lot of studies have been performed on a concept called mobility hubs. This concept can also be applied to water hubs, as it is a general hub design concept that can be applied to all locations where different modalities meet. The perceived effectiveness of mobility hubs is expected to be similar to that of water hubs due to the overlap of activities taking place there.

In support of the mobility hub concept, government agencies in particular have developed various guidelines for choosing the right type of mobility hub for a location type using decision criteria. A selection of usable guidelines that were found to develop and select mobility hubs and/or decision criteria is shown in Table 6. The documents that had a general approach and are intensively used in this study to define mobility hub types and associated decision criteria are by ComoUK (2019, 2020); Metrolinx (2011), Monzón et al. (2016) and Urban Design LA (2021).

The other documents from Table 6 are mainly supportive and discuss several decision criteria that are already discussed by these four parties more in depth. The purpose of this research is to arrive at a set of potential multi-modal water hubs for Seabubbles and a set of decision criteria that can be considered relevant in practice to distinguish between water hub typologies.

Table 6: Used documents for determining relevant mobility hubs and decision criteria for Seabubbles

Document Title	**Author/Publisher**	**Actor type**	**Focus**
MOBILITY HUB GUIDELINES	Metrolinx (2011)	Government	Mobility Hub / Decision Criteria
Mobility Hub Features Catalog	San Diego Association of Governments (SANDAG)(2017)	Government	Decision Criteria
Integration of shared mobility approaches in sustainable urban mobility planning	European Platform on Sustainable Urban Mobility Plans (2020)	Government	Decision Criteria
Shaping the Future of Mobility	European Parliamentary Technology Assessment (2017)	Government	Decision Criteria
Mobility Hubs Guidance	ComoUk commissioned by European Union (2019)	Government	Mobility Hub/Decision Criteria
Mobility Hub Accreditation: setting quality standards	ComoUk commissioned by European Union (2020)	Government	Mobility Hub/Decision Criteria
Efficient urban interchanges: the City-HUB model	Monzón et al. (2016)	Academic	Mobility Hub/ Decision Criteria
Verkenning Openbaar Vervoer over Water	dS+V, afdeling Verkeer & Vervoer commissioned by Stadsregio Rotterdam (2006)	Government	Decision Criteria
Beleidskader Personenvervoer over Water Rotterdam – Drechtsteden	Province of Zuid-Holland (2018)	Government	Decision Criteria
Mobility hubs: Advancing equitable & sustainable mobility in East Boston	TransitMatters and The Harborkeepers (2019)	Interest Groups	Mobility Hub/Decision Criteria applied to specific region
Guidelines for Accessible Maritime Passenger Transport	Irish Department of Transport and NDA (2010)	Government	Decision criteria for disabled people
Mobility Hubs - A reader's guide	Urban Design LA (2021)	Interest Group	Mobility Hub/Decision Criteria

The definition of mobility hubs may vary slightly among the sources consulted in Table 6, but the core of a mobility hub is to provide a seamless connection between private modes (walking, cycling and cars) and shared mobility modes. These hubs are usually strategically placed near common public transport nodes to increase the connectivity and accessibility with existing transport networks. At the hub's location, the transport services can be expanded by adding other amenities, e.g. food trucks, package pickup points, etc., depending on the needs of the travellers in the area. In Figure 8 examples by ComoUK (2019) of components that could be part of mobility hubs are shown. A mobility hub can be very limited in what it offers on one location, but very extended on another. This totally depends on the needs of the traveller types that use the hub.

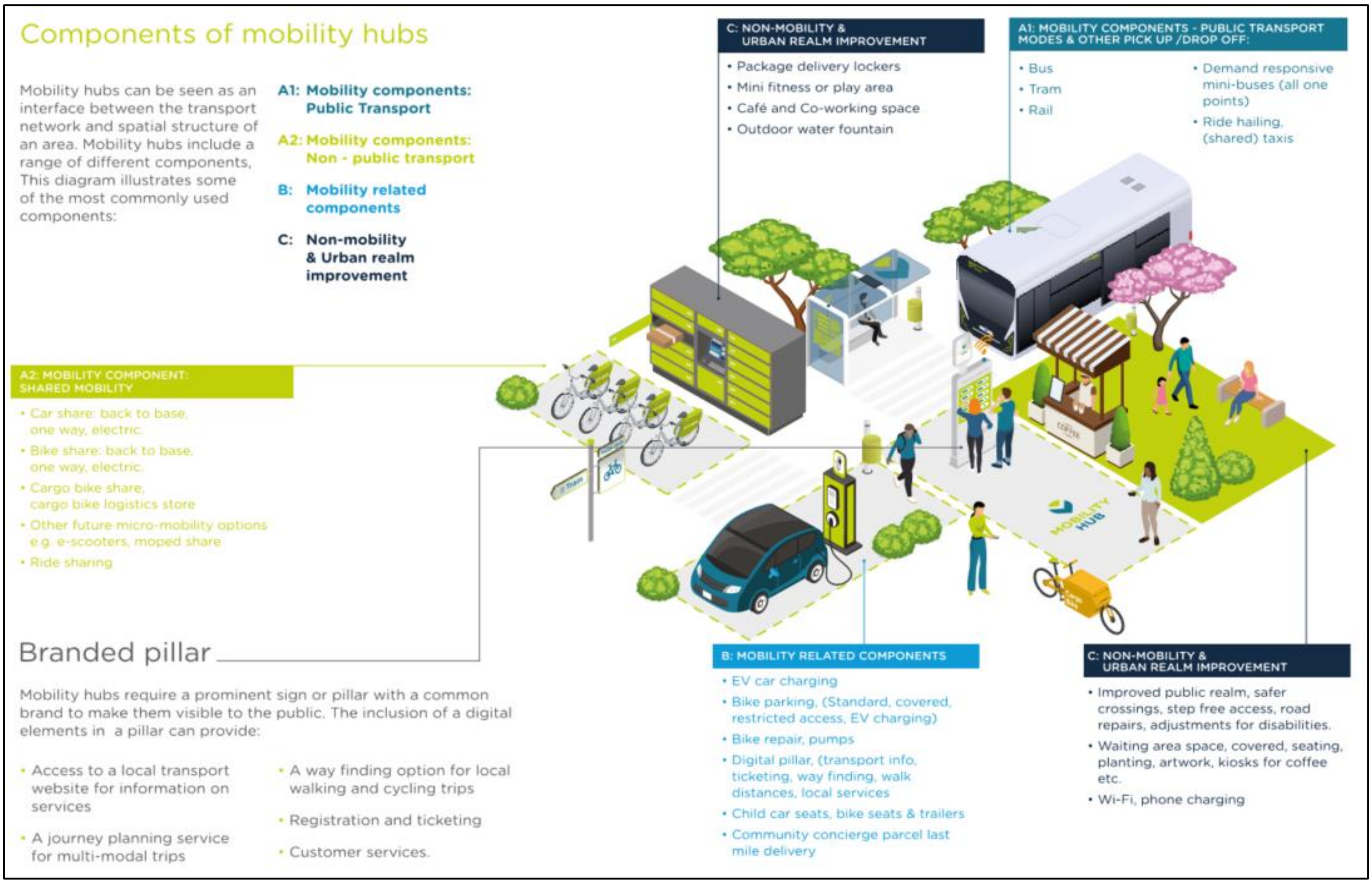

Figure 8: Components of mobility hubs (ComoUK, 2019)

Shared Mobility

One of the core aspects of mobility hubs is that they offer some form of shared mobility, depending on the needs of the travelers in the urban area in which the hubs are located; see Figure 9 for examples.

Shared mobility is an umbrella term for all transport options that are publicly accessible and can be offered by private or public organizations (Shaheen, Bell, Cohen, & Yelchuru, 2017). Much of the new shared mobility modes are emerged from an urge to complement common public transport that provides transportation through fixed routes and schedules.

Figure 9: Mobility Hubs. Left: A Mobil.punkt in Germany offering shared e-cars and bikes (Mobil.Punkt, 2020); Right: Mobipunt in the Netherlands offering shared bikes (Advier, 2019)

Although regular public transport is also a form of shared mobility, the term shared mobility is often used in the literature to refer to new sustainable and flexible forms of shared transport that have emerged in the last decade (Machado, De Salles Hue, Berssaneti, & Quintanilha, 2018). As shown in Figure 10, Roukouni and Homem de Almeida Correia (2020) drew up a diagram of most of the modes of transport referred to when shared mobility is discussed. These shared modes are usually used to complement private modes and common scheduled public transport.

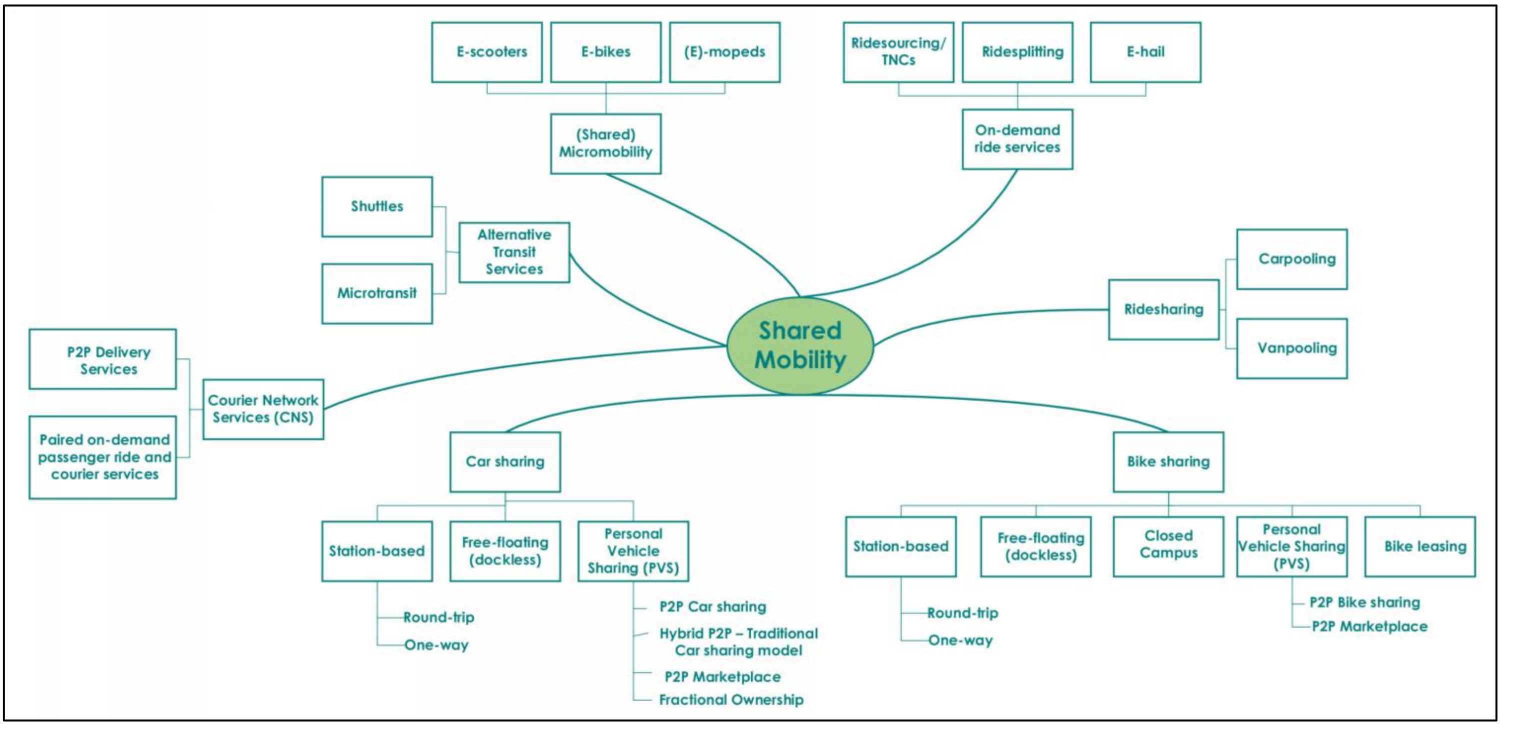

Figure 10: Shared mobility modes and services (Roukouni & Homem de Almeida Correia, 2020). P2P=Peer-2-Peer

On-demand Seabubbles can also be seen as part of this shared mobility concept, since they also serve as a complement to regular scheduled waterborne services and land transport modes.

Although the new flexible shared mobility modes are part of a concept that emerged in the last decade, the topic has already been extensively researched and a number of positive impacts have been noticed in some key areas (Roukouni & Homem de Almeida Correia, 2020). The main key areas where positive impacts are noticed are shown in Table 11. The increase in shared mobility led in general to a decrease in the urge to own private cars, which automatically leads to additional socio-economic and environmental benefits.

User experience

Water modes are a form of non-traditional transport. Non-traditional transport modes are known to generate latent demand as these modes are popular and beneficial due to the travel experience itself regardless of the destination (Mokhtarian & Salomon, 2001).

Seabubbles are futuristic looking small hydrofoils with a capacity of seven persons, whose hull emerges from the water to create the impression of floating boats. Due to the hydrofoil technique, the boats can travel at 40 kilometers per hour over the water without causing significant wave action, emissions or noise. In addition, the ship has an open view, so that an optimal perception of the environment can be experienced (Seabubbles.nl, 2019).

Commuters are expected to be reluctant to use the service, due to the ticket prices (similar to road-taxi prices) compared to alternatives and the fact that water transport does not provide door-to-door service. Attracting a wide audience will only be possible if other modes of transport are seamlessly integrated. Here, the importance of the function of water hubs is again emphasized. The user should experience some effectiveness over the whole journey in order to use the water service. Due to the nature of waterborne transportation (from shore to shore), the travel route generally consists of several multi-modal trips when traveling from origin to destination. Since switching to other modes detracts from the trip experience, because some effort is demanded, it is important that the switch is experienced as seamless as possible when travelers arrive at a water hub location (Cheemakurthy et al., 2017). This can be achieved by offering enough transfer options on the hub, such as availability of enough public transport connections or forms of shared mobility. Depending on the main function that the hub fulfills, which depends on the main user type it will serve, the services should be determined to minimize the inconveniences of transfers as much as possible.

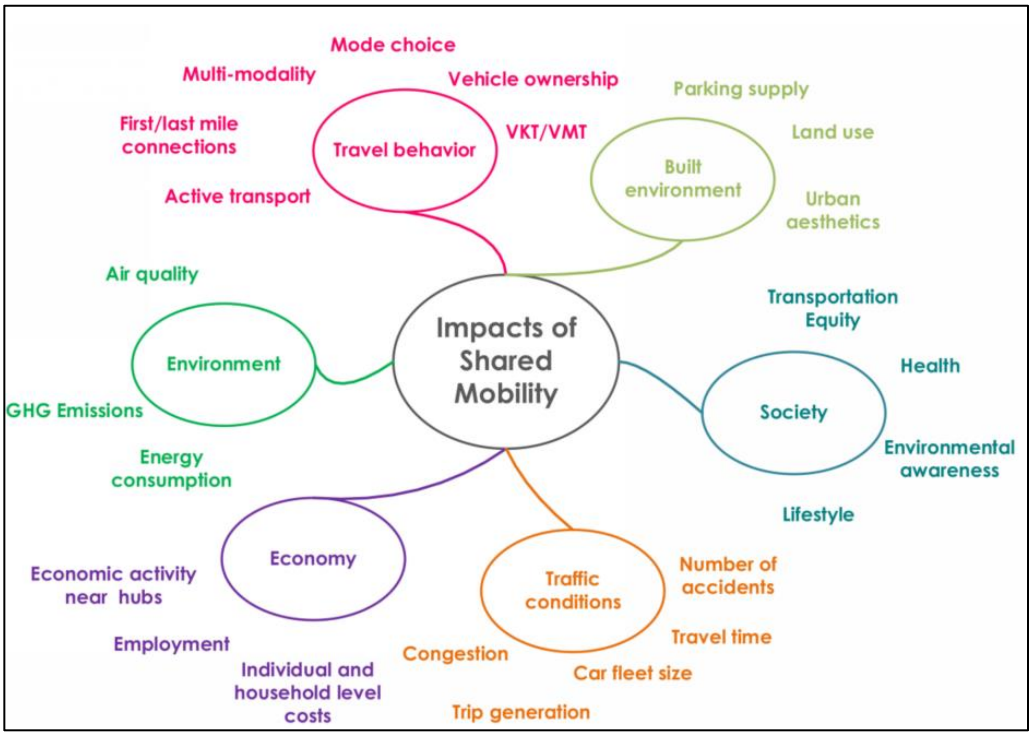

Figure 11: Key areas where positive effects of shared mobility are noticed (Roukouni & Homem de Almeida Correia, 2020).

4.2.2 Perception of Problems

Although mobility hubs seem like a good omen for future mobility, it takes a lot of effort and time to change travel behavior. Governments are therefore highly involved in mobility hub projects to support the initiatives. Besides that it takes time to introduce a new concept and to change travel behavior, there is a risk that the hubs will not catch on in certain regions at all e.g. in case of insufficient demand or if the provided services are considered too expensive (Smart Mobility Living Lab London, 2020). Therefore, most projects in Europe are heavily subsidized by EU grants, including through the eHUB project. Through Interreg North West Europe, a budget of 8.86 million euros has been allocated for the launch of mobility hubs in the period 2019-2022 in 6 cities in 5 European countries to cover the high investment costs (Interreg North-West Europe, 2019). This gives entrepreneurs the necessary time to familiarize people with the mobility hubs, as it can take some time for people to switch transport modes and actually use the services.

Moreover, the high investment costs are also caused by the nature of the transport concept. A single stand-alone mobility hub will not work, because the power of the concept lies in creating an integral network of hubs, increasing the accessibility of an entire area. Since most shared transport modes that are offered at mobility hubs can only be parked at the operator's hubs, an extensive network of hubs is needed so that there is always a hub nearby to minimize walking distances from departure points and destinations (Karbaumer, 2020). Shared mobility projects that do not make use of a sufficiently large network of mobility hubs with a sufficient supply of transport options do not always succeed. A good example is the Pronto bike-sharing project in Seattle, which failed mainly because there were not enough bikes and hubs available during peak hours, so the service competed with bus services and people eventually stopped using the bikes (Sun, Chen, & Jiao, 2018). Bad weather conditions, such as rain or snowfall also amplify this competition effect, because bad weather is negatively correlated to the usage of shared mobility options (El-Assi, Mahmoud, & Habib, 2017).

This competition with other modes also occurs when a shared mobility service is too expensive compared to alternatives that can offer the same transportation at a much lower price. This is especially the case when water modes, such as on-demand Seabbubble, are involved. There should be no competition from nearby bridges or tunnels that can carry frequent transit lines such as rail or bus. The water modes will then be considered too expensive and cannot compete, unless attractive ticket prices are offered (Walker, 2012). An example where this competing phenomenon occurs is the ferry service that runs from Hoboken, New Jersey to Midtown Manhattan, New York City. Right next to the ferry service is a much cheaper underground train service ($2,75/single trip), making the ferry service ($9/single trip) an elite means of transportation for the commuter (Rome2rio, 2021). In addition, bridges and tunnels can provide more connected transportation networks because transit lines extend deeper into both land sides of the river, whereas a ferry service only travels from bank to bank. So, the scenic experience that water transportation brings makes it a widely supported transportation initiative, but to be viable in the long term, the service must be useful compared to its alternatives (Walker, 2019).

In addition to considering how to provide sufficient connected mobility options, it is also necessary to carefully examine which target groups are important for the viability of the shared mobility service in order to determine whether there is a stable demand for the service and if mobility hubs are necessary at certain locations. In the university town Delft in the Netherlands, the concept of Mobikes was introduced which was mainly used by international students and expats visiting the Delft University of Technology (Smit, 2020). However, with the outbreak of the Covid-19 pandemic, the use of the bikes stopped almost completely, forcing the operator to remove the bikes from the streets to prevent unnecessary vandalism and theft. The pandemic has been going on for some time and it is not known if the bikes will be back in town once sufficient demand is expected again.

A sort like risk is being dependent on fluctuating demand of tourists and recreational users. If there is no supercharged tourism sector, where a seamless kind of services and connections are offered, this market can easily be overestimated (Walker, 2019). If an on-demand water mode is completely dependent on the recreational sector it is key to be able to deal flexible with the situation if travel demand drops. Transport with Seabubbles is expected, especially in the beginning, to attract mainly tourists, other leisure users and occasional business travelers to act as a form of recreational way of transportation. This is especially the case if the Seabubbles will sail autonomous. Because of the hydrogen innovation and the need to be successfully implemented first, the Seabubbles can currently be operated by captains only (Advier, 2020). However, the goal for the future is to offer autonomous on-demand transport, so that on-demand water transportation can also be made attractive to daily commuters who will find the service otherwise too expensive if alternatives are available.

4.2.3 Conclusion Social Feasibility

In this part the first two research sub-questions are addressed, where the perceived effectiveness and problems of multi-modal water hubs are examined.

A properly integrated multi-modal water hub in the transport network can play a crucial role in connecting various hub locations within an urban area or region. However, since urban water hub types are not well researched it is hard to tell what water hub fits best in what area.

The mobility hub concept is a relatively new concept that can be used to distinguish between multi-modal water hubs. Government entities have developed various guidelines for choosing the right type of mobility hub for a location type using decision criteria.

This mobility hub concept can be used for this study, since the purpose of this research is to arrive at a set of potential multi-modal water hubs for Seabubbles and a set of decision criteria that can be considered relevant in practice to distinguish between water hub typologies. The implementation of mobility hubs offers opportunities for strengthening the strategic connection between various transport modes, so that less people are going to use private modes if they perceive increased connectivity benefits. An important aspect of mobility hubs is that they offer a form of shared mobility, depending on the needs of travelers in the urban area where the hubs are located. Most shared mobility forms arose from a need to complement public transport, which provides transportation via fixed routes and schedules. Providing flexible modes of transportation can enhance the user experience when using public transportation.

On-demand Seabubbles can also be seen as part of this shared mobility concept, as they also serve to complement regular waterborne and land-based transport services. Due to the nature of waterborne transportation (from shore to shore), the travel route generally consists of several multi-modal trips when traveling from origin to destination. Since switching to other modes detracts from the trip experience, because some effort is demanded, it is important that the switch is experienced as seamless as possible when travelers arrive at a water hub location.

Although mobility hubs seem like a good fit for the mobility of the future, it takes a lot of effort and time to change travel behavior of people. Governments are therefore highly involved in mobility hub projects to support the initiatives. Most mobility hub projects in Europe have been heavily subsidized by EU grants in order to implement them. Because of the funding, there is a chance that a distorted image of the actual success of these mobility hub projects is propagated.

Another point of interest is that implementing water hubs for an innovative water mode involves very high investment costs, even higher than land modes. And on top of that, a single stand-alone mobility hub will not work, because the strength of the concept lies in creating an integral network of nodes, increasing the accessibility of an entire area.

4.2.4 Technical requirements

Mobility hubs-Urban area

Mobility hubs are expected to help create a robust network of seamless transportation connections to change travel behavior to reduce emissions and congestion. A network of strategically located mobility hubs is perceived to create a more connected and dynamic urban environment which also increases the user experience of travellers (CCTA, 2021; Hive Mobility, 2021; Hub, 2021; Mobipunt, 2020; TransitMatters & The Harborkeepers, 2019)

If successfully implemented, mobility hubs can grow into connected dynamic socio-economic nodes of the village, neighborhood or region where they are located (Hub, 2021). A mobility hub includes not only the location it itself, but all services and destinations that can be reached within 5 minutes, depending on the displacement possible through the used mode. The surrounding area is usually divided into three or four zones and is determined based on the accessibility options by foot, bike and driving, see Figure 12.

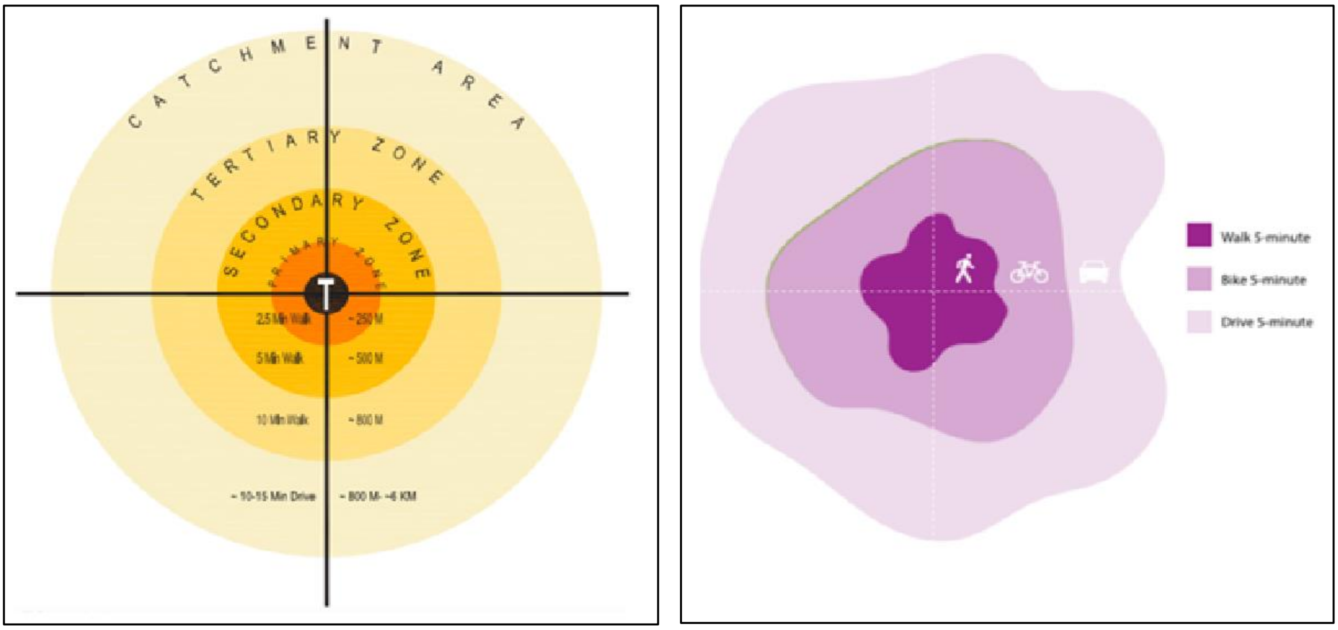

Figure 12: Mobility hub access zones; Left: Metrolinx (2011), Right: SANDAG (2017)

The three inner circles are still considered part of the mobility hub, as they are of great importance in facilitating access to the dock (Metrolinx, 2011; SANDAG, 2017). The primary zone for water hubs is where passengers enter and exit the transit area and must be able to transfer safely and smoothly to other modes or facilities. This zone is within a 250 meter/2.5 minute walk radius. Depending on the available hub space, and transportation function (entry, destination or interchange), most facilities will be located within the primary zone boundary (see Figure 12). This means that the main decision criteria for selecting a hub type will be related to the facilities needed in this zone, such as the need for a P+R, shared mobility, place making etc.

The secondary zone is important to increase the accessibility of other modes to and from the mobility dock. The zone extends to about 500meters/5min walk from the hub. This zone is mainly used by cyclists and also by pedestrians. It is therefore important that the area is provided with a good and safe bicycle route network, while at the same time encouraging a rapid flow of other forms of transport as well. This zone is additionally used to provide other forms of transportation if there is insufficient opportunity for it in the primary zone, such as public transportation or parking options.

The tertiary zone is about 800 meters/10 minute walk away from the hub location and hereby indicates the edge of the hub. This distance is too far to walk to an interchange, but is still just within the reach of the hub, as the area is important for making the hub accessible to motorists and public transport. A well connected road network is important here. However, this also applies to the bicycle network.

The catchment area is considered to be the area outside the mobility hub zone and to some extent determines the transport function of the hub, which can be an entry, interchange or destination. An entry function means that there is a lot of outgoing traffic from the surrounding area, so usually the main users are commuters. A destination node, on the other hand, has mostly incoming visitors, such as tourists or business people who need to be in the area. They usually leave again at some point during the day. An interchange functions primarily as a stopover where incoming visitors do not always need to be in the area, but can also transfer to other modes to reach their final destination.

Mobility hubs- Key areas and associated decision criteria

Each multi-modal hub can be divided into three key areas and based on the needs of the travelers that visit the hubs, decision criteria can be linked to each of these zones. The key areas that are identified are as follows: Access/Egress Zone, Transport/Transfer Zone and the Facilities & Retail Zone (Monzón et al., 2016). Of course there are also areas related to technical maintenance & operations of the dock, but these areas are not within the scope of this research, because they are not accessible to travelers. As can be seen from Figure 13, these three key areas are interconnected and closely related to each other.

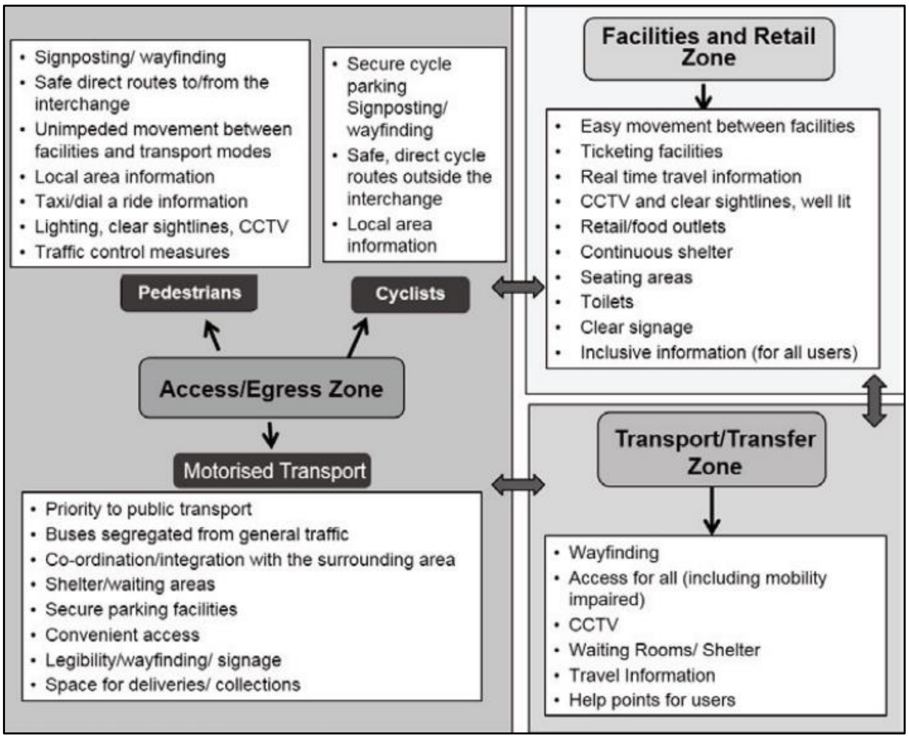

Figure 13: Multi-modal hub zones with associated decision criteria (Monzón et al., 2016)

There may even be an overlap in the use of the space in case of small hubs. In the diagram also some decision criteria are shown that can be connected to the key areas.

However, the needed decision criteria can vary depending on the hub type and function the hub needs to fulfill.

All three key areas of all mobility hubs must meet certain essential criteria to meet the safety requirements and basic needs of travelers. It is important that all zones of the hubs are integrated well in the surrounding environment, secured (CCTV), equipped with adequate lighting and modern & clean infrastructure (ComoUK, 2019; SANDAG, 2017). All areas must be accessible to all, i.e. taking into account good and safe walking paths and access for the disabled without blockages (Irish Department of Transport & NDA, 2010). In addition, the hub area will require regular maintenance to maintain a continuous use and safe environment. If there are modes of transportation where waiting is required, covered seating should be added to the concerned key areas as well (ComoUK, 2019). Each of the individual key areas as presented by (Monzón et al., 2016) has also its own essential and desirable criteria. The key areas and their important decision criteria will be discussed below and supplemented with information from additional sources where needed.

The Access/Egress Zone - Land side

This is the area where users enter or exit the hub. This area ideally lies entirely within the primary zone as indicated by Metrolinx (2011) and SANDAG (2017) and covers a maximum radius of 250 meters/2.5m walking time. This zone is where all users are entering or leaving the hub by walk, public transport, bicycle, private car or any other form of shared mobility. Since multiple modes converge on a hub, it is important to allow a good traveler flow by offering accessible and safe transfers to other modes, safe crossing pavements, and safe cycling paths. The access/egress zone is where people need be able to recognize that there is a hub, thus clear and uniform signage/way finding and on-site information about the hub are necessary. Another requisite within this zone is that at least one shared mode is offered and that there should also be at least 1 public transportation connection nearby (ComoUK, 2019).

In addition to the essential criteria for this key area, depending on the location and type of hub, additional services may be offered to better meet the needs of users. If people use private modes to go to the hub, parking facilities for bicycles or cars may be important. Transportation services can be expanded by including 2 or more links to public transportation and/or shared mobility. Within the shared mobility options, a distinction can be made between station based modes that need to be returned to the hub and modes that do not need to be returned to the hub, but can be dropped off in (allocated) zones outside the hub zone (Roukouni & Homem de Almeida Correia, 2020). Also a nearby taxi-stand to transport travelers, like tourist or business people from and to the hub might be an option to consider.

The Access/Egress Zone - Water side

This zone is not included in the diagram, as the study by Monzón et al. (2016) solely focuses on land transport hubs. As mentioned before, on-demand water transport is a form of shared mobility, so land models can also be used to add the water modes to the transport network. However, given the nature of waterborne modes, which occupy a separate space that is slightly more distant from land transport modalities, the waterborne modes are assigned a separate Access/ Egress zone. This zone focuses on the actions around departure and arrival by water mode. In general, the same essential safety requirements and basic user needs are required as for the land side for all water sides, but since there is a transition between land and water, there are also additional safety requirements. Fall hazards must be minimized and appropriate aids such as guardrails and walkways must be used for this purpose (Bruzzone, 2012; Lebkowski, 2018). Additional security staff could be used to safely manage larger passenger flows and serve as an additional source of information.

On-demand taxi services have no fixed schedule and usually operate 24/7. The service reliability and GPS tracking to locate the vehicle are considered some of the key elements of on-demand land transport (SANDAG, 2017). When considering on-demand water modes, the importance of service reliability and availability of real-time travel data (via app or at location) should also be examined.

In addition, it is important to determine whether it is necessary to maintain a water hub that is operational 24 hours a day, 7 days a week, or whether a schedule will be implemented that establishes the operational hours of a water hub for the Seabubbles. Conventional ferries typically operate between fixed operational hours during the day, with no activity at night. Access to the dock is usually closed to the public at night (Bruzzone, 2012).

The Transport/Transfer Zone

In the Transport/Transfer Zone users are waiting for the transport modes, so here it is important that the area is accessible and safe for everyone. This means that safe walkways, signage and camera surveillance, are necessary. Covered seating to protect people from the weather and availability of travel information of scheduled modes, such as public transportation or shuttles, are also necessary. This zone usually overlaps with the Access/Egress Zones and Facilities & Retail zone.

The Facilities and Retail Zone

In the facilities area additional services are offered to travelers that have some more time to spend at the hub. Just like in the other zones, it is important that the area is accessible and safe for everyone, with safe walkways, signage and camera surveillance. The desired amenities depend on the type of user that visit the hub and thus may vary from hub to hub.

If there are a lot of tourists or leisure travelers visiting the hub, real time travel data, tourist information and digital stands for buying (combi-) tickets & way-finding are desired (ComoUK, 2019). In addition, toilets and on-site facilities for leisure can be added, such as restaurants, cafes and/or retail. On the other hand, business and commuters have other desires. They might favor a kiosk to grab a quick refreshment or coffee or have access to free WIFI connection. Business people may also want to have on-site facilities for business (e.g., meeting room/work space). Needless to say, the more facilities that are added, the larger the hub becomes. The importance (and usually the size) of the hub can be represented by the number of facilities offered there.

Decision criteria

Each of the key areas on each mobility hub is bound by essential criteria to meet the safety requirements and basic needs of the end users. These decision criteria are equally important at all hubs and branded as essential decision criteria for this purpose.

Table 7 summarizes the essential decision criteria found for each key area.

Since these essential criteria are important for all mobility hubs they do not define the type of hub that is needed at a certain location, because they form the basis for the viability of each hub. However it is still important to mention these criteria in order to recognize them as a must have on all water hubs. In the scientific papers that were studied in the Literature Study in Chapter 2, most of these decision criteria were mentioned as well as being essential.

Table 7: Selection of essential decision criteria for water hubs – retrieved from the documents from Table 6.

	Essential decision criteria
Key area	
All zones (Access/Egress, Transport/Transfer and Facilities & Retail zones)	Well integrated in the surrounding environment
	Travel information
	Way-finding
	Disabled access, no blockages
	Lighting/ clear sightlines/ CCTV
	Frequent maintenance
	Covered seating (in case of waiting time)
	Modern & clean infrastructure
	Safe walking paths
	Easy flow of travelers
Access/Egress Water-Side zone	Safe transfers
	guardrails and walkways
Access/Egress Land-Side zone	Clear & uniform signage
	Information point/poster on what the hub is & where to find what
	Safe crossing pavements
	Safe cycling paths
	1 public transport link
	Access to a private or shared transfer mode co-located in primary zone (250m /2,5 min walking time)
	Safe transfers

On the other hand, the decision criteria that do differ in desirability level depending on the visitors visiting the hubs are listed in Table 8. These decision criteria are retrieved from the mobility hub guidelines by ComoUK (2019) and Metrolinx (2011). In the table the decision criteria are shown with explanation. The importance level of these decision criteria differs per hub type, which can be indicated as essential, desired, or not present. Since the importance levels of the criteria are not equal to each hub, they are suitable to select different hubs types based on the desirability of these decision criteria. For the Transportation/Transfer zone, the decision criteria are the same for all hubs and are included in the essential decision criteria in

Table 7. For this reason, this zone will not be included in the rest of the study, since the selection of water hub types is not dependent on this essential area.

Table 8: Selection of desirable decision criteria for water hubs (ComoUK, 2019).

Decision Criteria related to land side	**Explanation**
> 1 Public Transport link	Availability of at least 2 public transport links
>1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)	Availability of at least 2 shared mobility options that can only be returned back to the hub after use, i.e. bicycle rental.
>1 Shared mobility options **not** to be returned to hub (e-scooters, e-bikes, etc.)	Availability of at least 2 shared mobility options that don't have to be returned back to the hub after use but can be parked in another zone, i.e. Felix e-scooter
Shared mobility for business travel (shuttle buses)	Shuttle service that brings people from and to business areas
On-site Bicycle parking	Private bicycle parking within a maximum radius of 250 meters/2.5min walk
Car parking	Private car parking within a maximum radius of 250 meters/2.5m walking

	time.
Kiss +Ride	Ability for car users to drive very close to the hub to drop off travelers
Taxi stand	Taxi stand within a distance of maximum radius of 250 meters/2.5min walk
Decision Criteria related to water side	**Explanation**
Staff support	Availability of support staff for information and safety oversight
Flexibility in service (fixed/on-demand)	Possibility to deploy Seabubbles as fixed scheduled based rides next to on-demand services (This means that less bubbles are available for on-demand transport if scheduled bubbles are active).
Wide operational timeslots	The importance of offering a wide timeslot in which the transport modes operate, or even a 24/7 service
Decision Criteria related to Facilities & Retail Zone	**Explanation**
Tourist Information	The availability of tourist posters with information, direction signs, etc.
Real-time travel data	Boards with real time travel data of all scheduled modes (public transport) on the hub location. GPS tracking of the reserved Seabubble via an app or at the location
Digital stand for buying (combi-) tickets and way-finding	Stands to make a reservation for a Seabubble or buy tickets for public transport or other modes.
Toilets	Availability of on-site toilets.
Kiosk	Small eatery to offer information and small refreshments.
On-site activities for business (e.g. meeting hall)	Offer the possibility to make reservations for on-site meeting rooms or workspaces
On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)	Offer facilities that add to the user experience due to reduction of waiting times, such as restaurants and shops.
Wifi	Availability of a good free internet connection

Mobility hubs- hub types

Metrolinx (2011) has categorized urban areas and ComoUK (2019) uses similar areas to define fitting mobility hub types for these environments. The types of mobility hubs are distinguished from each other by the varying importance of the presence of the desired decision criteria, of which are listed in Table 8. In the guidelines, a distinction is made between six different hub types that can also be applied to define water hub types for Seabubbles, since they also have to deal with the same environmental contexts. In Table 9, for each of these hub types the main hub functions are presented (Metrolinx, 2011).

Table 9: Urban context, urban mobility hubs and transport function of the hubs (ComoUK, 2019; Metrolinx, 2011)

Urban context	**Mobility Hub type**	**Main function**
Central city	Large interchange - City Centre Mobility hubs	Interchange
Urban Transit Nodes	Medium Interchange- Transport Corridor/Linking hubs	Interchange
Emerging Urban Growth Centres	New housing development hubs/ Business parks	Entry/ Destination
Historic Suburban Town Centres	Village hubs/small market towns	Entry/ Destination
Suburban transit Nodes	Suburb hubs	Entry
Unique destinations	Tourism hubs	Destination

Waterborne transportation rarely provides door-to-door transportation because the total transportation route is divided into three parts: origin-shore, shore-shore, and shore-destination. Nevertheless, it is useful to classify the docks by entry, interchange, and destination, because based on the transport trajectory of travelers, the appropriate facilities can be offered at the right location. For example, at a location that is primarily used as a departure location to other places, it may be unnecessary to offer a wide range of station-based shared mobility options because people have to take care of their own travel from their origin and do so by their own bicycle, car, or public transportation. In these areas it would be very important that supporting parking facilities for private modes are present. In the following sections, each of the hub types will be described using the guidelines by Metrolinx (2011), ComoUK (2019) and Urban Design LA (2021) as a base. The mobility hubs are categorized based on the transport function they fulfill and practical examples are used to make the concepts tangible.

Interchange hubs

As shown in Table 9, the largest types of mobility hubs, large City Centre or medium Linking hubs are considered interchange nodes. These hubs are usually centrally located and handle a large volume of travelers daily. These interchange nodes are a major transfer point in the regional rapid transit network with interchanges between at least two rapid transit lines and/or other public transit services. These hubs often connect multiple operators. The design of such hub types should therefore mainly focus on seamless transition between modes of transportation.

Large interchanges handle large passenger volumes, as the hubs are usually located in high-density areas and multiple destinations can be reached from these hub types. High travel activity among travelers is caused by all transportation activities, i.e., starting or ending trips and transferring between modes. In centrally located areas, expansion opportunities for surrounding space may be limited, meaning that emphasis should be placed on sustainable, efficient modes of transportation and last-mile connections. Therefore, a high potential exist to offer various sustainable modes at the hubs to offer last-mile options. This includes shared mobility that is hub-bound, such as rental bikes, but also non-hub-bound shared mobility that does not require returning to the hub, such as e-scooters.

Usually there are on-site passages that provide a wide range of stores, eateries, supporting staff and other facilities to enhance the entire user experience and provide the traveler with the best possible service. An example of such large interchange hub is Amsterdam Central station in the Netherlands, see Figure 14. In this major hub, multiple transport modalities come together and a wide range of retail stores, eateries and other facilities are offered. On the landside of the station, metro, tram, bus, train, bicycle parking and shared mobility (bike rental, Greenwheel cars) are available. In addition, the transportation network for pedestrians and cyclists is also very well represented. At the water side of the station, a free ferry service is available that runs every 15-30 min, depending on the time of day. Since bicycles are allowed on the ferries, there is also additional bicycle parking offered at the water side. The taxi-stand and K+R locations are located as well at the sides of the water front.

Figure 14: Amsterdam Central station. Left: Land side of Amsterdam Central station, retrieved from www.nu.nl, 01/06/2021. Right: Map of Amsterdam Central Station, retrieved from: https://almeretours.com/amsterdam-centraal-station-map-guide/, 01/06/2021

wide variety of public transport options and facilities. Medium interchanges can also exist in the form of a network of mobility hubs. The main focus of medium interchanges is to link surrounding residents to core network services. Here as well, a high potential exist to offer various sustainable modes at the hubs for last-mile options. A good example of a medium interchange that is applied in the form of a network is mobil.punkt in the municipality of Bremen, Germany. Mobil.punkte are small stations in residential areas with 2-3 cars (Karbaumer, 2020).

Figure 15: mobil.punt in Bremen, Germany (Karbaumer, 2020)

The goal of the municipality is to grow the mobil.punkt network by 8-10 hubs each year, eventually reaching a maximum distance of 300 meters between two hubs to create a highly covered and connected network. This is important, since the cars can only be parked at a mobil.punkt station. Of the more than 40 nodes, there are about ten larger centralized nodes. The remaining hubs are smaller micro-hubs and serve as entry hubs (ComoUK, 2019). Each hub is strategically placed near public transportation hubs and bicycle parking is also provided.

Entry hubs:

Entry hubs are usually located within sub-urban areas with low-medium population density, where the car is typically a dominant mode of transportation. Entry hubs handle especially travelers during the morning peak. The travelers, mostly commuters, come to the hub via a first-mile option, such as car, bicycle, or on foot. Typically, these hubs are small micro-hubs with a link to public transport and available bike parking and P+R. Depending on the population density different amenities can be offered at the hub. However, additional retail and other facilities are usually not present because the user density is too low. At these hubs, it is important that accessibility is well researched so that everyone can visit/ leave the hub in a safe and practical way.

Suburban hubs are usually located on the outskirts of the city and are focused on providing good connections to public transportation for car drivers. These hubs have large parking lots and good public transportation connections that connect to city centers. There is also parking space for private bicycles, as the main function of the hub is to allow travelers to park their own means of transport so that they can continue their journey to their destination using a sustainable last-mile mode. On the city edge of Groningen, against a highway exit, lies the hub P+R Hoogkerk (Hub, 2021). This hub acts as an entry hub with the main function of providing car parking, so that travelers can continue their journey to the city center via various lines of public transport, a taxi or bicycle. The P+R offers parking space for 1,000 cars. At the hub, e-bikes and hub taxis are also available for last-mile transportation. The e-bikes can be used at a fee and must be returned to the P+R. The hub-taxis can be used at a reduced rate for transportation to and from the hub within a radius of 20km. Outside this range, normal taxi rates apply again. The hub also offers covered bicycle parking and bicycle lockers. An additional facility placed at the hub is a water tap.

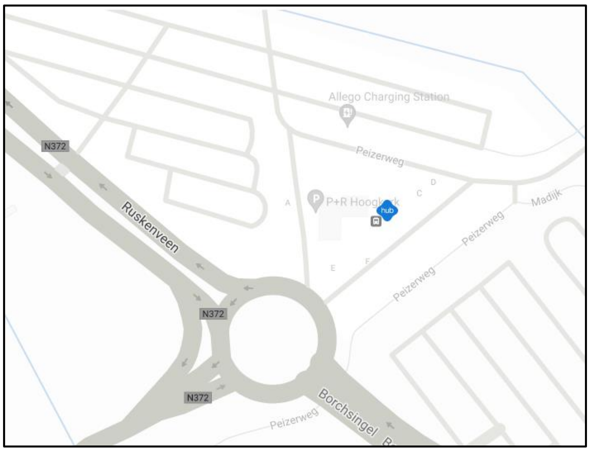

Figure 16: Hub P+R Hoogkerk, Groningen, the Netherlands (Hub, 2021)

Entry/Destination hubs

A hub that functions as both, an entry and destination, has both outbound and inbound traveler flows during peak hours. So in addition to local residents using the hub to get out of the area, there is also an incoming flow of people because there are certain activities offered in the area, such as businesses, markets, etc. Depending on the destination type additional amenities can be offered at the hub location. These hubs are usually larger than entry hubs, because they can process larger traveller flows. The private car ownership of users is also usually high, as the surrounding transport network is mainly designed for car traffic due to the somewhat remote location of the center cities.

New housing development hubs/ Business parks are located in emerging urban growth Centres. This usually involves areas that are still in the process of development and are often also located on the edges of center cities. However, due to the high activity levels, there is a high density of users. This also creates the need to offer commuter connections for outbound and inbound trips. These areas are also very car-oriented due to their location, so mobility hubs with parking options are also highly desirable. In addition, business parks may be located nearby, making shuttle services to and from mobility hubs desirable. At the hub location amenities related to surrounding activities can be offered, such as eateries and meeting halls.

Village hubs/small market towns are small urban areas with lower density of residents. However, there can be some local amenities, such as markets, shopping centers or other public buildings that can generate visitor flows. For these hubs, it is therefore important to offer sufficient possibilities for first-last mile options, including shared cars to also reach the more distant locations.

Mobipunt Leiespiegel Deinze is located in Belgium and is a village/market town hub (Deinze, 2018). The hub is surrounded by some local public buildings, such as a courthouse, city hall, library and theater, see Figure 17. There is also a market nearby. The hub is connected to public transport buses and is about one km from the nearest train station. The car-sharing system Cambio provides three on-site shared cars that can also be parked at the train station.

The hub itself also offers twelve on-site shared Blue-bikes that can be accessed 24 hours a day. There is also bicycle parking available for private bikes. Additional amenities offered are a bicycle pump and charging stations for electric cars.

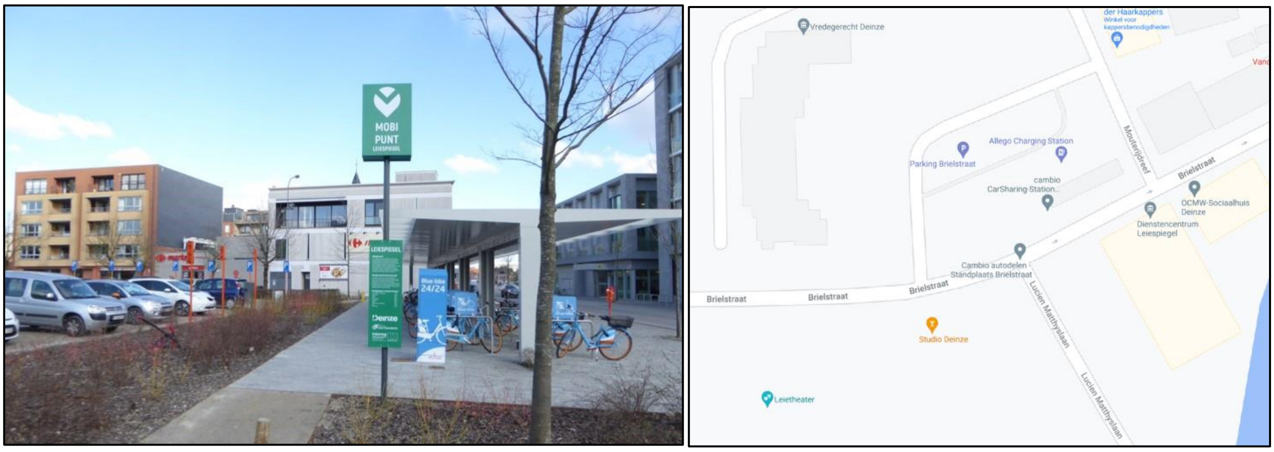

Figure 17: Left: Mobipunt Leiespiegel Deinze, Belgium (Meuleman, 2018), Right: Map of Mobipunt Leiespiegel Deinze, retrieved from https://www.google.com/maps, 05-06-2021.

Destination hubs

A node is considered a destination node if it is surrounded by a concentration of businesses, recreation and/or institutional uses. There are usually large numbers of inbound trips in the morning. These types of hubs also act as a front door for destinations that can be reached from the hubs, with lots of information and staff support to help visitors navigate through the hub and surrounding area. The focus lies on very good accessibility for pedestrians and cyclists, as these modes are used for the last-mile trips. In addition, these hubs are well connected with various shared mobility options and public transport modes. On the hubs additional facilities can be offered, such as toilets, eateries, retail shops etc.

Tourism hubs primarily serve tourists who visit the surrounding areas, usually on a seasonal basis. Tourist nodes are usually located in rural areas because of the nature of the recreational activities. However, they may also be located in high-density areas. Typical tourism hubs have airports, universities, or tourist attractions nearby. This means that a very good connection with public transport exists, which can include various bus lines, trams, metros, etc. Since large volumes of tourists can also arrive by bus or cars, there must be sufficient parking spaces available. In addition, since recreants have more time to spend on hubs, a wide variety of facilities can be offered on-site, such as toilets, (touristic) retail shops, eateries, drug stores, staff support etc.

A small tourist hub located in the Netherlands is the Hub Winschoten, see Figure 18. A P+R is available for commuters and tourist visitors. There is a very good connection to public transport with train or bus. A hub taxi service and a covered bicycle parking can also be found on-site. At this hub you can find walking routes for the area that has a rich history, but is also located in a very beautiful nature reserve. The additional facilities offered at the location are toilets, a kiosk, water taps and walking routes.

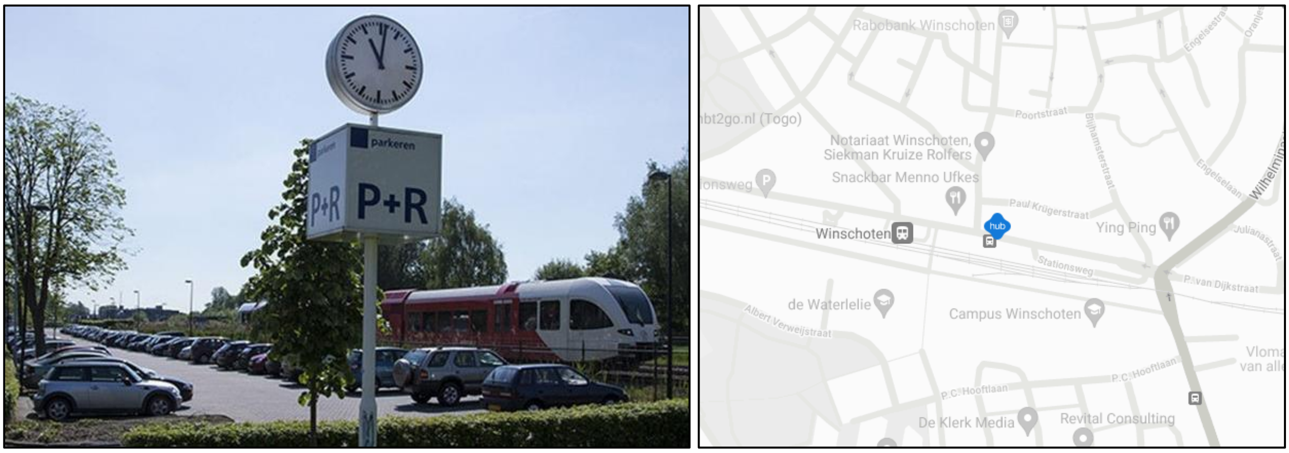

Figure 18: Hub Winschoten, the Netherlands (Hub, 2021)

4.2.5 Conclusion Technical feasibility

In this section the technical feasibility of the potential multi-modal water hubs is investigated using the mobility hub concept. By doing so the third and fourth research sub-questions could be addressed. This involved using relevant sources to determine relevant decision criteria for potential water hubs. In addition, it was also intended to reduce the large number of different types of water hubs to a manageable number so that later in the study a ranking could take place to determine the best fitting dock for the case study.

Mobility hubs can become connected socio-economic hubs of the village, neighborhood or region where they are located, if successfully implemented. A mobility hub includes not only the location itself, but also all services and destinations that can be reached within 5 minutes, depending on which mode of transportation is used.

Each multi-modal hub can be divided into three key areas and based on the needs of the travelers that visit the hubs, decision criteria can be linked to each of these zones. The key areas that are identified are as follows: Access/Egress Zone, Transport/Transfer Zone and the Facilities & Retail Zone.

For the multi-modal water hubs the Access/Egress Zone Land side zone, Access/Egress Zone Water side zone and the Facilities & Retail Zone are relevant, because desirable decision criteria can be assigned to these zones that make it easier to differentiate between water hubs.

Each of the key areas on each mobility hub is bound by essential criteria to meet the safety requirements and basic needs of the end users. These decision criteria are equally important at all hubs and branded as essential decision criteria for this purpose. Since these essential criteria are important for all mobility hubs they do not define the type of hub that is needed at a certain location, because they form the basis for the viability of each hub.

In contrast, 19 technical feasible decision criteria could be identified in this Chapter whose degree of desirability varies depending on the urban location and type of visitors visiting the hubs. The importance level of these decision criteria differs per hub type, which can be indicated as optional, recommended, or vital.

The identified decision criteria are distributed as follows: 8 criteria for the Access/Egress Land side zone, 3 criteria for the Access/Egress Water side zone and 8 criteria for the Facilities & Retail zone.

The next step was to reduce down the amount of possible water hubs and determine multi-modal hub types that could also be implemented as water hubs. The mobility hub guidelines by (ComoUK, 2019) distinguish between six different types of mobility hubs based on the urban context in which they are located. These mobility hub concepts can also be applied to define social and technical feasible potential water hub typologies for Seabubbles. In this mobility hub concept, Seabubbles are a form of on-demand transport modes that can also be implemented in a multi-modal urban environment.

The six potential multi-modal water hubs that could be identified and are in line with this study are as follows:

- Large interchange - City Centre Mobility hubs
- Medium Interchange- Transport Corridor/Linking hubs
- New housing development hubs/ Business parks
- Village hubs/small market towns
- Suburb hubs
- Tourism hubs

The six types of mobility hubs can be distinguished from each other because they place a different importance on each of the 19 decision criteria that were identified earlier. These social and technical feasible decision criteria and the six hub types are the key results from the desk research and will be used in the next Chapters to continue with answering the main research question.

5 CASE STUDY: MULTI-MODAL WATER HUBS FOR SEABUBBLES IN THE DRECHTSTEDEN REGION

From the desk research in the previous chapter, a good image could be created of which decision criteria and hub typologies are desired in which urban areas, using the mobility hub concept. However, this approach was mainly land transport oriented and not sufficiently applicable to the deployment of on-demand Seabubbles, as the water side was not highlighted enough. In order to provide the deployment of Seabubbles with some more context, it is therefore important to introduce a case study, where some additional decision criteria on the water side might emerge. By conducting interviews with water transport experts, business interests and local and regional decision makers, decision criteria could be determined for water hubs that can facilitate on-demand Seabubbles that could not be derived from the desk research.

The Drechtsteden region is already looking to introduce a small water transport service and has its eye on a 'first' potential water hub location in Alblasserdam. A case study for a multi-modal hub in Alblasserdam was deemed well suited for this research, as innovative concepts are encouraged by the region and on-demand hydrogen Seabubbles fit into their way of thinking.

5.1 Seabubbles in the Drechtsteden Region

The Drechtsteden region is encouraging the development of sustainable and innovative water transport services in order to become future-proof so that next generations are not disadvantaged (De Drechtsteden, 2020). The Drechtsteden consist of a cluster of cities that are located at the coastline of rivers. The cities that are part of the Drechtsteden region are shown in Figure 19.

Figure 19: Cities that are part of the Drechtsteden Region (excl. Hardinx-veld-Giessendam, (Plaatsengids.nl, 2018).

As this figure shows, the cities within the Drechtsteden region are located very close to each other, but are separated by rivers. The three main roads, the two highways (A15 & A16) and the national road (N3) connect the Drechtsteden from the outer edges of the cities. These highways are also transit routes for trucks between the Port of Rotterdam and hubs in Germany (eastbound) and Belgium (southbound). This makes these highways one of the busiest transportation bottlenecks in the Netherlands. Travel time can add up quickly if people decide to travel by car from one location to another within the Drechtsteden region.

Another problem facing the Drechtsteden is that these highways are scheduled to undergo major and lengthy maintenance in the coming years. This will create an enormous connectivity problem for the whole area if there is no solution to reroute the current traffic. The Drechtsteden are therefore looking for alternative transportation options to increase accessibility within the region. The most ideal solution would be to avoid the construction of other roads and expand the water transit network (De Drechtsteden, 2020). However, the areas are not densely populated enough to be served by larger vessels, such as the Waterbus (Aquabus B.V.). The Waterbus now calls at a few points in the Drechtsteden area (See Figure 20), but it usually involves only one stop per town and it does not sail frequently enough to serve all travel demand. Demand outside the current sailing schedule is too scattered to increase frequency for such large vessels.

The fluctuating demand for transportation has resulted in the Waterbus operating a direct service to the tourist attraction Kinderdijk only during the peak tourist period of July 19 through August 30 (Waterbus, 2020). During the winter months, it is not possible to sail directly to Kinderdijk with the Waterbus. Therefore, a smaller ferry service, de Driehoeksveer, has taken on the task of connecting Kinderdijk with two other boarding points, Krimpen a/d Lek and Ridderdijk (De Schans). This solution is still not ideal, as the Driehoeksveer only operates within this triangle area and transfers are required to reach one of the other water stops. In addition, the Driehoeksveer also operates on a fixed schedule and therefore also has to deal with not being able to respond to fluctuating demand.

Figure 20: Waterbus and Driehoeksveer stops in the Drechtsteden region (Waterbus, 2020)

It is expected the region that the use of supportive small-scale on-demand water transport will provide a better match to the fluctuating demand in the region, so that increased accessibility can be achieved.

The deployment of on-demand Seabubbles in the region can support the thick water lines that are now inflexible due to their robust nature caused by the large vessels, lower frequency rates, amount of stops, etc. In addition, these vessels run on fossil fuels, making them an unsustainable choice for frequent use compared to the hydrogen-powered Seabubbles.

5.2 Water hub location in Alblasserdam

One area that could be part of a potential network of water hubs for the Seabubbles is located in Alblasserdam. The municipality of Alblasserdam has its eye set on a location in the 'Het Nieuwland' industrial park, where a water hub for a water transit service could possibly be built. The area is located near the tourist attraction Kinderdijk. Mill Park Kinderdijk is a tourist attraction, which has been on the UNESCO World Heritage list since 1997 (Kinderdijk, 2020). The mills and farmland are increasingly visited by tourists and the area has reached an amount of around 700 thousand visitors in 2018.

The potential location for the dock is now a wasteland that belonged to a former metal yard, Nedstaal. The municipality plans to restructure and develop this site into an area where education and sustainable initiatives are widely represented.

Besides tourists, the area is also pressured by commuter traffic that visits the industry area from outside the city. Due to this overcrowding, Alblasserdam is faced with increasing congestion and parking problems. The water hub should therefore provide water-taxi transport to Kinderdijk, other touristic hotspots and the waterfront businesses in the industrial areas. Besides it has to be connected well to the land transport network.

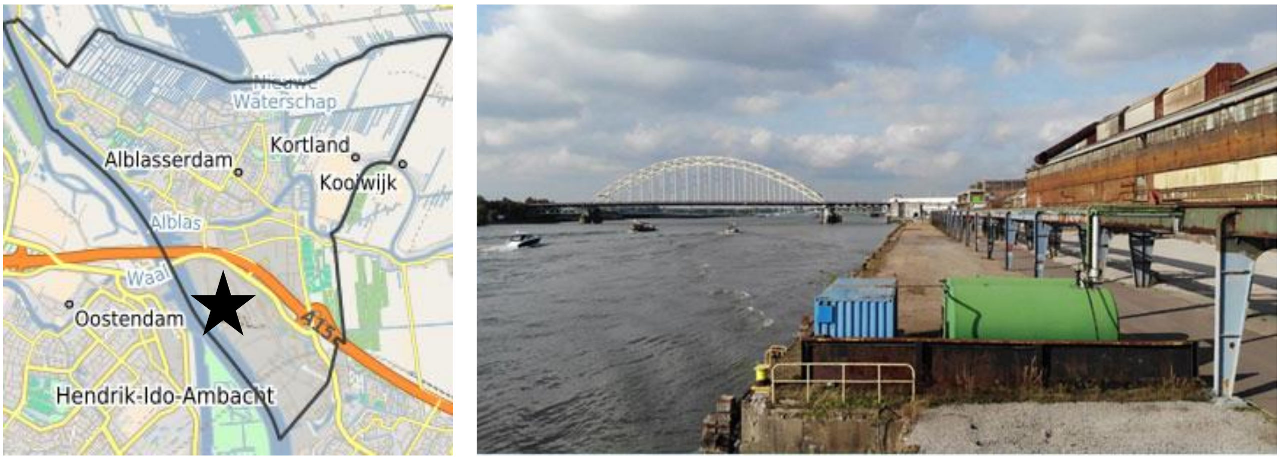

Figure 21: Left: Star indicates potential location for a water hub in Alblasserdam (map is derived from Planviewer.nl (2021)); Right: Wasteland with remains of metal yard Nedstaal (Alblasserdam.net, 2018)

The municipality of Alblasserdam wants to significantly increase the urban accessibility and connectivity of the city within the Drechtsteden region by including more water transit services in the transportation plans (Alblasserdam, 2019). Alblasserdam is part of a heritage line that connects multiple monumental spots with one common historical story, the Water Triangle. The Water Triangle consists of the heritage sites: Mill Park Kinderdijk, the historic city of Dordrecht and landscape Biesbosch (see Figure 22).

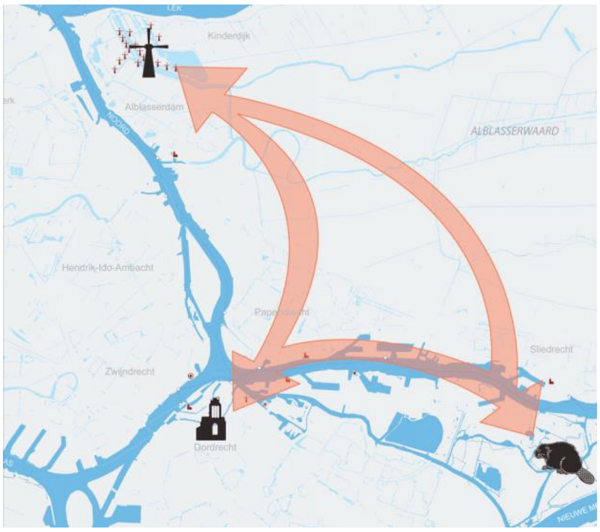

Figure 22: Heritage line, the Water Triangle in the Drechtsteden Region (Alblasserdam, 2019)

In this, Alblasserdam forms the gateway to Kinderdijk. The Water Triangle heritage line is of great importance within the development plans of Alblasserdam, because it gives quality to the space and offers great recreational and tourist opportunities. One of the plans is therefore to invest in the expansion of the water transport network to connect these three heritage sites with each other. Waterborne transportation contributes to the user experience of recreationists, which is expected to have a positive effect on recreational opportunities in the Drechtsteden region.

The case study will run like a thread through the rest of this research, providing tangible context where necessary. Following the theoretical underpinnings of feasible hubs and decision criteria from the previous chapter, Chapter 6 will take a closer look at the case study by discussing the results of interviews with relevant actors from the Drechtsteden region on how they envision the implementation of Seabubbles. The interviewees are also asked to evaluate decision criteria in order to select a feasible dock for the potential hub in Alblasserdam so that the case study can act as an example for future practice. The case study will supplement this research with insights, so that a general approach can be reached to select feasible water hubs for regions where on-demand Seabubbles or other small sustainable water-modes are deployed.

6 CASE STUDY: INTERVIEW RESULTS

In addition to the Desk research from Chapter 4, interviews were held with the actors as presented in the Political Economy Model, being 3 Experts, 4 Industry interests and 4 Non-business interests. The interviews were held from the perspective of potentially introducing Seabubbles at a potential location in Alblasserdam and then expanding this to the rest of the Drechtsteden, such as explained in Chapter 5. During these interviews some insights came up that were not evident from the theoretical research. Almost all interviewees preferred to remain anonymous, because they did not want to be associated with speaking out too positively about the Seabubble, which could potentially falsely send out the wrong message that they prefer Seabubbles over other companies. Therefore, for this study, it was decided not to publish the names of the interviewees. The main findings of the interviews will be discussed in general in this chapter in order to answer the fifth research sub-question, which concerns what decision criteria should be used to distinguish between potential multi-modal hub types for Seabubbles.

6.1 Interview Set-up

The aim of the interviews was twofold. The first objective was to see if the interviewees would mention some of the decision criteria that had emerged from the desk research without the interviewer pointing them out. This was necessary to determine the relevance and validity of the found decision criteria for the case study. The second objective was to come up with additional important decision criteria for the key areas that could not be derived from the theoretical studies and link them to potential water hubs using a heuristic scoring approach. The scoring of the hubs takes place in the next chapter.

To meet both objectives, semi-constructed interviews were conducted in which interviewees were asked a number of questions to scope down the study topic, but otherwise they were free to provide their own interpretation and important decision criteria. All interviewees where asked the same questions:

1. How feasible do you think that the deployment of on-demand hydrogen Seabubbles is?
2. Where do the opportunities and where do the challenges lie for water hubs for on-demand hydrogen-powered water-taxis?
3. What land connections are important for the successful deployment of on-demand water-taxis?
4. Do you have any other remarks that are important to take into account?

Each interview lasted approximately 30-45 minutes. From the interviews it appeared that people from the same organizations shared similar preferences and concerns. Therefore, the interview results were classified at the organizational level rather than the individual level, see Table 10.

Table 10: Categorization of interviewees

	# of interviewees	Organization	Category
Experts	1	Aquabus B.V.	EXP_A
	2	Port of Rotterdam	EXP_B
Industry Interests	2	Advier	IND_A
	2	Economic Development Board	IND_B

Non-Business Interests	1	Drechtsteden Region	NBI_A
	3	Municipality of Alblasserdam	NBI_B

For all interviewees, the most important "take-aways" for each actor type are discussed. At the bottom, the decision criteria that were mentioned during the interviews are presented. As indicated earlier, the purpose of the interviews is to collect decision criteria that can be used to compare with those already found in the desk research, in order to validate them for relevance. The other goal is to come up with additional decision criteria.

6.2 Experts

From all interviewees, the experts have the most experience when it comes to using water modes as a means of transportation. All interviewed experts were highly concerned with safety issues. Especially both experts from the Port of Rotterdam, EXP_B, could not emphasize enough the need for very thorough research of the volume of traffic on the river waterways and how other vessels will experience the presence of Seabubbles. Incidents involving waterborne transportation are usually of greater magnitude and also have a greater impact on society than incidents involving land modes.

On top of that, one of the EXP_B stated that hydrogen is a hugely sensitive topic, as implementation in transport modes is still in its infancy. Careful consideration should be given to whether a charging point near a passenger boarding point is necessary, in order to minimize risks as much as possible. Besides, if dock sharing with other water transport modes will be considered, good agreements must also be made about this to avoid miscommunication and incidents.

Another point that was raised by all experts concerned the travel time and travel costs. In order to be able to compete effectively with other modes of transportation such as the car, a seamless connection to other land transport modes is critical to the success of deployment of on-demand Seabubbles. The Waterbus expert, EXP_A, particularly emphasized a good connection with public transportation, shared mobility, bicycles and car parking. Since water modes only travel from shore to shore, it is important that first and last mile transport options are available. The scheduled Waterbus service experiences the same in this sense. The Waterbus has the advantages over Seabubbles that it is cheaper and travelers can bring their own bikes on board. However, if the water-taxi service can serve demand where thick water transport lines, such as the Waterbus cannot dock, and if it is well integrated in the land transport network, there is a good chance that people will value the experience more than the price of the ticket. Therefore, the operational reliability of the water taxi service has to be very high.

The EXP_A also indicated that a thorough research of the customer journey should be conducted for each individual hub location and based on that, facilities should be selected for the hubs. The EXP_B indicated that on-site facilities are likely to be of interest only if the main visitors are leisure-oriented or tourists. If people can make a reservation for on-demand transportation, waiting time is almost eliminated and people have no reason to stay longer at a hub.

Table 11: Decision criteria derived from interviews with Experts (*= Criteria that were not derived from theoretical desk research)

Expert	Water side zone	Land side zone	Facilities zone
Exp_A	Operational reliability*	Bicycle parking	
	Wide operational timeslots	Public transport	

	On-site hydrogen bunkering *	Shared mobility	
	On-demand access to waiting area*	P+R/ car parking	
	Dock sharing with other water transport* modes		
Exp_B	Flexibility in service (scheduled/on-demand)*	Business travel	Tourist information
	On-site hydrogen bunkering *	Bicycle parking	On-site activities for leisure
	Dock sharing with other water transport* modes	Public transport	
		Car parking	
		Shared mobility	

All the main decision criteria that the experts came up during the interviews are shown in Table 11 per expert category. As shown in the table, the experts came up with some waterfront decision criteria that could not be derived from the theoretical research. However, the decision criteria mentioned in the other key areas, namely the landside and the facility & retail zone, have already been mentioned, so this is an indication that the decision criteria from the mobility hub concept in these areas are valid for the case study.

6.3 Industry Interests

Industry interests are driving the adoption of innovative sustainable transport solutions.

According to both, the IND_A and IND_B interviewees, for regions with increasing accessibility problems, waterborne transport can certainly offer a solution to address congestion and accessibility problems. The expansion of passenger transport by water should therefore be seen by governments primarily as a major step forward in increasing the accessibility of areas that are currently separated by rivers. A sustainable on-demand Seabubble could offer a solution here. If you look at the Drechtsteden region you see that the areas are now poorly accessible and that the surrounding traffic on the A15 and A16 is sometimes completely stuck. The presence of flexible on-demand Seabubbles that can take business people and tourists from one shore to the other, from where they can continue to their final destination by bicycle or shared mobility options, is certainly desired.

IND_A states that a comfortable Seabubble that sails tourists from one tourist attraction to another brings a completely different user experience than a car trip. Recreationists and tourists are willing to pay for an extra piece of experience, while business people are willing to pay for time savings. Therefore, especially in the beginning when introducing the Seabubbles, these target groups should be targeted and associated facilities should be offered on the water hubs. In this case, it is interesting to make a hotspot out of central touristic/business water hubs by offering enough seats, eateries, stores, tourist information points, meeting rooms , Wi-Fi etc.,. The presence of a transferium where these target groups can park their cars is also very important. The governmental bodies are now thinking mainly in terms of such a transferium and water transport, like Seabubbles, must support this concept.

According to IND_B not all hubs need to be equipped with extensive facilities, but at some centrally located stops with a high flow of travelers, this becomes very interesting. It is therefore very important to look at the environmental context and passenger origins and destinations when determining the type of water hub. In addition, only when there are enough water hubs and it is proven that the Seabubbles are a good addition to the broader transport network, it is feasible that the concept will catch on with other target groups.

For IND_A, the aim is for passengers to be able to embark and disembark at a quay wherever they wish by using a GPS system that displays the exact location of the passenger and Seabubble in real time, as is the case with an Uber. In this way, maximum flexibility is achieved and it is the closest thing to the concept of on-demand taxi-transport, where passengers are transported from door-to-door.

IND_B indicated that if the Seabubbles are going to run on hydrogen, charging points for hydrogen need to be looked at carefully. Hydrogen technologies are still in the development phase, and the projects that are running in passenger transport mostly serve as pilots. Both IND_A and IND_B state that it is desirable that the Seabubbles can refuel while passengers are boarding. In addition, it is not necessary to have a charging station at each stop, as a Seabubble running on hydrogen has a sailing time of about two hours. Refueling hydrogen in a Seabubble takes only 4 minutes, while an electric alternative would take 40 minutes. However, by offering on-site refueling of hydrogen, the operators will have to deal with a lot of regulations as well.

According to the IND_B interviewees, travelers should also be able to have immediate access to the land transport network, in the form of private transportation, rental, or shared transportation in the nearby area of a water mode. The quality and connection to the surrounding transport network can determine the success of the Seabubbles. Also according to IND_B , the outgoing journey can still be planned well, because use can be made of e.g. one's own bicycle, car (including Kiss & Ride). However, a Seabubble takes you from shore to shore. The journey usually does not end here, so there must be public transport connections, shared bicycles, rental bicycles, e-bikes, etc., available for the traveler to cover his last mile. IND_A also suggest transforming the water hubs into a Mobipunt. At a Mobipoint, different shared mobility options are offered, such as shared bicycles and cars and this can also be extended to other transport options. It is very important that the surrounding area has a very good bicycle network and people can park their private bikes as well.

It would also be desirable if travelers could book a combination ticket for the entire trip, for example a parking space, a trip with Seabubble and a reservation for a shared bicycle. This adds to the travelers' experience because they are taken care of and do not need to arrange transportation at a water hub.

For IND_A, it is also important to look to the future. Public transportation as we know it today is expected to slowly give way to on-demand autonomous transportation. Public transport will remain only on the long distances. The Seabubble will now initially be used primarily for on-demand taxi-transport for the recreational or business passenger because of the ticket prices. For daily commuting it may still be too expensive. The next step is to introduce autonomous Seabubbles, where you no longer need a captain and thus can save costs. In this way, the Seabubble could become accessible to everyone, regardless of the purpose of the trip. By already taking this possibility into account when developing the hubs, the concept can be introduced earlier.

Table 12: Decision criteria derived from interviews with Industry Interests (*= Criteria that were not derived from theoretical desk research)

Industry Interest	Water side zone	Land side zone	Facilities zone
IND_A	Operational reliability*	Bicycle parking	Real-time travel data
	Wide operational timeslots	Public transport	On-site activities for leisure
	On-site hydrogen bunkering *	Shared mobility	On-site activities for business
	On-demand access to waiting area*	P+R/ car parking	Tourist information
	Dock sharing with other water transport* modes	Kiss & Ride	Wi-Fi
	Prepare dock for autonomous sailing		Digital stand for buying (combi-) tickets and way-finding
IND_B	On-site hydrogen bunkering *	Business travel	Tourist information
	Dock sharing with other water transport* modes	Bicycle parking	On-site activities for leisure
	Operational reliability*	Public transport	Digital stand for buying (combi-) tickets and way-finding
		Car parking	
		Shared mobility	
		Rental (returning to hub) mobility	

6.4 Non-Business Interests

The Non-Business Interests are all part of the Drechtsteden region, as the municipality of Alblasserdam is located in the Drechtsteden region. However, to distinguish between the views of the municipality and the region, an alderman from another municipality (Sliedrecht), NBI_A, was asked to participate in this study as well.

The interview with the respondents from the municipality of Alblasserdam, NBI_B, took place at the same time and since they shared the same motives, there was not really a different view among the respondents on the discussed points during the interview.

One of the most important drives for NBI_B to consider sustainable hydrogen water modes was to put Alblasserdam better on the map. The case study area is going to be restructured and developed in the spirit of sustainable initiatives and education. The implementation of innovative sustainable forms of waterborne transportation to visit Kinderdijk and other tourist attractions throughout the Drechtsteden region would be a good fit for their motives. Innovative water modes such as on-demand hydrogen Seabubbles would add to the city branding of Alblasserdam and all the other towns in the Drechtsteden region.

The main challenge for the NBI_B is to make the public transport route to Kinderdijk more attractive compared to car transport. For example, visitors can visit the region by Waterbus and then transfer to a Seabubble to visit Kinderdijk. However, in addition to the experience aspect, travel time will also play an important role here. It is therefore expected that the main mode of transportation to the region will still remain the car. The idea is to build a large car transferium next to the case study site where people can park their cars and transfer to Seabubbles or other modes, such as electric shuttle buses and bicycles to explore the area and the windmills in Kinderdijk. The NBI_B also state very clearly that shared mobility that does not need to be returned to the hub will not work in the area. The system should really be a rental system that offers transportation modes that must be returned to the rental location.

The NBI_B also feels like that if there is space available, hospitality facilities for tourists should be offered. However, the need must be properly explored, because once a water hub is in place it is challenging to add amenities later.

According to NBI_A, the status of car ownership is disappearing, leading to more efficient use of the available modes of transport. If a water taxi is used, short distances can be covered more efficiently and quickly, making the car unattractive because it takes longer. This is especially interesting for business people, since they value time more. However, the water service should be very reliable. The new post-corona working will also stimulate the use of shared mobility more. If the hub at the case study location has a strategic central location, where everyone has about the same travel time, then multiple target groups can be served from here: tourists, business market, etc. For such hubs it is very interesting to offer eateries, business meeting rooms, stores and other facilities. In other cases, facilities are not needed because with on-demand transportation, the need to wait at a hub for transport disappears.

The NBI_A stated that the following facilities can be facilitated by the municipality: bicycle parking, (e-) car parking, shared mobility, hydrogen filling stations and connections to public transport.

In the table below, the decision criteria are indicated that emerged from the interviews with the Non-business Interests

Table 13: Decision criteria derived from interviews with Non-Business Interests (*= Criteria that were not derived from theoretical desk research)

Non-Business Interest	**Water side zone**	**Land side zone**	**Facilities zone**
NBI_A	Operational reliability*	P+R/ car parking	On-site activities for leisure
	On-site hydrogen bunkering*	Public transport	On-site activities for business
		Shared mobility	Tourist information
		Bicycle parking	
		Taxi	
		Business travel	
NBI_B	Dock sharing with other water transport* modes	car parking	On-site activities for leisure
		Shared mobility	
		Public transport	
		Bicycle parking	

6.5 Conclusion Interviews

The interviews revealed that Seabubbles will initially serve primarily a recreational, touristic and/or business community, and that the water hubs need to be aligned with this. Another important point that came up in a general sense is that the water hubs need to be really well integrated into the surrounding (land) transportation network in order to be implemented successful.

The purpose of these interviews was to find out if there was some kind of overlap with the decision criteria from the desk research to determine relevance. In addition, it was also intended to possibly come up with new decision criteria for the Access/Egress Water side Zone in particular. An overview of all decision criteria, including additional found criteria are shown in Table 14. Of each category of actors examined, it was also indicated whether the decision criteria were mentioned or somehow described during the interview.

Table 14: Summary of all reported decision criteria by surveyed category.

	Decision Criteria for the case study area	**EXP_A**	**EXP_B**	**IND_A**	**IND_B**	**NBI_A**	**NBI_B**
Key area							
Access/Egress Land side zone	> 1 Public Transport link	x	x	x	x	x	x
	>1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)	x	x	x	x	x	x
	>1 Shared mobility options **not** to be returned to hub (e-scooters, e-bikes, etc.)	x	x	x	x		x
	Shared mobility for business travel (shuttle buses)		x		x		x
	On-site Bicycle parking	x	x	x	x	x	x
	Car parking	x	x	x	x	x	x
	Kiss +Ride			x			
	Taxi stand					x	
Access/Egress Water Side zone	Staff support						
	Operational reliability	x		x	x	x	
	Wide operational timeslots	x		x			
	Allow on-site bunkering to decrease waiting times	x	x	x	x		
	Flexibility in service (fixed/on-demand)		x				
	On-demand access to waiting area (e.g. via app)	x		x			
	Prepared dock for future autonomous sailing			x			
	Dock sharing with other water transport modes	x	x	x	x	x	
Facilities & Retail zone	Tourist Information		x	x	x		
	Real-time travel data			x			
	Digital stand for buying (combi-) tickets and way-finding			x	x		
	Toilets						
	Kiosk			x			
	On-site activities for business (e.g. meeting hall)			x			x
	On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)		x	x	x		x
	Wifi			x			

As shown in the table, a set of five (bolded) additional decision criteria were found for the waterfront. There was also overlap in mentioning these decision criteria among the interviewees, making them even more relevant to the case study.

When looking at the interviews with the Experts, they have especially emphasized the safety risks that the adoption of Seabubbles could possibly entail.

However, they came up with a significant amount of decision criteria that overlapped with the desk research and in addition they also mentioned four additional decision criteria for the waterfront that had not yet been mentioned in the desk research. The experts, especially the Waterbus experts, mainly focused on the technical necessities on the landside and waterside during the interview. There was no real focus on Facilities and Retail zone, as they feel that should be determined for each individual location based on a customer research.

Compared to the other parties interviewed, the Industry Interests, both Advier and the Economic Development Board, came with a lot of information and decision criteria and were very knowledgeable about possible concepts for the water hubs and how they can be future-proofed.

The non-business interests have approached this study primarily from the perspective of the road traveler, the car owner. The municipality has made it very clear that there will be a large parking lot at the case site and that water modes such as the Seabubble will supplement this facility, as will other road modes such as rental bikes and public transportation. This is reflected in the table, as they have mainly concentrated on mentioning decision criteria related to the land side of the water hub.

It can be concluded that both objectives of the interviews were achieved. From all decision criteria found in the desk research only two criteria, Toilets and Kiosk, were not mentioned at all by the interviewees. However, if someone is talking about on-site amenities for the Facilities & Retail zone, this probably automatically includes these criteria. Perhaps that is why they are not specifically mentioned, because interviewees may automatically assume that if there is a restaurant at a hub, for example, there will be restrooms.

The research also resulted in five additional decision criteria. This brings the number of decision criteria that can be used in the evaluation method in the next chapter to 24 criteria.

7 CASE STUDY: BWM METHOD

This chapter aims to determine what type of multi-modal water hub would potentially be the best fit for implementing on-demand Seabubbles for the case study. By doing so, the last research sub-question can be answered.

To determine what potential water hub is most feasible for the case study in Alblasserdam, a description of the case study and the decision criteria that were determined in the previous chapters where presented in a survey (see Appendix B) for a pairwise comparison to the interviewees from the previous chapter. However, only two surveys came back from the experts; two from the Industry Interest and one from the Non-Business Interests. Of these surveys, two were unusable because they were not completely filled out by the participants and, unfortunately, there were no further responses to requests for full completion.

Before the surveys were processed, the six multi-modal water hubs had to be scored on each of the 24 decision criteria, using the desk research and interviews as sources. The scored hubs were used in the BWM model to distinguish between them. The pairwise comparisons that came out of the surveys were further processed in the BWM solver that resulted in a ranking of potential multi-modal water hub types for the case study.

The steps that are taken to perform the BWM method are following the methodological approach described in Section 3.3 of Chapter 3.

7.1 Scoring of multi-modal water hubs

The desk research and interviews resulted in a set of 24 potential decision criteria that can be used to differentiate between the potential six water hub types for Seabubbles for the Alblasserdam case study. In order to determine the importance levels of the decision criteria for each water hub type, the hubs needed first be scored on each of these decision criteria. The scoring is based mainly on the guidelines as proposed in Table 6 and some of the real cases used in the previous section.

Only the guidelines by ComoUK (2019) and Urban Design LA (2021) show specifically what decision criteria are necessary and which ones are desirable for specific mobility hub types. The other guidelines, such as by Metrolinx (2011), see Appendix A, Part II, don't specifically assign decision criteria to mobility hub types, but they rather explain the importance and advantages of each element for the hubs.

The guidelines unfortunately do not cover all decision criteria, especially those that are part of the Access/Egress Water side zone. If the research sources could not be used, because the decision criteria were derived from the interviews, a heuristic approach was used to come to analytical scoring using the interviews as a starting point. Therefore for this research, a combination of derived scoring and estimated scoring based on analytical thinking is used.

The Guidelines by Urban Design LA (2021), see part I of Appendix A differentiate between three different hub types, where decision criteria are assigned to as Optional, Recommended or Vital. The hub types are differentiated based on the urban context they are situated in, being Neighborhood, central or Regional. The hubs are scored on 19 decision criteria, but unfortunately they are not all the same criteria as used in this research.

The Guidelines by ComoUK (2019), see Appendix A, Part III, differentiate between six hub types and consider more than 40 essential and desirable decision criteria. For each hub type it is indicated what element is essential or desirable. They also approach the mobility hub concept from the perspective that the more criteria are allocated to a hub, the more it contributes to the visitors' experience.

Within this study, the guidelines by ComoUK (2019) are leading for scoring the hubs on each of the decision criteria, since the same mobility hub types are used for the case study and some of the criteria are already allocated as essential or desirable. Besides, these guidelines were made for general use, while the guidelines from Metrolinx (2011) and Urban Design LA (2021) where initially intended to provide guidance for specific regions in the USA. The guidelines by ComoUK (2019) have been widely implemented and are created as part of the EU Interreg North Sea Region "SHARE-North" project to provide mobility designers, e.g. city and regional authorities, with guiding tools for designing mobility hubs from concept to reality. These guidelines aim for efficient use of space by integrating public and (on-demand) shared transport into mobility hub designs. Although the focus of the guidelines for the mobility hubs lies mainly on multi-modal land transport, the hub typologies can easily be applied to water hubs as well, since the multi-modal mobility concept remains the same.

For the scoring system, a combination of the approaches of Urban Design LA (2021) and ComoUK (2019) is used. If a decision criterion is considered essential for a hub type it receives the highest score Vital (score=3). If the decision criterion is considered desirable, it receives the score Recommended (score=2). If a criterion is not mentioned or considered optional it receives the score Optional (score=1).

Although the mobility hub guidelines by ComoUK (2019) are leading for the scoring of the hub types on the decision criteria, some of the decision criteria are not covered. This is especially the case for the Access/Egress Water side zone. In these cases the interviews are used in combination with analytical thinking to score the hubs in a heuristic approach. The hubs are scored based on their transport function rather than each individual type to limit down the estimations. If hubs are a combination of two transportation functions, the average score between the two is used, but if the average has decimal points, the lowest score is given.

7.1.1 Scoring Access/Egress Land side zone

The mobility guidelines by ComoUK (2019) state that it is essential for all hub types to have: 1 public transport link, 1 shared mobility link and cycle parking. However, since we are interested in differentiating between hubs, we are going to look at hubs where more than 2 public transport links and shared mobility options are required. Therefore other mobility guidelines are consulted to score these decision criteria.

> 1 Public Transport link

Metrolinx (2011) classified the hubs by transportation function. Section 4.2 shows which hubs fall under which section. In Appendix A, Part II, it can be found that the Destination and Interchange functions must have >1 connections to public transport, so score=3. For the Entry function nothing is said about this, so it gets the score 1. Hubs that have a combined Destination/Entry function receive the average score of 2.

> 1 Shared mobility options to be returned to hub

There has not been really a guideline on this decision criterion in the mobility hub guidelines. Therefore, the real case studies from section 4.2 are consulted to see if the investigated hubs offer more than 1 shared mobility options. In the interchange Amsterdam

Centraal a large amount of OV-Fietsen, rental bicycles are offered, so the score=3 for interchanges. For a destination location such as a tourist hub, it is important that last mile options are available. Since visitors are expected to return to the hub at some point, it may be convenient to add more than one rental shared mobility options to the hub, such as rental bicycles, so score=3.

Entry hubs have a low-medium population density, where the car is typically a dominant mode of transportation. So visitors can visit the hub with their own modes of transport, so it is not necessary to have more than one shared mobility options, which results in score=1.

> 1 Shared mobility options not to be returned to hub

The interchange Amsterdam Centraal offers more than two shared mobility services, at least Greenwheels, Urbee, Cargoroo and many more. Therefore the score=3. For a destination location such as a tourist hub, it is important that last mile options are available, however they don’t have to be in the form of shared mobility that is not returned to the hub, so score=2.

As stated earlier, entry hubs have a low-medium population density, where the car is typically a dominant mode of transportation. So visitors can visit the hub with their own modes of transport, so it is not necessary to have more than one shared mobility options, which results in score=1.

Shared mobility for business travel

The guidelines by ComoUK (2019) were usable for this decision criterion.

On-site bicycle parking

The guidelines by ComoUK (2019) and Urban Design LA (2021) were both usable for this decision criterion.

Car parking

The guidelines by ComoUK (2019) and Metrolinx (2011) were both usable for this decision criterion. The Entry and Destination hubs are usually located in sub-urban areas where the population is still highly dependent on cars. Therefore, car parking is important in this area, score=3. For interchanges a car parking area is recommended, score=2

Kiss & Ride

Kiss & Ride possibilities are interesting for the hubs that have a lot of outgoing trips in the morning, such as Entry hubs (Metrolinx, 2011). Interchange hubs also have to deal with a significant amount of outgoing trips. On the other hands, destination hubs usually have a lot of incoming trips in the morning, so a Kiss + Ride is not necessary. The hubs can be scored as follows: Entry hub gets score=3, Interchange gets score=2 and Destination hub gets score=1. This is interesting for the Business park and the village hub, because they serve as entry and destination hubs.

Taxi

The guidelines by ComoUK (2019) were usable for this decision criterion. For all hubs a taxi was desired (score=2), except for the Suburb Hub. Here the taxi was not mentioned (score=1).

The scores obtained by the multi-modal water hubs for all decision criteria related to the Landside Access/Egress zone are shown in Table 15.

Table 15: Scoring of multi-modal water hubs against decision criteria of the Access/Egress Land side zone

		Hub type					
		Large Interchange	**Medium Interchange**	**Business park/ New housing**	**Village Hub**	**Suburb Hub**	**Tourism Hub**
Decision Criteria Access/Egress Land side zone	**Scoring source**	**Optional(1)/Recommended(2)/ Vital(3)**					
> 1 Public Transport link	Metrolinx (2011) Real case studies	3	3	3	2	1	3
>1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)	Real case studies (analytical thinking)	2	2	3	1	1	3
>1 Shared mobility options **not** to be returned to hub (e-scooters, e-bikes, etc.)	Real case studies (analytical thinking)	3	3	2	2	1	3
Shared mobility for business travel (shuttle buses)	ComoUK (2019, 2020)	1	1	3	1	1	1
On-site Bicycle parking	ComoUK (2019, 2020) Urban Design LA (2021)	3	3	3	3	3	3
Car parking	Metrolinx (2011) ComoUK (2019, 2020)	2	2	3	3	3	3
Kiss +Ride	Real case studies (analytical thinking)	2	2	2	2	3	1
Taxi stand	ComoUK (2019, 2020)	2	2	2	2	1	2

The main criteria for the Access/Egress Land Side zone are:

- >1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)
- >1 Shared mobility options not to be returned to hub (e-scooters, e-bikes, etc.)

These criteria have the most distinctive scores assigned to the hubs, because less than 4 similar scores are assigned to the hubs.

As also can be seen in the table, the decision criteria on-site bicycle parking has the same score=3 for all hubs. This does not allow for differentiation on this specific decision criterion and although it was initially recognized as a desirable decision criterion, it turns out that it is an essential criterion and could have been omitted. However, since it has no negative effect on the study results and the BWM surveys were already sent out for ranking at moment of discovery, this criterion is kept in the study.

7.1.2 Scoring Access/Egress Water side zone

For the derived waterfront criteria that emerged from the interviews, the scoring was primarily based on a heuristic approach using the views of the interviewees as a starting point if no theoretical theory could be found on these decision criteria. However, also some other guidelines and papers that were used in the desk research were used were relevant to back up the heuristic scoring of the hubs on these key criteria.

Allow on-site bunkering of hydrogen to decrease waiting times

The Waterbus expert took the bunkering of fossil fuels by Waterbus vessels as an example. They have one recharging point in Dordrecht where all ships refuel. For the Seabubbles, it is also not necessary to refuel at every hub because the ship can sail for two hours at a time. The Waterbus wanted to reduce the risks by moving the recharging point completely away from the passengers. Given the still developing nature of hydrogen, it makes sense to keep the recharging point as far away from the busy quays of Interchanges (Score=1) and Destination (score=1) hubs as possible. However, charging can be done at a less frequented Entry hub, but it would still not be essential (score=2).

Staff support

The guidelines by ComoUK (2019) were usable for the scoring of the hubs on this decision criterion.

Flexibility in service (fixed/on-demand)

Both the research paper by Monzón et al. (2016) and the interviewed Experts raised this decision criterion. The interviewees expected that a fixed service could be used if on-demand transport of Seabubbles was not intensively used. The fixed service could then be offered outside the tourist season or during peak hours. However, the Seabubbles deployed for fixed schedules will then be unable to be available for on-demand transport. Thus, this may be of particular interest to tourism hubs (outside the tourist season) and business hubs (peak season). All hubs receive the optional score=1, except the tourism hub and the business hub, which receive the score=2, since flexibility in service is not essential.

Operational reliability

The guidelines by SANDAG (2017) and the NBI_A interviewee stated that the on-demand nature of transport mode will require that the operational reliability is very high. It is the same concept as with an Uber. You don't want to wait to long for an on-demand water-taxi, otherwise the credibility of the service will suffer and people will look for alternative transport possibilities, so all hubs score=3.

Wide operational timeslots

According to the guidelines by SANDAG (2017) and the NBI_A interviewee, wide timeslots are relevant for on-demand transport. Since the on-demand Seabubble concept can be compared to the Uber-taxi concept that is available 24/7, wide operational timeslots are desired for all hubs, but especially on the Destination hubs, because people need to travel back from these hubs. This results in a score=3 for the Destination hubs and a score=2 for the other hubs.

On-demand access to waiting area (e.g. via app)

From the interview with the EXP_A interviewee appeared that most small hubs of the Waterbus are not fenced because of the use of scheduled water transport, but in the case of on-demand water transport the frequent docking of a ship is removed. Safety at the smaller water hubs can then be ensured by granting on-demand access to visitors who have made a reservation for a Seabubble. On the larger hubs, this need not necessarily be offered, because there are already many facilities present to guard the safety. Therefore, the Interchange and destination hubs get a score=1, and entry hubs a score=3.

Prepared dock for future autonomous sailing

The industry interest Advier is very explicit about implementing autonomous sailing. The idea is that after successful deployment, the Seabubbles will also appear in autonomous setting to reach a wider audience at lower cost, since there is then a reduction in labor costs. Now the water mode would be too expensive for commuting. However, it is unclear when the first autonomous passenger ships will be able to sail safely. This is not even known for hydrogen sailing ships with captains. By preparing the docks already for autonomous sailing, future construction costs can be avoided. This is especially something to think about for interchanges and destination docks (score=2) that have higher processing of visitors. For the smaller water hubs (entry docks) it is not necessary (score=1).

Dock sharing with other water transport modes

Almost all interviewees spoke about sharing a water hub with other waterborne modes in order to use the existing water hub network as efficiently as possible. Passengers can thus transfer for example from the Waterbus to the Seabubble and vice versa. This is recommended for all hubs location where another water transport mode is nearby. However the larger water modes, such as the Waterbus will mainly be found at more central locations such as interchange and destination hubs (score=3). The service will probably be less applicable to smaller entry hubs (score=1).

The scores obtained by the multi-modal water hubs for all decision criteria related to the Access/Egress Water zone are shown in Table 16.

Table 16: Scoring of multi-modal water hubs against decision criteria of the Access/Egress Water side zone

		Hub type					
		Large Interchange	**Medium Interchange**	**Business park/ New housing**	**Village Hub**	**Suburb Hub**	**Tourism Hub**
Decision Criteria Access/Egress Water Side zone	**Scoring source**	**Optional(1)/Recommended(2)/ Vital(3)**					
Allow on-site bunkering to decrease waiting times	IND_A/NBI_A	1	1	2	2	2	2
Staff support	ComoUK (2019, 2020)	3	3	2	2	1	2
Flexibility in service (fixed/on-demand)	Monzón et al. (2016) EXP_A / EXP_B	1	1	2	1	1	2
Operational reliability	SANDAG (2017) NBI_A	2	2	3	3	3	3
Wide operational timeslots	SANDAG (2017) NBI_A	2	2	3	3	2	3
On-demand access to waiting area (e.g. via app)	EXP_A	1	1	2	2	3	1
Prepared dock for future autonomous sailing	IND_A	2	2	2	1	1	2
Dock sharing with other water transport modes	EXP_A/EXP_B/IND_A/NBI_A	3	3	2	2	1	3

The main criteria for the Access/Egress Water side zoned are: Staff support, On-demand access to waiting area (e.g. via app) and Dock sharing with other water transport modes.

These criteria show the most variance in scoring levels scoring compared to the other criteria.

7.1.3 Scoring Access/Egress Facilities & Retail zone

All decision criteria for the Facilities & Retail zone were retrieved from the guidelines from the desk research. Most decision criteria could be scored by the ComoUK (2019, 2020) guidelines, see Table 17.

Table 17: Scoring of multi-modal water hubs against decision criteria of the Access/Egress Facilities & Retail zone

		Hub type					
		Large Interchange	Medium Interchange	Business park/ New housing	Village Hub	Suburb Hub	Tourism Hub
Decision Criteria Facilities & Retail zone	**Scoring source**	**Optional(1)/Recommended(2)/ Vital(3)**					
Tourist Information	ComoUK (2019, 2020)	1	1	1	1	1	3
Real-time travel data	ComoUK (2019, 2020)	3	3	2	2	1	2
Digital stand for buying (combi-) tickets and way-finding	ComoUK (2019, 2020)	2	2	2	1	1	2
Toilets	ComoUK (2019, 2020)	3	2	2	3	3	3
Kiosk	ComoUK (2019, 2020)	2	2	2	2	1	2
On-site activities for business (e.g. meeting hall)	ComoUK (2019, 2020)	1	1	3	1	1	1
On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)	ComoUK (2019, 2020)	2	2	2	2	1	2
Wifi	ComoUK (2019, 2020)	2	2	2	2	1	2

The most important criterion in this table is Real-time travel data, since it is showing different scores for the hubs. The other criteria have assigned similar preference scores to four or more hubs, and are therefore less distinctive.

7.2 Best- Worst Method - Data processing

7.2.1 Consistency of weights

The pairwise rankings that emerged from the three surveys were incorporated into the BWM Solver as described in the modified 5-step plan in Section 3.3. The respondents were asked to do a pairwise comparison for four decision criteria sets. First, the three key areas were asked to be ranked against each other, by selecting a 'best' and 'worst' key area and then comparing the criteria relative to each other. The next step was to do the same, but for each of the subgroups of key areas. Thus, the decision criteria were compared in pairwise fashion in their own key area.

This approach was conducted for each individual survey and by solving the linear optimization problem with the BWM solver, the optimal weights for each individual criterion could be calculated. The resulting weights were later consolidated into resulting tables that can be found in Appendix D.

For all weights in all surveys, the Consistency Index ξ was also calculated to determine whether the outcome of the calculations was reliable enough to label the survey inputs as valid. However, the maximum allowed consistency value was nowhere near the maximum allowed Consistency Index of 5.23. As already explained in Chapter 3, the max ξ allowed is dependent on the number of scaling levels used for the pairwise comparisons, which can vary from 1-9. In this study 9 levels were used to rank the criteria, since that is common practice with the BWM.

Also, the Consistency Ratio (CR) did not exceed the maximum threshold of 0.2122 for the pairwise comparisons of the three key areas, see Table 18. This means that the rankings that were conducted by the participants can be considered valid and reliable.

Table 18: For the Key areas, the ξ_{max}=5,23 and the CR_{max}=0,2122 were not exceeded for all surveys, which make the rankings consistent

KEY areas	ξ	Consistency Ratio = ξ/CI
Expert	0,2841	0,0543
Industry Interest	0,2959	0,0566
Non-Business Interest	0,2500	0,0478

The Consistency Ratio (CR) for the other decision criteria sets did also did not exceed the maximum threshold of 0.4587, see Table 19. The thresholds for the CR were also introduced in Chapter 3 and are related to the number of criteria that are ranked within a set and the used scaling levels.

Table 19: For the decision criteria related to the key areas, the ξ_{max}=5,23 and the CR_{max}=0.4587 were not exceeded for all surveys, which make the rankings consistent

Access/Egress Land Zone	ξ	Consistency Ratio = ξ/CI
Expert	0,3017	0,0577
Industry Interest	0,2979	0,0570
Non-Business Interest	0,1237	0,0237

Access/Egress Water Zone	ξ	Consistency Ratio = ξ/CI
Expert	0,0794	0,0152
Industry Interest	0,0959	0,0183
Non-Business Interest	0,1248	0,0239

Facilities & Retail Zone	ξ	Consistency Ratio = ξ/CI
Expert	0,1397	0,0267
Industry Interest	0,2007	0,0384
Non-Business Interest	0,1128	0,0216

Since the ranking of the participants can be considered consistent, the weights that are assigned to each key area or decision criterion can also be considered reliable. In Figure 23 the weights that are assigned to each Key area is shown.

As shown in the figure, all actors assigned the greatest importance to the land side of the water hubs. This means that they consider the connections of the water hubs to the land transport network to be the most important. An interesting observation in the rest of the results is that there is only one major visible deviation, and that is that the Non-Business Interest also assigned a relatively high importance to the water side of the water hub.

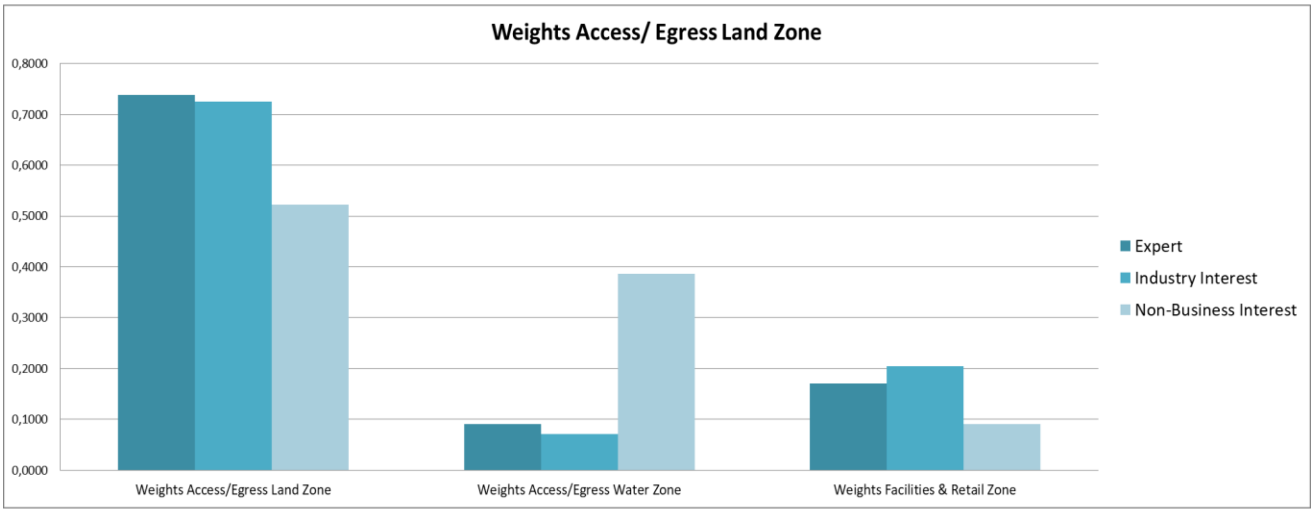

Figure 23: Weights assigned per actor to the Key areas

The differences in how the weights are assigned to each decision criterion for each key are can also be further explored to explore similarities and deviations among the different actors.

In Figure 24 the assigned weights for the Access/Egress Land zone are presented.

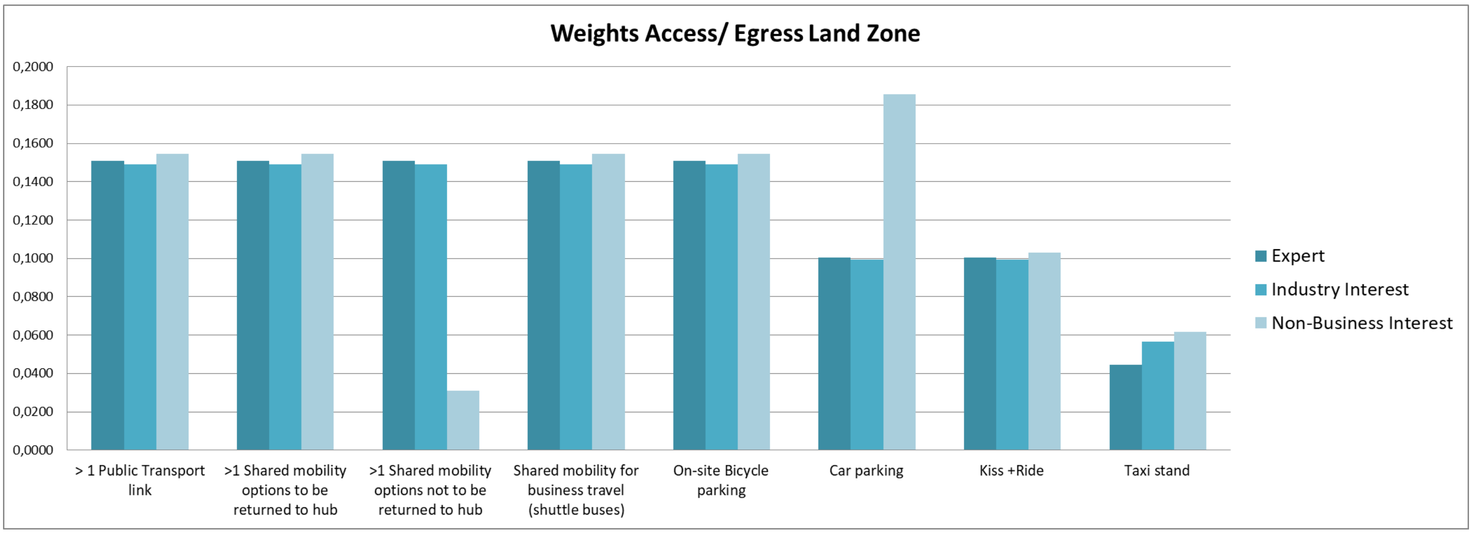

Figure 24: Weights assigned per actor to the Access/Egress Land Zone

The first thing to notice is that the weights for the Access/Egress Land Zone are almost equally distributed by all actors. What also stands out is the almost equal importance of bicycle parking, public transport and shared mobility. This shows that sustainable last-mile options are considered more important than car and taxi by the actors. However, there are some big deviations from the non-business interest angle when it comes to the shared mobility options that do not need to be returned to hubs and car parking. During the interviews with politicians, it became already clear that they do not think that shared mobility without a fixed location would work outside of densely populated urban centers. In addition, they think that especially in Albasserdam a large parking area is necessary, because most visitors that visit the tourist attraction Kinderdijk come by car.

In Figure 25, the weights assigned per actor to the Access/Egress Water Zone are displayed. Here as well, you can see an almost parallel distribution of weights per decision criteria by the actors, especially by the expert and industry interest. Operational reliability of on-demand Seabubbles is considered the most important criterion compared to the other decision criteria by all actors. This was to be expected, given the nature of on-demand transport. On-demand access to the hub is considered by almost all actors less important than the other criteria.

Staff support, flexibility in service, wide operational timeslots and dock sharing with other water modes are considered equally important by all actors. This gives an indication that these decision criteria are all desired at the hub. On the other hand, it is considered less important to prepare the water hub for autonomous Seabubbles. It might be that it seems an elusive concept from the future.

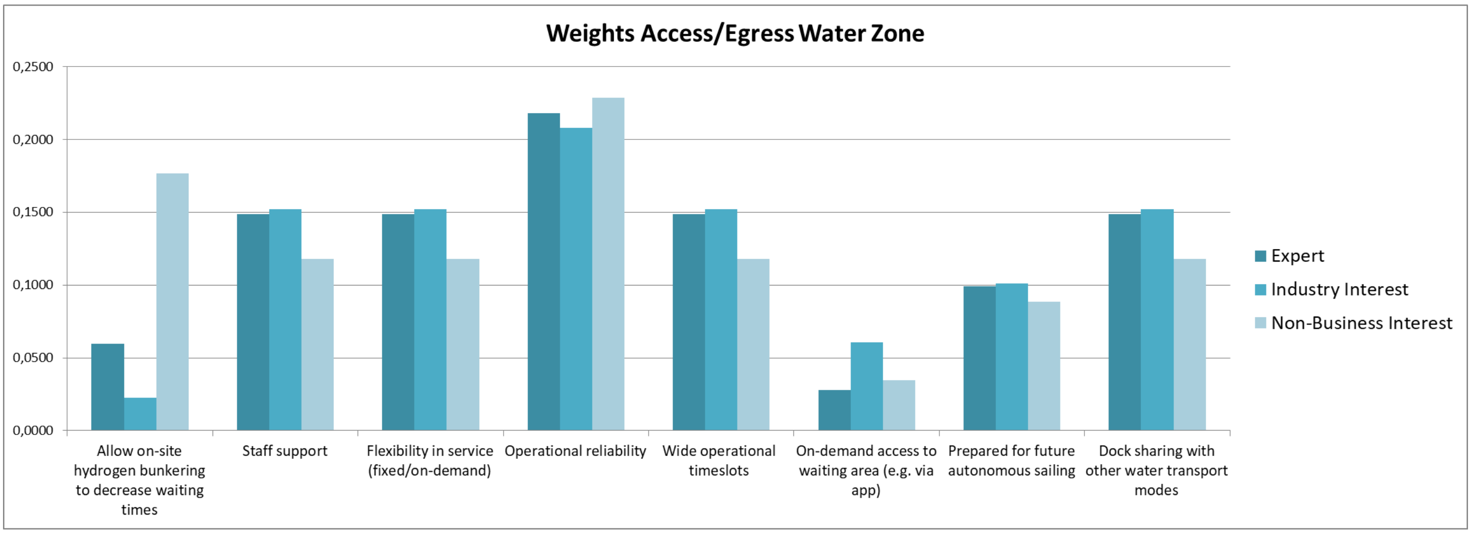

Figure 25: Weights assigned per actor to the Access/Egress Water Zone

The decision criterion on which opinions differ widely is the on-site bunkering of Seabubbles with hydrogen to reduce waiting times. The non-business interest of politicians has given great weight to this decision criterion compared to the other actors. This may have to do with the importance of introducing hydrogen as a sustainable fuel for transportation and using it as part of city branding.

The last key area for which a decision criteria set was pairwise compared is the Facilities & Retail Zone, as can be seen in Figure 26. Again, the expert and the Industry Interest resulted in almost similar weights for most decision criteria, making the decision criteria equally important to them. However, the non-business interest differs again from this pattern. He somewhat follows the pattern, but has some extreme values compared to the other actors, for example there is a very high weight assigned to Toilets, but a very low weight to on-sides leisure activities.

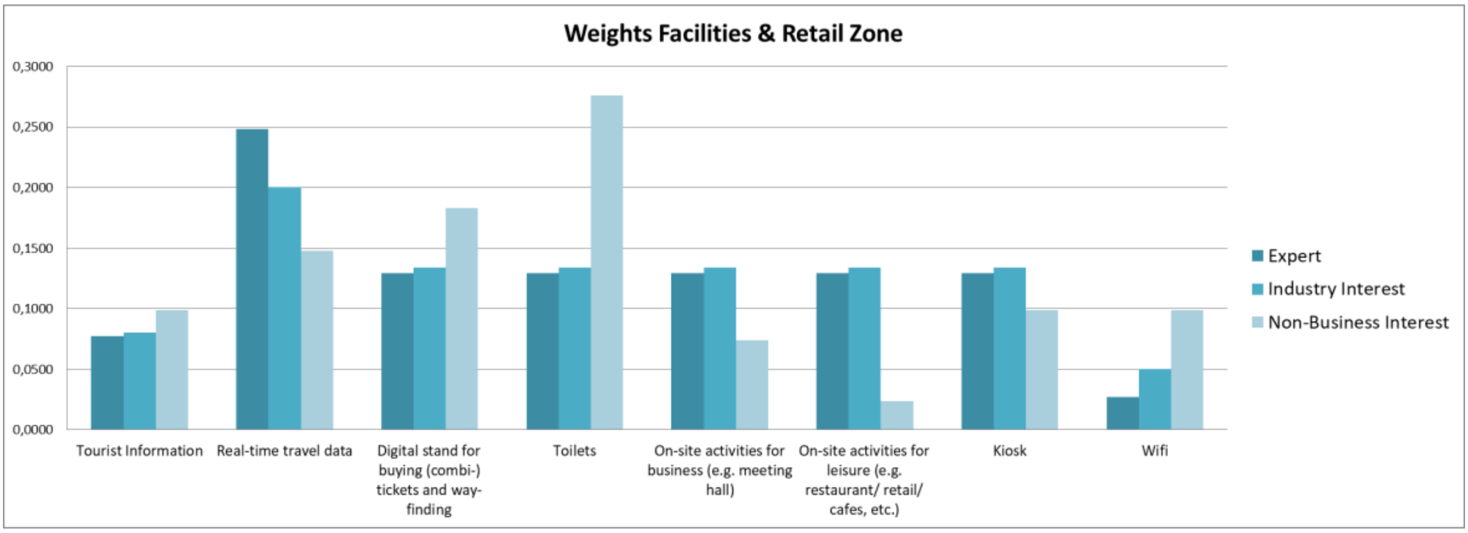

Figure 26: Weights assigned per actor to the Facilities & Retail Zone

It seems a bit strange that the Non-Business Interest did not assign a high weight to on-site leisure activities and on-site business activities, since the main users of the hub in Alblasserdam will probably be tourists or business people. However, it was also pointed out during the interviews with the Non-Business Interests that there may be no need for leisure facilities due to the nature of on-demand transport. Since there is a direct connection to most forms of shared mobility and the on-demand Seabubbles, people may not feel the need to linger at the hub, because they can continue their journey immediately. However, this theory is a bit contradictory to the weight assigned by the Non-Business Interest to WIFI. If people don't spend time on the hub, it wouldn't be necessary either.

7.3 Results: Best fitting multi-modal water hub type for Alblasserdam

After the decision criteria were assigned weights, they could be further used as part of a performance matrix to determine a feasible water hub type for the Seabubbles.

First the overall weight of the decision criteria had to be determined. To arrive at an overall weight for each decision criterion, the weight of each individual decision criterion should be multiplied by that of the corresponding key area. After completing this multiplication, the sum of the weights of all decision criteria should be equal to 1.

The next requirement was adding the scoring matrix in Appendix C, which assesses hubs against various decision criteria to the performance matrix in the BWM model. This scoring matrix plays a crucial role in the evaluation method because the scores determine which hub types are desired for which combinations of decision criteria. The scores in the matrix can have the value, 1,2 or 3 and by using the Linear Max approach these values could be standardized to a value between 0 and 1. To arrive at the standardized value, the score for each decision criterion is divided by the maximum score that appears for that decision criterion. After the scores were standardized, the weighted sum-product was taken over the hub scores and overall weights of the decision criteria. These steps were performed for all three actors, resulting is the performance matrices as can be found in Appendix E. The hub type with the highest resulting value, the Business park/New housing development hub, fitted the case study best in all actor scenarios, see Figure 27.

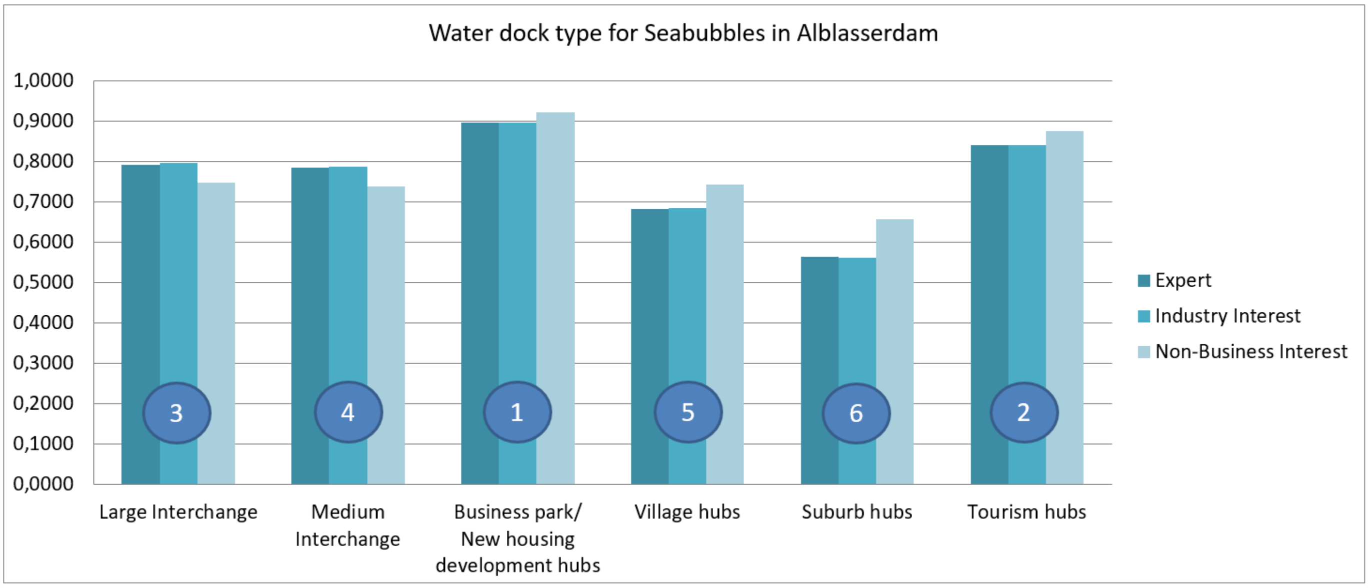

Figure 27: Best fitting hub type for the Case study in Alblasserdam

As shown in the figure, the hub type that best fits the case study is the Business park/New housing development hub. However, there is only a very small difference between the choices for the Tourism hub and the Large Interchange. The real scores for each actor are presented in Table 20, see Appendix E for more detailed performance matrices of all actors results.

In the table below it can be seen that the values are not that far from each other. This was already to be expected, as there are many overlapping decision criteria preferred in both hubs, because they are both considered destination hubs. What is also striking is that even though there have were sometimes large differences between weights assigned to the decision criteria in the key areas for different actors, this does not seem to be the case now.

Table 20: Results of performance matrices of all three actors

Hub type choice	Large Interchange	Medium Interchange	Business park/ New housing development hubs	Village hubs	Suburb hubs	Tourism hubs
Expert	0,9460	0,9161	0,8632	0,7268	0,7103	0,9542
Industry Interest	0,9497	0,9148	0,8601	0,7224	0,6973	0,9528
Non-Business Interest	0,9065	0,8571	0,8232	0,7350	0,7103	0,9657

With the determination of a feasible water hub type that can support on-demand Seabubbles in Alblasserdam, the evaluation of the multi-modal water hubs with the BWM is completed. The model can also be used for determining water hub types for other locations in the Drechtsteden area.

7.4 Conclusion BWM

Before the BWM could take place, the six hub types needed to be scored first on the found decision criteria. By scoring each of the hub types on the decision criteria as vital (score=3), desirable (score=2), or optional (score=1), the respective hub is assigned a preference level for the decision criteria. The scores are derived from the mobility hub guidelines that were introduced in Chapter 4. If no score could be assigned due to lack of theoretical resources, a score was derived based on a heuristic approach using analytical thinking and the conducted interviews.

Despite the fact that there were only three usable responses to the surveys, it appeared that the three different inputs from the actors resulted in weights that were fairly close, although the Non-business Interest differed from the others on some decision criteria. The Industry expert and the Expert followed almost the same trend in the weights for the decision criteria, where the Non-Business Interest had some fluctuating weights. There are however insufficient surveys to draw a conclusion about the differences between actors, because it is also possible that one of the participants did not understand the questionnaire correctly.

A very remarkable thing about the results is that all hubs are ranked the same for all actors. This means that all actors that were surveyed seemed to be in line with each other on the importance levels of the decision criteria per key area of the potential hub in Alblasserdam. This is either very coincidental or the model is suitable to give a good first impression for the hub type to be selected for a particular location. If the latter is the case, the model can help determining a first impression for the type of water hubs that are needed at other locations in the Drechtsteden region.

It must also be admitted that more research needs to be conducted first in order to properly test the model for its reliability, since the weights of the rankings of the potential water hubs were quite close to each other. It also could just as easily have been that the outcome may have been a Tourist hub or Large Interchange. This would not be surprising either, as there was a lot of overlap in the desirability scores of certain decision criteria on these three hubs.

In the used case study it was already beforehand somewhat clear what type of hub is needed, but it may also be that this is not the case and then this research can potentially help to bring out preferences that are not evident from the environmental context.

In addition, the most feasible dock may also be a combination of two or more hubs, so it is also important to look at the hubs that are not ranked as the "best" option. The advantage of the Best-Worst method is that it does not completely rule out the other options, but merely indicates which water hub comes out best in the ranking.

The outcome of the Best-Worst Method was a Business park hub for Alblasserdam for all surveys, which was somewhat expected. However the second in line was the Tourist Hub, which is also applicable to the area. The set expectation and the resulting output allow for some validation of the model.

8 DISCUSSION

This research has resulted in a MCDA model to select from six potential hub types a best fitting dock type for a case study in Alblasserdam based on pairwise comparison of 24 decision criteria. Although the case was specific to the study in Alblasserdam, this model can potentially also be used to propose potential dock types for other areas in the Drechtsteden region, since the used decision criteria apply to a wide variety of mobility hubs. However, one should be careful if the model is applied for other water modalities than the Seabubbles. The relevance of the decision criteria on the Access/ Egress water side can then no longer be guaranteed, since they are related to the deployment of on-demand hydrogen Seabubbles.

Given the location of the case study, it was possible to predict somewhat what the most appropriate hub types would be for the study. The potential hub location in Alblasserdam will be visited by tourists that visit Kinderdijk and on top of that, the location is also situated in an industrial area. It was therefore almost obvious that the outcome would be at least a destination hub that would serve as a tourist hub, a business park hub, or a combination of the two. The model proved to be consistent and indeed represented the business park hub as the most feasible potential hub type for the location based on the input of all participating actors. However, there is a head-to-head race with the tourist hub, which also indicates that probably with more respondents, different results for 'best fitting' water hubs might be expected. Since only the surveys of three respondents could be used to rank the potential water nodes, there is still a chance that the results may be based on coincidence.

Very interesting about the results is that all hubs have the same ranking for all actors. This means that all surveyed actors seemed to be somewhat aligned in terms of the importance levels of the decision criteria of each key area for the potential hub in Alblasserdam. This may indicate that the selected decision criteria for this study do not fall into a desirability category after all, but still fall into the essential category for all hubs, making them indispensable, just like the criteria related to safety and the bicycle parking. This could then indeed explain why the weights assigned to the decision criteria are almost equal for the Expert and Business interest which thus lead to the same ranking of best fitting water hubs.

It may even be the case that the scoring system that was used is not appropriate and that more differentiation levels should have been applied to capture more significant differences between the decision criteria. In each key area, there were several decision criteria whose scores were the same for four or more hubs, which could contribute to making it harder to distinguish between the hubs. This could also explain the similar hub outcomes for all actors as well, since there were only a few decision criteria that really showed different scores for all hubs.

It must also be kept in mind that the decision criteria and evaluation model that were used to arrive at a best water hub are no guarantee that there will always be a correct outcome. This model will at best be able to be used as a good start to get an idea of the surrounding area, the expected visitor types and the required modalities and facilities of a potential water hub. Also, the scoring method derived from the guidelines used is based on rough estimates, since only a few practical source guidelines could be used for this purpose. In addition, when no sources were available, score estimates had to be made based on analytical thinking.

It may also be that the scoring system that is used is not appropriate and that more differentiation should have been made in scoring levels to capture significant preferences of decision criteria. Now only three levels have been used, so there was a lot of overlap in scores for hubs with the same transportation function, being interchange, entry or destination.

Since the BWM remains a subjective method and is blind to all other unnamed decision criteria that may also be very important one must be careful not to adopt results indiscriminately. Besides, also combinations of two or multiple different hubs can be an outcome. The outcomes for the dock for Alblasserdam showed that the Business park hub and the Tourist hub were very close for all actors and the choice for a hub could easily have fallen on the tourist hub as well. This is also an indicator that it could be a good idea to check out the characteristics for the two or three upper 'best' hubs when deciding upon a water hub for the location.

On the other hand, if the criteria and scoring system are considered reliable, which would become clearer with more surveys, this model shows that even with very few results it can make an appropriate choice of a potential water hub for a hub location.

There were insufficient surveys to draw any reliable conclusion about the differences between actors, because it is also possible that one of the participants did not understand the questionnaire correctly. I received two unusable surveys back from other respondents because they probably didn't understand what to do. I unfortunately did not receive any responses back on follow-up contact.

The reason there were so few survey responses is most likely due to the fact that initiatives such as the Region Deal (regional funding projects) were running in the Drechtsteden Region during the research period of this thesis. Funding opportunities were made available to redevelop the region and its waterfronts and also to give commercial businesses the opportunity to think about innovative waterborne passenger transport. By participating in this research, interviewees feared expressing an unintended preference for Seabubbles. Unfortunately, the pressure public figures face when speaking about sensitive issues did not benefit this study. Since almost all interviewees explicitly did not want to be associated with any research dedicated to a commercial party, such as Seabubble, they also wanted to keep the interview results anonymous. It would probably have been helpful to this study if it had not been specifically linked to the Seabubbles and if instead the potential water hubs for general hydrogen water-taxis were examined.

The mobility hub concept lies at the heart of this research, which arrived at 24 decision criteria and six potential multi-modal water hubs that can be used to select potential social and technical feasible water hubs for Seabubbles.

Practical guidelines from government agencies on mobility hubs allowed for a hub typology for the water hubs. The water hubs could be differentiated based on the urban environment and the function of the water hubs. This study relied heavily on these guidelines because no other typologies for water hubs for on-demand water modes could be found. While the guidelines were a good starting point and mobility hubs seem to have great potential, one must be aware that the concepts are still very new. The mobility hub concept was introduced almost a decade ago and is promoted as a key solution for future mobility to relieve congested cities and reduce emissions. Success is supposed to lie in the availability of multiple types of shared mobility at the hubs, so that it is not necessary to own a mode of transport anymore. To increase the user experience, the hubs can also be enhanced with additional facilities, such as stores, eateries, etc.

Research has shown that the feasibility of the mobility hubs is increased if the concept consists of a larger network of hubs that is well integrated into the surrounding transport network and that also provides sufficient opportunities for shared mobility. However, this does not yet guarantee that it will work, as users need to undergo a change in travel behavior. They need to distant themselves from private modes, such as cars, and take the effort to use shared mobility. Shared mobility can be more expensive than using private modes and users have to compromise on comfort. Using shared mobility usually results in a fragmented journey where multiple transport modes are used. In addition, these modes may each have a different provider that you must reserve for separately.

This dependency on acceptance of users brings in high risks for commercial parties to invest in mobility hubs, which have led to government agencies having to step in and finance most mobility hub concepts. The situation is even more sensitive for shared water modes, because in almost all cases water transport does not offer door-to-door transport and therefore additional modes have to be used for the first and last miles. This is a very important aspect to consider when on-demand Seabubbles are being considered for implementation. For the Seabubble concept to succeed, it will also likely need to be funded by government agencies to become familiar with potential users and to build a robust multi-modal water hub network so that it can be integrated into the surrounding transportation network.

Although the mobility hub concept seems the solution for a new way of travelling, we should be careful with seeing it as the solution for the future, because it is still in its development phase. Besides, introducing changes in a transport network system takes a lot of time and requires changed traveller behavior. It is also not yet certain if mobility hubs will be viable on the longer term, because most of the ongoing mobility hub projects are heavily subsidized.

9 CONCLUSION AND RECOMMENDATIONS

9.1 Conclusion

The aim of this research was to determine what potential multi-modal water hubs are socially and technical feasible to support the adoption of on-demand hydrogen Seabubbles. The potential adoption of Seabubbles itself is not explored because that would require a different research that is more focused on the customer experience and journey. The focus in this study was exclusively on determining a few feasible potential multi-modal water hubs that could be used to support Seabubbles. This required extensive research on the necessary facilities that are needed on these hubs. It could be implied that each water hub location has three key areas that that could be used to differentiate between water hubs: Access/ Egress Land zone, Access/Egress Water zone and a Facilities & Retail zone.

The desk research and interviews helped with identifying relevant decision criteria that could be linked to each of these zones. A set of 19 decision criteria resulted from the desk research and a set of 5 decision criteria resulted from the interviews with actors linked to the Alblasserdam case study. The 19 decision criteria from the desk research were derived from practical guidelines using the mobility hub concept. In the mobility hub concept, the connection with the land transport network and the travel experience play crucial roles. The used guidelines where mainly produced by governmental entities.

Because the mobility hubs are mainly related to land hubs, there were enough decision criteria that could be assigned to the Access/ Egress Land zone(8) and the Facilities & Retail zone(8). For the Access/Egress Water Zone three decision criteria could be found.

Since no classification of water hubs could be found in the literature, the possibilities for potential hub types were enormous. However, by using the mobility hub concept as a starting point, the number of feasible hub types could be reduced to six potential multi-modal water hubs that could be used for Seabubbles, namely:

- Large interchange - City Centre Mobility hubs
- Medium Interchange- Transport Corridor/Linking hubs
- New housing development hubs/ Business parks
- Village hubs/small market towns
- Suburb hubs
- Tourism hubs

Each water hub has its own characteristics related to the environmental context in which it is located and to the transportation function it performs: interchange, entrance or destination.

By classifying hubs by the surrounding environment in which they can be located, the number of potential hubs could be quickly reduced to a manageable amount of six hubs. Each multi-modal hub type interacts with its environment differently and is therefore configured accordingly. The function of the hub determines the type of visitor that is visiting the hub and can also give an indication of what facilities are needed at the hub location.

The desk research had not exposed the Access/ Egress Water zone well enough, because only three decision criteria could be found. This is were the interviews came in handy. Interviews were held with 3 Experts, 4 Industry interests and 4 Non-Business interests.

The interviews served a multiple purpose. The first purpose was to find out if the interviewees would bring up some of the decision criteria that emerged from the desk research. This way the relevance of the found criteria for the case study could be examined. The second objective was to come up with additional relevant decision criteria for especially the Access/Egress Water zone that could not be derived from the theoretical desk studies. Since these decision criteria could not be found in the desk research, the interviews were also used to score the found hub types on these criteria in a heuristic approach where analytical thinking was used.

The interviews with all actors resulted indeed in an overview of overlapping decision criteria with those derived from the desk research. This made the criteria found in the desk research relevant enough to proceed with the study. The interviews also helped with identifying 5 decision criteria that could be used for the water side. Especially the interviewee from the Waterbus and Advier had a hand in adding these decision criteria to the research. The other parties were mainly focused on the needed connections at the land side of the water hub.

The main results of the desk research and interviews consisted of an overview of 24 decision criteria and 6 potential multi-modal water hub typologies. These results could be used to select a potential water hub for the case study location in Alblasserdam. However, the six hubs had to be scored first against the found decision criteria. By scoring each of the hub types on the decision criteria as vital (score=3), desirable (score=2), or optional (score=1), the respective hub is assigned a preference level for the decision criteria. The scores are derived from the mobility hub guidelines and real case studies that were used in the desk research. If no score could be assigned due to lack of references (derived water side criteria from the interviews), a score was derived based on a heuristic approach using analytical thinking with the conducted interviews as a base. The most important decision criteria for each key area could be determined based on the extent to which they differed in their scoring levels across water hubs:

- The main criteria for the Access/Egress Land Side zone are:
  - >1 Shared mobility options to be returned to hub and
  - >1 Shared mobility options not to be returned to hub
- The main criteria for the Access/Egress Water Side zone are:
  - Staff support
  - On-demand access to waiting area
  - Dock sharing with other water transport modes
- The main criteria for the Facilities & Retail zone is:
  - Real-time travel data

The other criteria have assigned similar preference scores to four or more hubs, and were therefore less distinctive.

The multi-modal hub typologies are not stand-alone units; they can also have overlapping characteristics and form a combination hub. The "Best-Worst" method was therefore found to be suitable for evaluating these water hubs, because the decision criteria could be compared pairwise by selecting the ‘best’ and ‘worst’ criteria. This means that the "best" decision criterion of a key area does not necessarily eliminate the other criteria related to the key area. It only indicates that it has a higher importance level compared to the other criteria. Based on the respondents' pairwise comparison of the criteria, the result was a ranking of the potential water hubs from best to worst; and again, this does not necessarily exclude the hub types that are next in line.

Despite the fact that there were only three usable responses to the surveys, it appeared that the three different inputs from the actors resulted in weights that were fairly close to each other, although the Non-business Interest differed from the others on some decision criteria. The Industry expert and the Expert followed almost the same trend in the weights for the decision criteria, where the Non-Business Interest had some fluctuating weights. There are however insufficient surveys to draw a conclusion about valid differences between actors, because it is also possible that one of the participants did not understand the questionnaire correctly.

A very remarkable thing about the results is that all hubs are ranked the same for all actors. This means that all actors that were surveyed seemed to be in line with each other on the importance levels of the decision criteria per key area of the potential hub in Alblasserdam. This is either very coincidental or the model is suitable to give a good first impression for the hub type to be selected for a particular location. If the latter is the case, the model can help determining a first impression for the type of water hubs that are needed at other locations in the Drechtsteden region.

This study aimed to help fill the research gap by proposing a solution whereby, based on the assigned importance level of specific decision criteria, a potential social and technical feasible multi-modal water hub type can be selected for a potential hub location.

This research has helped to help bridge the research gap. By allowing stakeholders to pairwise compare a set of relevant decision criteria through the Best-Worst method to arrive at a "best" fitting water hub for the case study, it can be said that this has been achieved.

Although the model seemed to work well for the case study in Alblasserdam, there are a few side notes that need to be taken into account as well.

The first very important remark is that I did not receive enough surveys to be able to validate the research method sufficiently on reliability and applicability. Nevertheless, the model did show well what type of hubs fit best for the case study location.

Another important aspect to realize is that the whole method is based on subjective input. The derivation of the decision criteria, the hub scoring system, survey inputs and resulting results are based on the views of active stakeholders from the case study, making the perspective of the model one-sided and subjective. This makes that the proposed model is not comprehensive and only intended to help determine a first impression of which potential water hub typology is appropriate for a site.

The subjective element in the model does not mean that the model should be rejected, but only indicates that it is probably only applicable in the Drechtsteden region. Since a network of hubs would need to be established in the Drechtsteden region to enable the adoption of Seabubbles, the proposed model certainly remains relevant. Besides, all input can of course also be adjusted to new circumstances. The approach and basis of the model can however still be used as a starting point for other areas.

A final point of interest is that extensive use of a number of mobility hub guidelines is made in order to determine the hub types and associated decision criteria. However, the guidelines mostly convey the mobility hub principle conceptually. Therefore this whole mobility hub concept does not imply that it is actually technically or socially feasible on the longer term. The mobility hub concept is still in the development phase and might as well prove unsuccessful in the future. However, given the investments being made in similar projects, which could include Seabubble's water hubs, it seems that the government and the private sector do believe it is a viable concept, provided the operators are given a financial push to get things started.

9.2 Recommendations for further research

This section makes some recommendations for further research that could make the model more complete and fill the research gap at a more detailed level.

- In order to frame the scope of the research, the Political Economy Framework was used to investigate the feasibility of water hubs that support the deployment of on-demand Seabubbles. However, only parts of the social feasibility and technical feasibility are researched within this study. It is recommended to also examine the other parts of the framework, such as the political feasibility to complete all feasibility levels for the potential multi-modal water hubs. The political feasibility dives deeper into the role of governmental entities when it comes to the adoption of new transport modes.
- Because of the sensitivity to bias in the BWM, it is therefore recommended to conduct a sensitivity analysis by applying additional quantitative methods other than the Linear Max approach and/or the weighted Sum-Product and then compare the results with the current model to test the robustness of the model.
- Since this study can also be used for general implementation of hydrogen on-demand modes, it may not be necessary to link further research to a commercial party, such as Seabubble. Since the implementation of new transport modes is a sensitive topic among politicians and other stakeholders, it may be better for future research to take a more objective approach. Unfortunately, this research suffered from the politically sensitive climate, which resulted in an insufficient response rate as far as the case study was concerned.
- Only three respondents participated in the MCDA, which increases the risk of incredibility and unreliability. More surveys should be distributed among relevant actors to test the model on reliability.
- Further it is recommended to use the model for multiple test case studies and discover if the model is still reliable when other environmental contexts are used.
- It is recommended to perform a stakeholder analysis, since many actors are involved with water hubs that need to support an innovative transport mode. By investigating the needs of each stakeholder, interest conflicts can be identified at the beginning of the process. There are different layers involved of governmental institutions, businesses, interest groups, end-users, etc.
- Customer journeys are also recommended for each potential water hub location, as the end user may or may not use the hub. It is very important to investigate whether there is a need for a hub in an area, before it is located. It is also good to recognize what function a hub will fulfill so that a better estimate can be made of the decision criteria that will be needed.
- This research was mainly concerned with a non-monetary evaluation method based on desired decision criteria for potential water hubs. Since many mobility hubs need to be subsidized in order to be aired, and water hubs cost even more than land hubs, a Cost- Benefit Analysis is recommended to get insight in the expected investing costs.

9.3 Recommendations for interviewed actors

Each stakeholder has an interest in introducing well-connected water hubs that fit well into the environment and also meet user needs. This section makes some recommendations to the stakeholders interviewed on how to address the implementation of potential water hubs for Seabubbles.

Experts

Safety issues related to an increase in Seabubble traffic and the number of objects (water hubs) in the rivers may also rise on already busy rivers. Small boats are less visible for large containerships. An incident involving a Seabubble or water hub would attract much more attention than an accident involving land transport. It is therefore important that experts join the discussions on potential adoption of Seabubbles in a very early stage to point out the potential risks of the deployment. The experts have the expertise and knowledge levels on transport over water and they should be consulted when it comes to safety.

Industry Interests

Despite the fact that all interviewees expressed positive views on the deployment of Seabubbles in the Drechtsteden region to expand the existing transport network, a number of reservations were also expressed. Because a water hub facilitates the transition between land and water transport, there are many stakeholders involved with conflicting interests on the land side and on the water side. Therefore, it is important that the views of all parties are aligned as much as possible by selecting a single party who will lead and roll out the initiative, so that an overview is maintained. The implementing party can take on this task, but must make proper arrangements for this with all parties involved. Determining who these parties are is also a recommendation for future research.

Another point that should be looked in closely is the investor attention once the "hype" surrounding the introduction of hydrogen-powered Seabubbles dies down. It is important that the involved industry actors, such as Advier and Seabubbes, need to take advantage of the hype surrounding the innovation especially in the first few years to attract tourists and other leisure activities in order to keep the investors' attention, which also includes governmental entities. It will take some time for the Seabubble to be fully accepted and integrated into the water transport network.

It is also important for industry interests to conduct a comprehensive study of customer travel by origin and destination to determine traveler needs and also to determine potential hub locations. The model resulting from this research can then be used to provide insight into hub types that can facilitate hub locations.

Non-Business Interests

While politicians are most enthusiastic about the deployment of innovative water modes such as Seabubbles because of the expected "city branding" for the entire region, they are somewhat reluctant to invest in a new mode of transportation that has not yet been proven to work. Decision-makers are now approaching the initiative primarily from a facilitator role rather than as an investor, which can make it difficult to raise enough money to finance the Seabubbles and network of water hubs. Since the Seabubble can be part of the mobility hub concept, it may be a good idea to introduce the Seabubbles as a similar pilot project and to label and subsidize it as such.

If the Seabubble concept is developed properly and a network of multi-modal water hubs can be implemented, it could make a significant contribution to the image of the region, but above all serve as an example for other cities and regions to start similar sustainable concepts.

The introduction of Seabubbles involves high investment costs and the system will not work if there is no network of strategically placed water hubs. The strength of a supportive on-demand water transport system lies primarily in the ability to dock at as many places as possible that would otherwise be difficult to reach when using the common transport modes. This means identifying in advance potential hub locations and necessary decision criteria that may be important for the user groups in the area. This study can serve as a tool to help with selecting socially and technical feasible water hubs for potential hub locations.

Appendix A. Scoring Mobility Hubs

PART I : Scoring table for Mobility Hubs – A Reader's Guide (Urban Design LA, 2021)

Mobility Hub Amenities	Bicycle Connections			Vehicle Connections			Bus Infrastructure		Information-Signange			Support Services				Active Uses		Pedestrian Connections	
	2.1. Bike Share	2.2. Bike Parking	2.3. Bicycling Facilities	3.1. Ride Share/Pick up-Drop off	3.2. Car Share	3.3. EV Charging Stations	4.1. Bus Layover Zone	4.2. Bus Shelters	5.1. Wayfinding	5.2. Real-time Information	5.3. Wi-Fi / Smartphone Connectivity	6.1. Ambassadors	6.2. Waiting Area	6.3. Safety and Security	6.4. Sustainable Approach	7.1. Retail	7.2. Public Space	8.1. To the Mobility Hub	8.2. At the Mobility Hub
(N) Neighborhood	●	●	■	■	○	○	■	○	●	○	○	■	○	○	○	■	■	○	○
(C) Central	●	●	○	●	●	●	○	●	●	●	●	○	○	●	●	○	●	●	●
(R) Regional	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●

Legend: Vital: ● Recommended: ○ Optional: ■

PART II : Scoring Mobility Hubs– MOBILITY HUB GUIDELINES For the Greater Toronto and Hamilton Area (Metrolinx, 2011)

Mobility Hub Typology - Transportation Function

TRANSPORTATION TYPOLOGY		EXAMPLES	DESCRIPTION
T1	Entry	 • Fairview GO • Downtown Milton	• High proportion of outbound trips in the morning peak • Typical amenities include local transit terminals, commuter parking, and bicycle parking and related facilities • Design should address station access requirements and large activity peaks during rush hour
T2	Transfer	  • Kennedy • Etobicoke Centre	• Major transfer point in the regional rapid transit network with transfer between two or more rapid transit lines and other transit services • Often connect multiple transit operators • Large portion of traveller activity within this hub consists of traveller movements within the rapid transit station(s) • Design should focus on ensuring seamless transfer between lines
T3	Destination	  • Union Station • North York Centre	• Major destination in the regional rapid transit network with concentration of employment, recreation, and institutional uses • Typically served by a high number of rapid transit lines • High proportion of inbound trips in the morning peak, with potential to achieve a greater inbound/outbound balance • Design of these hubs should address the destinations served with a greater focus on walking connections to and from the hub (e.g., the PATH network)

PART III : Mobility Hub Quality Standards Assessment Table (ComoUK, 2020)

Typologies	Choice of sustainable modes (including retrofit of existing sites)	Visibility & accessibility	Ease of switching modes	Safety	Practical facilities	Visual, social, community appeal
Large interchanges / City hubs Larger multi-purpose or a network of smaller mobility hubs. High passenger numbers for starting /ending journeys / transferring between modes. Potential to convert private car and taxi trips to sustainable modes by raising the profile and improving links. Space may be limited meaning there may be a need to focus on priority sustainable, efficient modes and links to last mile modes	**Essential** • 1 public transport option • 1 shared mobility option • Cycle parking **Desirable categories:** • Space to increase range and scale of services • **Public transport** e.g.: rail, tram, bus • **On demand** buses, Taxi, private hire • **Shared**: e.g. Car club bay - electric & conventional bike share - electric & conventional • **Infrastructure** e.g. Large scale cycle parking, EV charging bays	**Essential:** • Clear signage with network branded totem • Information on what the hub is at site and in the community • Located in prominent, well-lit location • Safer crossing, pavement repairs • Disabled access, no blockages. **Desirable:** • Safe cycle route • Consideration for hidden disabilities	**Essential** • Co-located within 2 min walk • Real time transport information • Poster transport timetable • Staff support **Desirable** • Digital pillar, (transport info, ticketing, way finding, walk distances, local services). • Immediate co-location • MaaS digital integration • Local tourism information	**Essential** • Street lighting • Staffing core hours **Desirable** • Staffing 24/7 • CCTV	**Essential** • Indoor heated shelter • Toilets **Desirable** • Wi-Fi /phone charging • Kiosk for refreshments • Water fountain • Package delivery lockers	**Essential** • Modern clean infrastructure • Community consultation **Desirable categories** • Visual: e.g. greenery /parklet / statue / art • Social: e.g. Notice board, play area, exercise equipment, • Community: café with seating or retail, edible garden, community art, shared books • Potential for human interaction

Typologies	Choice of sustainable modes including retrofit of existing sites)	Visibility & accessibility	Ease of switching modes	Safety	Practical facilities	Visual, social, community appeal
Transport corridor, smaller interchanges / Linking hubs. Focus on services which link residents in surrounding area to core network services. An opportunity to offer greater choice to people for first and last trips	**Essential** • 1 public transport option • 1 shared mobility option • Cycle parking **Desirable categories:** • Space to increase range and scale of services • **Public transport** e.g.: rail, tram, bus • **On demand** buses, Taxi, private hire • **Shared**: e.g. Car club bay - electric & conventional bike share - electric & conventional • **Infrastructure** e.g. Large scale cycle parking, EV charging bays	**Essential:** • Clear signage with network branded totem • Located in prominent, well-lit location • Safer crossing, pavement repairs • Disabled access, no blockages. • Information on what the hub is at site and in the community **Desirable:** • Safe cycle route • Consideration for hidden disabilities	**Essential** • Co-located within 2 min walk • Real time data • Poster transport timetable **Desirable** • Staff support • Digital pillar,(transport info, ticketing, way finding, walk distances, local services). • Immediate co-location • MaaS digital integration • Local tourism information	**Essential** • Street lighting • Staffing or intercom & CCTV **Desirable** • Staffing 24/7 • CCTV	**Essential** • Covered seating **Desirable** • Toilets • Indoor heated shelter • Wi-Fi /phone charging • Kiosk for refreshments • Water fountain • Package delivery lockers • Bike repair stand / pump	**Essential** • Modern clean infrastructure • Community consultation **Desirable** • Visual: e.g. greenery /parklet / statue / art • Social: e.g. Notice board, play area, exercise equipment, • Community: café with seating or retail, edible garden, community art, shared books

Typologies	Choice of sustainable modes including retrofit of existing sites)	Visibility & accessibility	Ease of switching modes	Safety	Practical facilities	Visual, social, community appeal
Business park / new housing development hubs High density of users. A need to offer commuting links and back to base solutions.	**Essential** • 1 public transport option • 1 shared mobility option • Shared fleets for business travel • Cycle parking **Desirable** • Space to increase range and scale of services • Local bus • On demand buses • Taxi • Back to base car club bay with choice of van / estate car • Bike share e.g. shuttle or back to base bike share, pool • E-cargo bike share / trailers	**Essential:** • Clear signage with network branded totem • Located in prominent, well-lit location • Safer crossing, pavement repairs • Disabled access, no blockages • Information on what the hub is at site and in the community **Desirable:** • Safe cycle route • Consideration for hidden disabilities	**Essential** • Co-located within 2 min walk • Poster transport timetable **Desirable** • Real time data • Digital pillar, (transport info, ticketing, way finding, walk distances, local services). • Immediate co-location • MaaS digital integration • Local tourism information	**Essential** • Street lighting **Desirable** • Staffing 24/7 • CCTV	**Essential** • Covered seating **Desirable** • Toilets • Indoor heated shelter • Wi-Fi /phone charging • Kiosk for refreshments • Water fountain • Package delivery lockers • Bike repair stand / pump	**Essential** • Modern clean infrastructure • Community consultation **Desirable** • Visual: e.g. greenery /parklet / statue / art • Social: e.g. Notice board, play area, exercise equipment, • Community: café with seating or retail, edible garden, community art, shared books

Typologies	Choice of sustainable modes including retrofit of existing sites)	Visibility & accessibility	Ease of switching modes	Safety	Practical facilities	Visual, social, community appeal
Suburbs / Mini hubs Lower density of people with higher private car ownership, mobility hubs can be designed to address local issues e.g. car club spaces to take away issues of over-crowded streets, bike share or secure cycle parking for flats without space for bike storage or DRT to supplement restricted bus services.	**Essential** • 1 public transport option • 1 shared mobility option • Cycle parking **Desirable** • Space to increase range and scale of services • Local bus • On demand services • Car club e.g. Back to base car club bay with range of vehicles • Bike share e.g. Electric / cargo bikes	**Essential:** • Clear signage with network branded totem • Located in prominent, well-lit location • Safer crossing, pavement repairs • Disabled access, no blockages. • Information on what the hub is at site and in the community **Desirable:** • Safe cycle route • Consideration for hidden disabilities	**Essential** • Co-located within 2 min walk • Poster transport timetable **Desirable** • Real time data • Digital pillar, (transport info, ticketing, way finding, walk distances, local services). • Immediate co-location • MaaS digital integration • Local tourism information	**Essential** • Street lighting • Safe crossings • Quality paving without obstacles **Desirable** • CCTV?	**Essential** • Covered seating **Desirable** • Indoor heated shelter • Wi-Fi /phone charging • Kiosk for refreshments • Water fountain • Package delivery lockers • Bike repair stand / pump	**Essential** • Modern clean infrastructure • Community consultation **Desirable** • Visual: e.g. greenery /parklet / statue / art • Social: e.g. Notice board, play area, exercise equipment, • Community: café with seating or retail, edible garden, community art, shared books

Typologies	Choice of sustainable modes including retrofit of existing sites)	Visibility & accessibility	Ease of switching modes	Safety	Practical facilities	Visual, social, community appeal (placemaking)
Small market town, village hubs The extra space in these types of areas can be used to provide a wider range of services as long as there is critical mass to ensure there is viability. Assess local needs such as the limited public transport with pools of shared e-bikes or 2+ ride share stops.	**Essential** • 1 public transport option • 1 shared mobility option • Cycle parking **Desirable** • Space to increase range and scale of services • Regional rail or tram • Local bus • On demand buses • Taxi • Car clubs e.g. Back to base car club bay with choice of van / estate car • Bike share e.g. Back to base bike share, E-cargo bike share / trailers	**Essential:** • Clear signage with network branded totem • Located in prominent, well-lit location • Safer crossing, pavement repairs • Disabled access, no blockages. • Information on what the hub is at site and in the community **Desirable:** • Safe cycle route • Consideration for hidden disabilities	**Essential** • Co-located within 2 min walk • Poster transport timetable **Desirable** • Real time data • Digital pillar, (transport info, ticketing, way finding, walk distances, local services). • Immediate co-location • MaaS digital integration • Local tourism information	**Essential** • Street lighting **Desirable** • Staffing (for information, or other services) or intercom & CCTV	**Essential** • Covered seating • Toilets **Desirable** • Indoor heated shelter • Wi-Fi /phone charging • Kiosk for refreshments • Water fountain • Package delivery lockers • Bike repair stand / pump	**Essential** • Modern clean infrastructure • Community consultation **Desirable** • Visual: e.g. greenery / parklet / statue / art • Social: e.g. Notice board, play area, exercise equipment, • Community: café with seating or retail, edible garden, community art, shared books

Typologies	Choice of sustainable modes including retrofit of existing sites)	Visibility & accessibility	Ease of switching modes	Safety	Practical facilities	Visual, social, community appeal (placemaking)
Tourism Hubs Focus on services with easy registration for visitors which can then provide a seasonal boost to the viability of service for rural residents. Ideally well integrated with journey planning and wider ticketing services (e.g. combined travel with destination entry). While tourism areas are often in rural areas, they can also be areas of high demand where having a tangible, focal point for sustainable modes especially for visitors unfamiliar with the area. Could also apply to tourist destinations in more urban areas.	**Essential** • 1 public transport option • 1 shared mobility option • Cycle parking **Desirable** • Space to increase range and scale of services • Regional rail or tram • Local bus • On demand services • taxi • Car clubs e.g. back to base car clubs • Bike share. E.g Shuttle bike share linking key sites. Cargo & family friendly bikes.	**Essential:** • Clear signage with network branded totem • Located in prominent, well-lit location • Safer crossing, pavement repairs • Disabled signage & access, no blockages. • Information on what the hub is at site and in the community **Desirable:** • Safe cycle route • Consideration for hidden disabilities	**Essential** • Co-located within 2 min walk • Poster transport timetable • Local tourism information **Desirable** • Real time data • Digital pillar, (transport info, ticketing, way finding, walk distances, local services). • Immediate co-location • MaaS digital integration	**Essential** • Street lighting **Desirable** • Staffing (for information, or other services) or intercom & CCTV	**Essential** • Covered seating • Toilets **Desirable** • Indoor heated shelter • Wi-Fi /phone charging • Kiosk for refreshments • Water fountain • Package delivery lockers • Bike repair stand / pump	**Essential** • Modern clean infrastructure • Community consultation **Desirable** • Visual: e.g. greenery /parklet / statue / art • Social: e.g. Notice board, play area, exercise equipment, • Community: café with seating or retail, edible garden, community art, shared books

Appendix B. Survey

Multi-modal water dock in Alblasserdam to facilitate Seabubbles - Best-Worst Method-

Please select from the drop-down menus in the blue boxes

What is your role within this study (Expert: water transit/harbour, industry interest: company or interest group, non-business interest group: politician)?	

1. Key areas

1.a. Three key areas that are located on a multi-modal water dock are listed below. In your opinion, what are the MOST and LEAST important key areas?

Criteria
Access/Egress Zone - Land Side
Access/Egress Zone - Water Side
Facilities & Retail Zone

Most Important key area:	
Least Important key area:	

1.b. Select a number between 1 and 9 to indicate the preference of the MOST important key area over the other areas. The number 1 shows an equal importance of both key areas. Number 9 means that the MOST important key area is extremely more important than the other key areas.

Access/Egress Zone - Land side	Access/Egress Zone - Water Side	Facilities & Retail Zone

1.c. Select a number between 1 and 9 to indicate the preference of the key areas over the LEAST important key area. The number 1 shows an equal importance of both key areas. Number 9 means that a key area is extremely more important than the LEAST important key area.

Access/Egress Zone - Land Side	
Access/Egress Zone - Water Side	
Facilities & Retail Zone	

2. Decision criteria Access/Egress Zone – Land side

2.a. Eight decision criteria that are linked to the Access/Egress Zone – Land side are listed below. In your opinion, what are the MOST and LEAST important decision criteria?

Decision Criteria
> 1 Public Transport link
>1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)
>1 Shared mobility options **not** to be returned to hub (e-scooters, e-bikes, etc.)
Shared mobility for business travel (shuttle buses)
On-site Bicycle parking
Car parking
Kiss +Ride
Taxi stand

Most Important decision criterion:	
Least Important decision criterion:	

2.b. Select a number between 1 and 9 to indicate the preference of the MOST important decision criterion over the other decision criteria. The number 1 shows an equal importance of both decision criteria. Number 9 means that the MOST important decision criterion is extremely more important than the other decision criterion.

> 1 Public Transport link	>1 Shared mobility options to be returned to hub	>1 Shared mobility options **not** to be returned to hub	Shared mobility for business travel (shuttle buses)	On-site Bicycle parking	Car parking	Kiss +Ride	Taxi stand

2.c. Select a number between 1 and 9 to indicate the preference of the decision criteria over the LEAST important decision criterion. The number 1 shows an equal importance of both decision criteria. Number 9 means that a decision criterion is extremely more important than the LEAST important decision criterion.

> 1 Public Transport link	
>1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)	
>1 Shared mobility options **not** to be returned to hub (e-scooters, e-bikes, etc.)	
Shared mobility for business travel (shuttle buses)	
On-site Bicycle parking	
Car parking	
Kiss +Ride	
Taxi stand	

3. Decision criteria Access/Egress Zone – Water side

3.a. Eight decision criteria that are linked to the Access/Egress Zone – Water side are listed below. In your opinion, what are the MOST and LEAST important decision criteria?

Decision Criteria
Allow on-site hydrogen bunkering to decrease waiting times
Staff support
Flexibility in service (fixed/on-demand)
Operational reliability
Wide operational timeslots
On-demand access to waiting area (e.g. via app)
Prepared dock for future autonomous sailing
Dock sharing with other water transport modes

Most Important decision criterion:	
Least Important decision criterion:	

3.b. Select a number between 1 and 9 to indicate the preference of the MOST important decision criterion over the other decision criteria. The number 1 shows an equal importance of both decision criteria. Number 9 means that the MOST important decision criterion is extremely more important than the other decision criterion.

Allow on-site hydrogen bunkering to decrease waiting times	Staff support	Flexibility in service (fixed/on-demand)	Operational reliability	Wide operational timeslots	On-demand access to waiting area (e.g. via app)	Prepared for future autonomous sailing	Dock sharing with other water transport modes

3.c. Select a number between 1 and 9 to indicate the preference of the decision criteria over the LEAST important decision criterion. The number 1 shows an equal importance of both decision criteria. Number 9 means that a decision criterion is extremely more important than the LEAST important decision criterion.

Allow on-site hydrogen bunkering to decrease waiting times	
Staff support	
Flexibility in service (fixed/on-demand)	
Operational reliability	
Wide operational timeslots	
On-demand access to waiting area (e.g. via app)	
Prepared dock for future autonomous sailing	
Dock sharing with other water transport modes	

4. Decision criteria Facilities & Retail Zone

4.a. Eight decision criteria that are linked to Facilities & Retail Zone are listed below.
In your opinion, what are the MOST and LEAST important decision criteria?

Decision Criteria
Tourist Information
Real-time travel data
Digital stand for buying (combi-) tickets and way-finding
Toilets
Kiosk
On-site activities for business (e.g. meeting hall)
On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)
Wifi

Most Important main criterion:	
Least Important main criterion:	

4.b. Select a number between 1 and 9 to indicate the preference of the MOST important decision criterion over the other decision criteria. The number 1 shows an equal importance of both decision criteria. Number 9 means that the MOST important decision criterion is extremely more important than the other decision criterion.

Tourist Information	Real-time travel data	Digital stand for buying (combi-) tickets and way-finding	Toilets	On-site activities for business (e.g. meeting hall)	On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)	Kiosk	Wifi

4.c. Select a number between 1 and 9 to indicate the preference of the decision criteria over the LEAST important decision criterion. The number 1 shows an equal importance of both decision criteria. Number 9 means that a decision criterion is extremely more important than the LEAST important decision criterion.

Tourist Information	
Real-time travel data	
Digital stand for buying (combi-) tickets and way-finding	
Toilets	
Kiosk	
On-site activities for business (e.g. meeting hall)	
On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)	
Wifi	

Thank you!

Explanation of Decision Criteria for Multi-criteria Analysis

Key Area 1: The Access/Egress Zone - Land side is the area where users enter or exit the water hub location. This area ideally lies within a maximum radius of 250 meters/2.5min walk. All users are entering or leaving this area by walk, public transport, bicycle, private car or any other form of shared mobility.

Decision criteria:

Decision Criteria related to land side	Explanation
> 1 Public Transport link	Availability of at least 2 public transport links
>1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)	Availability of at least 2 shared mobility options that can only be returned back to the hub after use, i.e. bicycle rental.
>1 Shared mobility options **not** to be returned to hub (e-scooters, e-bikes, etc.)	Availability of at least 2 shared mobility options that don't have to be returned back to the hub after use but can be parked in another zone, i.e. Felix e-scooter
Shared mobility for business travel (shuttle buses)	Shuttle service that brings people from and to business areas
On-site Bicycle parking	Private bicycle parking within a maximum radius of 250 meters/2.5min walk
Car parking	Private car parking within a maximum radius of 250 meters/2.5m walking time.
Kiss +Ride	Ability for car users to drive very close to the hub to drop off travelers
Taxi stand	Taxi stand within a distance of maximum radius of 250 meters/2.5min walk

Key Area 2: The Access/Egress Zone - Water Side*:* Given the nature of waterborne modes, which occupy a separate space that is slightly more distant from land transport modalities, the waterborne modes in this research will be assigned a separate Access/ Egress zone. This area focuses on the actions around departure and arrival by water mode.

Decision Criteria related to water side	Explanation
Allow on-site hydrogen bunkering to decrease waiting times	To fully charge a Seabubble with hydrogen takes 5 minutes. If this can be on-site, the waiting times can be reduced, since no extra charging stops need to be made
Staff support	Availability of support staff for information and safety oversight
Flexibility in service (fixed/on-demand)	Possibility to deploy Seabubbles as fixed scheduled based rides next to on-demand services (This means that less bubbles are available for on-demand transport if scheduled bubbles are active).
Operational reliability	This relates to the time it takes before a Seabubble is available and if the indicated time also correct.
Wide operational timeslots	The importance of offering a 24/7 on-demand Seabubble transport service.
On-demand access to waiting area (e.g. via app)	The possibility to enter the water-side via an entrance that can only be accessed by the traveller that made a reservation (car parking principle, i.e. ParkBee)
Prepared dock for future autonomous sailing	The Seabubbles are planned to offer autonomous transport in the future. The criterion relates to the importance that the dock should be prepared for autonomous sailing, considering safety and accessibility.
Dock sharing with other water transport modes	The importance that other water modes can also use the water hub next to the Seabubbles

Key area 3: The Facilities and Retail Zone is where additional services, such as eateries and retail, are offered to travelers that have some more time to spend at the hub. The desired facilities depend on the user type and can therefore vary from hub to hub.

Decision Criteria related to Facilities & Retail Zone	**Explanation**
Tourist Information	The availability of tourist posters with information, direction signs, etc.
Real-time travel data	Boards with real time travel data of all scheduled modes (public transport) on the hub location. GPS tracking of the reserved Seabubble via an app or at the location
Digital stand for buying (combi-) tickets and way-finding	Stands to make a reservation for a Seabubble or buy tickets for public transport or other modes.
Toilets	Availability of on-site toilets.
Kiosk	Small eatery to offer information and small refreshments.
On-site activities for business (e.g. meeting hall)	Offer the possibility to make reservations for on-site meeting rooms or workspaces
On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)	Offer facilities that add to the user experience due to reduction of waiting times, such as restaurants and shops.
Wifi	Availability of a good free internet connection

Appendix C. Scoring of hubs on decision criteria

Table 21: Decision criteria scoring matrix for hubs

		Hub type					
		1	2	3	4	5	6
	Decision Criteria	**Optional(1)/Recommended(2)/ Vital(3)**					
Key area							
Access/Egress Land side zone	> 1 Public Transport link	3	3	3	2	1	3
	>1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)	2	2	3	1	1	3
	>1 Shared mobility options **not** to be returned to hub (e-scooters, e-bikes, etc.)	3	3	2	2	1	3
	Shared mobility for business travel (shuttle buses)	1	1	3	1	1	1
	On-site Bicycle parking	3	3	3	3	3	3
	Car parking	2	2	3	3	3	3
	Kiss +Ride	2	2	2	2	3	1
	Taxi stand	2	2	2	2	1	2
Access/Egress Water Side zone	Allow on-site bunkering to decrease waiting times	1	1	2	2	2	2
	Staff support	3	3	2	2	1	2
	Flexibility in service (fixed/on-demand)	1	1	2	1	1	2
	Operational reliability	2	2	3	3	3	3
	Wide operational timeslots	2	2	3	3	2	3
	On-demand access to waiting area (e.g. via app)	1	1	2	2	3	1
	Prepared dock for future autonomous sailing	2	2	2	1	1	2
	Dock sharing with other water transport modes	3	3	2	2	1	3
Facilities & Retail zone	Tourist Information	1	1	1	1	1	3
	Real-time travel data	3	3	2	2	1	2
	Digital stand for buying (combi-) tickets and way-finding	2	2	2	1	1	2
	Toilets	3	2	2	3	3	3
	Kiosk	2	2	2	2	1	2
	On-site activities for business (e.g. meeting hall)	1	1	3	1	1	1
	On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)	2	2	2	2	1	2
	Wifi	2	2	2	2	1	2

Hub 1: Large interchange - City Centre Mobility hubs
Hub 2: Medium Interchange- Transport Corridor/Linking hubs
Hub 3: Business park/ New housing development hubs
Hub 4: Village hubs
Hub 5: Suburb hubs
Hub 6: Tourism hubs

Appendix D. BWM Solver: Resulting weights for decision criteria for Case study Albasserdam

Table 22: Resulting weights and ξ for key areas from all surveys

Weights KEY areas	Access/Egress Land Zone	Access/Egress Water Zone	Facilities & Retail Zone	ξ
Expert	0,7386	0,0909	0,1705	0,2841
Industry Interest	0,7245	0,0714	0,2041	0,2959
Non-Business Interest	0,5227	0,3864	0,0909	0,2500

Table 23: Resulting weights and ξ for decision criteria for all key areas from all surveys

Weights Access/Egress Land Zone	> 1 Public Transport link	>1 Shared mobility options to be returned to hub	>1 Shared mobility options not to be returned to hub	Shared mobility for business travel (shuttle buses)	On-site Bicycle parking	Car parking	Kiss +Ride	Taxi stand	ξ
Expert	0,1508	0,1508	0,1508	0,1508	0,1508	0,1006	0,1006	0,0447	0,3017
Industry Interest	0,1489	0,1489	0,1489	0,1489	0,1489	0,0993	0,0993	0,0567	0,2979
Non-Business Interest	0,1546	0,1546	0,0309	0,1546	0,1546	0,1856	0,1031	0,0619	0,1237

Weights Access/Egress Water Zone	Allow on-site hydrogen bunkering to decrease waiting times	Staff support	Flexibility in service (fixed/on-demand)	Operational reliability	Wide operational timeslots	On-demand access to waiting area (e.g. via app)	Prepared for future autonomous sailing	Dock sharing with other water transport modes	ξ
Expert	0,0595	0,1488	0,1488	0,2183	0,1488	0,0278	0,0992	0,1488	0,0794
Industry Interest	0,0224	0,1519	0,1519	0,2079	0,1519	0,0608	0,1013	0,1519	0,0959
Non-Business Interest	0,1768	0,1179	0,1179	0,2288	0,1179	0,0347	0,0884	0,1179	0,1248

Weights Facilities & Retail Zone	Tourist Information	Real-time travel data	Digital stand for buying (combi-) tickets and way-finding	Toilets	On-site activities for business (e.g. meeting hall)	On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)	Kiosk	Wifi	ξ
Expert	0,0776	0,2484	0,1294	0,1294	0,1294	0,1294	0,1294	0,0272	0,1397
Industry Interest	0,0803	0,2007	0,1338	0,1338	0,1338	0,1338	0,1338	0,0502	0,2007
Non-Business Interest	0,0986	0,1479	0,1829	0,2763	0,0739	0,0233	0,0986	0,0986	0,1128

Appendix E. BWM Solver: Results of performance matrices for Case Study Albasserdam

Table 24: Performance matrix of Expert

		Hub score on each decision criterion (1=optionall, 2=recommended, 3=vital)						Standardized scores using Linear Max $n_{ij} = \frac{r_{ij}}{r_{max}}$						Weight of Key area multiplied by Weight of Decision Criterion
Key area	Decision criterion	Hub 1	Hub 2	Hub 3	Hub 4	Hub 5	Hub 6	Hub 1	Hub 2	Hub 3	Hub 4	Hub 5	Hub 6	
Access/Egres+B4+A4:D27+A4:D28+B4+A4:H27	> 1 Public Transport link	3	3	3	2	1	3	1,000	1,000	1,000	0,667	0,333	1,000	0,111
	>1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)	2	2	3	1	1	3	0,667	0,667	1,000	0,333	0,333	1,000	0,111
	>1 Shared mobility options not to be returned to hub (e-scooters, e-bikes, etc.)	3	3	2	2	1	3	1,000	1,000	0,667	0,667	0,333	1,000	0,111
	Shared mobility for business travel (shuttle buses)	1	1	3	1	1	1	0,333	0,333	1,000	0,333	0,333	0,333	0,111
	On-site Bicycle parking	3	3	3	3	3	3	1,000	1,000	1,000	1,000	1,000	1,000	0,111
	Car parking	2	2	3	3	3	3	0,667	0,667	1,000	1,000	1,000	1,000	0,074
	Kiss + Ride	2	2	2	2	3	1	0,667	0,667	0,667	0,667	1,000	0,333	0,074
	Taxi	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,033
Access/Egress Water side Zone	Allow on-site hydrogen bunkering to decrease waiting times	1	1	2	2	2	2	0,500	0,500	1,000	1,000	1,000	1,000	0,005
	Staff support	3	3	2	2	1	2	1,000	1,000	0,667	0,667	0,333	0,667	0,014
	Flexibility in service (fixed/on-demand)	1	1	2	1	1	2	0,500	0,500	1,000	0,500	0,500	1,000	0,014
	Operational reliability	2	2	3	3	3	3	0,667	0,667	1,000	1,000	1,000	1,000	0,020
	Wide operational timeslots	2	2	3	3	2	3	0,667	0,667	1,000	1,000	0,667	1,000	0,014
	On-demand access to waiting area (e.g. via app)	1	1	2	2	3	1	0,333	0,333	0,667	0,667	1,000	0,333	0,003
	Prepared for future autonomous sailing	2	2	2	1	1	2	1,000	1,000	1,000	0,500	0,500	1,000	0,009
	Dock sharing with other water transport modes	3	3	2	2	1	3	1,000	1,000	0,667	0,667	0,333	1,000	0,014
Facilities & Retail Zone	Tourist Information	1	1	1	1	1	3	0,333	0,333	0,333	0,333	0,333	1,000	0,013
	Real-time travel data	3	3	2	2	1	2	1,000	1,000	0,667	0,667	0,333	0,667	0,042
	Digital stand for buying (combi-) tickets and way-finding	2	2	2	1	1	2	1,000	1,000	1,000	0,500	0,500	1,000	0,022
	Toilets	3	2	2	3	3	3	1,000	0,667	0,667	1,000	1,000	1,000	0,022
	On-site activities for business (e.g. meeting hall)	1	1	3	1	1	1	0,333	0,333	1,000	0,333	0,333	0,333	0,022
	On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,022
	Kiosk	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,022
	Wifi	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,005
								0,793	0,786	0,898	0,683	0,565	0,841	1,000
								3	4	1	5	6	2	

Hub 1: Large interchange - City Centre Mobility hubs
Hub 2: Medium Interchange- Transport Corridor/Linking hubs
Hub 3: Business park/ New housing development hubs
Hub 4: Village hubs
Hub 5: Suburb hubs
Hub 6: Tourism hubs

Table 25: Performance matrix of Industry Interest.

		Hub score on each decision criterion (1=optionall, 2=recommended, 3=vital)						Standardized scores using Linear Max $n_{ij} = \frac{r_{ij}}{r_{max}}$						Weight of Key area multiplied by Weight of Decision Criterion
Key area	Decision criterion	Hub 1	Hub 2	Hub 3	Hub 4	Hub 5	Hub 6	Hub 1	Hub 2	Hub 3	Hub 4	Hub 5	Hub 6	
Access/Egres+B4+A4:D27+A4:D28+B4+A4:H27	> 1 Public Transport link	3	3	3	2	1	3	1,000	1,000	1,000	0,667	0,333	1,000	0,108
	>1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)	2	2	3	1	1	3	0,667	0,667	1,000	0,333	0,333	1,000	0,108
	>1 Shared mobility options not to be returned to hub (e-scooters, e-bikes, etc.)	3	3	2	2	1	3	1,000	1,000	0,667	0,667	0,333	1,000	0,108
	Shared mobility for business travel (shuttle buses)	1	1	3	1	1	1	0,333	0,333	1,000	0,333	0,333	0,333	0,108
	On-site Bicycle parking	3	3	3	3	3	3	1,000	1,000	1,000	1,000	1,000	1,000	0,108
	Car parking	2	2	3	3	3	3	0,667	0,667	1,000	1,000	1,000	1,000	0,072
	Kiss + Ride	2	2	2	2	3	1	0,667	0,667	0,667	0,667	1,000	0,333	0,072
	Taxi	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,041
Access/Egress Water side Zone	Allow on-site hydrogen bunkering to decrease waiting times	1	1	2	2	2	2	0,500	0,500	1,000	1,000	1,000	1,000	0,002
	Staff support	3	3	2	2	1	2	1,000	1,000	0,667	0,667	0,333	0,667	0,011
	Flexibility in service (fixed/on-demand)	1	1	2	1	1	2	0,500	0,500	1,000	0,500	0,500	1,000	0,011
	Operational reliability	2	2	3	3	3	3	0,667	0,667	1,000	1,000	1,000	1,000	0,015
	Wide operational timeslots	2	2	3	3	2	3	0,667	0,667	1,000	1,000	0,667	1,000	0,011
	On-demand access to waiting area (e.g. via app)	1	1	2	2	3	1	0,333	0,333	0,667	0,667	1,000	0,333	0,004
	Prepared for future autonomous sailing	2	2	2	1	1	2	1,000	1,000	1,000	0,500	0,500	1,000	0,007
	Dock sharing with other water transport modes	3	3	2	2	1	3	1,000	1,000	0,667	0,667	0,333	1,000	0,011
Facilities & Retail Zone	Tourist Information	1	1	1	1	1	3	0,333	0,333	0,333	0,333	0,333	1,000	0,016
	Real-time travel data	3	3	2	2	1	2	1,000	1,000	0,667	0,667	0,333	0,667	0,041
	Digital stand for buying (combi-) tickets and way-finding	2	2	2	1	1	2	1,000	1,000	1,000	0,500	0,500	1,000	0,027
	Toilets	3	2	2	3	3	3	1,000	0,667	0,667	1,000	1,000	1,000	0,027
	On-site activities for business (e.g. meeting hall)	1	1	3	1	1	1	0,333	0,333	1,000	0,333	0,333	0,333	0,027
	On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,027
	Kiosk	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,027
	Wifi	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,010
								0,797	0,788	0,898	0,686	0,562	0,842	1,000
								3	4	1	5	6	2	

Hub 1: Large interchange - City Centre Mobility hubs
Hub 2: Medium Interchange- Transport Corridor/Linking hubs
Hub 3: Business park/ New housing development hubs
Hub 4: Village hubs
Hub 5: Suburb hubs
Hub 6: Tourism hubs

Table 26: Performance matrix of Non-Business Interest

Key area	Decision criterion	Hub score on each decision criterion (1=optionall, 2=recommended, 3=vital)						Standardized scores using Linear Max $n_{ij} = \frac{r_{ij}}{r_{max}}$						Weight of Key area multiplied by Weight of Decision Criterion
Key area	Decision criterion	Hub 1	Hub 2	Hub 3	Hub 4	Hub 5	Hub 6	Hub 1	Hub 2	Hub 3	Hub 4	Hub 5	Hub 6	
Access/Egres+B4+A4:D27+A4:D28+B4+A4:H27	> 1 Public Transport link	3	3	3	2	1	3	1,000	1,000	1,000	0,667	0,333	1,000	0,081
	>1 Shared mobility options to be returned to hub (e-bikes, bikes, e-scooters, e-cars, etc.)	2	2	3	1	1	3	0,667	0,667	1,000	0,333	0,333	1,000	0,081
	>1 Shared mobility options not to be returned to hub (e-scooters, e-bikes, etc.)	3	3	2	2	1	3	1,000	1,000	0,667	0,667	0,333	1,000	0,016
	Shared mobility for business travel (shuttle buses)	1	1	3	1	1	1	0,333	0,333	1,000	0,333	0,333	0,333	0,081
	On-site Bicycle parking	3	3	3	3	3	3	1,000	1,000	1,000	1,000	1,000	1,000	0,081
	Car parking	2	2	3	3	3	3	0,667	0,667	1,000	1,000	1,000	1,000	0,097
	Kiss + Ride	2	2	2	2	3	1	0,667	0,667	0,667	0,667	1,000	0,333	0,054
	Taxi	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,032
Access/Egress Water side Zone	Allow on-site hydrogen bunkering to decrease waiting times	1	1	2	2	2	2	0,500	0,500	1,000	1,000	1,000	1,000	0,068
	Staff support	3	3	2	2	1	2	1,000	1,000	0,667	0,667	0,333	0,667	0,046
	Flexibility in service (fixed/on-demand)	1	1	2	1	1	2	0,500	0,500	1,000	0,500	0,500	1,000	0,046
	Operational reliability	2	2	3	3	3	3	0,667	0,667	1,000	1,000	1,000	1,000	0,088
	Wide operational timeslots	2	2	3	3	2	3	0,667	0,667	1,000	1,000	0,667	1,000	0,046
	On-demand access to waiting area (e.g. via app)	1	1	2	2	3	1	0,333	0,333	0,667	0,667	1,000	0,333	0,013
	Prepared for future autonomous sailing	2	2	2	1	1	2	1,000	1,000	1,000	0,500	0,500	1,000	0,034
	Dock sharing with other water transport modes	3	3	2	2	1	3	1,000	1,000	0,667	0,667	0,333	1,000	0,046
Facilities & Retail Zone	Tourist Information	1	1	1	1	1	3	0,333	0,333	0,333	0,333	0,333	1,000	0,009
	Real-time travel data	3	3	2	2	1	2	1,000	1,000	0,667	0,667	0,333	0,667	0,013
	Digital stand for buying (combi-) tickets and way-finding	2	2	2	1	1	2	1,000	1,000	1,000	0,500	0,500	1,000	0,017
	Toilets	3	2	2	3	3	3	1,000	0,667	0,667	1,000	1,000	1,000	0,025
	On-site activities for business (e.g. meeting hall)	1	1	3	1	1	1	0,333	0,333	1,000	0,333	0,333	0,333	0,007
	On-site activities for leisure (e.g. restaurant/ retail/ cafes, etc.)	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,002
	Kiosk	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,009
	Wifi	2	2	2	2	1	2	1,000	1,000	1,000	1,000	0,500	1,000	0,009
								0,748	0,740	0,923	0,744	0,658	0,877	1,000
								3	4	1	5	6	2	

Hub 1: Large interchange - City Centre Mobility hubs
Hub 2: Medium Interchange- Transport Corridor/Linking hubs
Hub 3: Business park/ New housing development hubs
Hub 4: Village hubs
Hub 5: Suburb hubs
Hub 6: Tourism hubs

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