University of Groningen

Industrial Engineering & Management

Final Report

Integration Project IEM:
Canals versus Roads

Performance difference measured, based on key performance indicators, for transportation form a hub to the city centre of Groningen

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Abstract

Urban freight logistics, currently, has a negative impact on the liveability of urban centres. This negative impact is a result of issues, such as emissions, congestion, noise pollution and traffic accidents. All of these problems originate from the chosen delivery method. Freight delivery in Groningen is done predominantly by road-based vehicles such as trucks.

The municipality of Groningen recognises the undesirability of greenhouse gasses and, together with many other parties, signed on to the 'Green deal ZES' which has the goal of making city centre logistics emission-free by 2025. Their ultimate goal is to make the city more attractive and liveable.

In this thesis, the current state of freight logistics in Groningen is assessed and an alternative delivery method is proposed. The proposed method, called canal-based freight transportation, will make use of boats and the waterways around Groningen to deliver a part of the cities goods, as well as collecting waste on its way back. The new method is evaluated on its ability to mitigate the issues present in the current system. A comparison between the current and the proposed method is made and its merits judged based on certain key performance indicators. This method is designed explicitly for the city of Groningen but it might prove to be applicable in other cities.

Water-based logistics is an interesting and promising transportation method. Based on the finding in this thesis, more research should be done to determine the practical viability of this method, especially the economic viability.

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Chapter 1 Introduction to Groningen's problematic freight transportation

1.1 Context: Topic and its relevance

The topic of this thesis is freight transportation in the city centre of Groningen. Freight transportation is a part of a city's Logistics. A well-working freight transportation system leads to economic opportunity and does not result in unwanted side-effects. This topic is relevant because of its, currently, negative impact on the economic viability of the city as well as its liveability and its appeal to visitors. The city of Groningen is seen as the economic centre of the north of the Netherlands (Rook, Piekema, van Rijn, Edzes, & Broersma, 2014), therefore its freight logistics will also have regional consequences.

The term transportation, used in the preceding paragraph, is meant as the two-way movement of a vehicle, meaning freight being drop-off at the customer and waste being collected and brought back to a loading area/depot. The term delivery will exclusively be used as a one-way flow of goods, except for delivery van, because this describes a class of vehicles.

According to the supply profile of Groningen (Buck Consultants International, 2013), freight delivery to the city centre is, currently, exclusively done by road. However, it can be divided into 6 sub-categories: bicycle couriers, passenger cars, delivery vans, small trucks, trucks and trailer pullers.

1.2 Problem description: Negative effects of an unsustainable transportation method:

Road-based transportation is the method currently being used for transporting goods to the centre of Groningen. This method, however, has some significant drawbacks. The vast majority of vehicles being used, at this moment, make use of fossil fuel based engines; this means they create emissions and noise while being used.

Besides the negative side-effects of the chosen power plant, the dimensions of the vehicle also play a role. Delivery vehicles are an active part of traffic and take up a significant amount of space on the road. Road-based Freight transportation, therefore, is a large contributor to congestion (*Transport en mobiliteit.*2016).

These dimensions also play a role when it comes to traffic accidents. Delivery vehicles need to park to make the actual delivery. However, the city centre of Groningen is not car friendly and has little to no parking sports for delivery vehicles. This means they have to (partly) park on the sidewalk. This blocks the sidewalk and creates dangerous situations with pedestrians, cyclists and other traffic. Besides parking, when driving, delivery vehicles, especially the larger ones have a blind spot. This means they cannot see part of the traffic in their mirrors, which is particularly troubling in a very busy inner city, as it can more quickly result in an accident (Moorlag, 2018).

Some of these side-effects are aggravated by government policy, in this case, the local government. Policies such as delivery timeslots and one-way streets make the city more cyclist and pedestrian friendly. However, it also makes it less delivery vehicle friendly. The effects of these policies are set to increase (*Uitvoeringsprogramma bestemming binnenstad 2016-2021*2016) and restrain access, for delivery vehicles, to more of the city. As well as impose stricter (Zero-) emission norms on the vehicles used to deliver goods (Green deal zes.2018)

In this thesis, the described side-effects will be quantified and an alternative method will be designed and compared to the current system values.

1.3 Problem owner: The municipality of Groningen

The problem owner in this thesis is the municipality of Groningen. They have recognised the negative side-effects of freight delivery for the city and they play a significant part in any possible solution. Their aim is to make the city more liveable for inhabitants and appealing to visitors and inhabitants (van der Vlugt, 2017).

The municipality is responsible for the well-being of the inhabitants of the city as well as for the economic prosperity of the city. This results in some conflicting stakes, as the wellbeing of the inhabitants requires both plentiful access to food and other types of goods, but that said, it also requires a good environment, meaning clean air, little noise pollution and in general a good future for the generation to come. The wellbeing of the inhabitants can also conflict with the economic prosperity of the city of Groningen. Stricter emission norms, while better for inhabitants health, can make it less or not profitable for goods to be delivered to the city. This can have a negative effect on the economic viability and prosperity of the city.

The municipality creates the rules that govern the transport industry in Groningen. This gives them significant power over the industry; this power can be used to lessen the aforementioned effects. They are also largely responsible for the infrastructure in the city centre.

1.4 Research goal and questions: Sustainable freight transportation in Groningen

Based on the aforementioned, the conclusion can be drawn that the current method for delivering goods to the city centre leads to some sub-optimal results. The goods, currently, get to their customers, but not without creating significant side-effects. Due to aggravating conditions, this method will not be sustainable in the future. The goal for this thesis will therefore be; **to design a method which will mitigate the side-effects of freight transportation and compared it to the existing method, based on certain key performance indicators (K.P.I.),** to determine viability.

To reach this goal and design such a method, certain knowledge will be required. This knowledge can be gained by asking and finding the answers to certain research and design questions.

Research questions:

- What are the defining characteristics of freight transportation in Groningen?
- What methods are currently being used or developed to lessen the side-effects of urban freight transportation?

Based on those questions a method was chosen and additional questions were asked:

Further research questions:

- How many tons/m3 of goods come into Groningen per year/month/day?
- What type of goods are they? How can they be classified?
- How much CO_2 is released in Groningen because of good transportation?
- How many accidents happen per year because of goods transportation?
- How much does transportation contribute to congestion?
- How much noise is generated because of transportation?
- What key performance indicators, can be used to describe the side-effects and compare the two methods?

Design questions:

- What does the waterway infrastructure of Groningen look like and what type, dimensions and load capacity boat will it support, if any?
- At what speed can the boat travel legally?
- What delivery route should be taken by such a vessel?
- How much horsepower should the engine of this vessel have to propel its cargo? How does this work when it is an electric engine?
- What is the best method to load and unload the boat?
- How will the end delivery to the customer be done?

Based on the design questions, a design for the method can be proposed. To compare this to the current method more questions will have to be answered.

- How much electricity will this design use per hour/day/week? And how much does that cost?
- How much CO_2 is created in the generation of this electricity?
- How many accidents take place on the water and for what reason?
- How much noise does an electric engine create and how will this be perceived from the canal side (quay)?

1.5 Research limits (scope): Centre of Groningen, transport between hub and city centre and Freight transportation

Transportation of goods can have as wide a scope as the planet. However, for this thesis, the scope will be the transportation of goods to the city centre of Groningen from a hub. The hub is chosen as both the starting and end point. Hubs are seen as an integral part of any future logistics system and will, therefore, also be part of any freight transportation system.

1.6 Design method:

The aim of this thesis was to create a design and compare this design to the current system. This design has to be supported by literature. However, it should also consider real-world implementation and plan for that in the design. A good design is one in which, stakeholders are clearly involved in setting design parameters. It must also have an iterative nature as the best designs are those that are adapted after gaining new insight. The regulative cycle, of van Strien in figure 1, lends itself perfectly to this task.

During the starting stage of the project information about the topic as well as information about the local implications of this topic where investigated. Contact with the problem owner was established, to discuss the problems presented by the topic. This information and knowledge gained from the problem owner as well as prior research was used in making a decision about the problem or set of problems which were later tackled in the project while keeping in mind the time frame. These problems were then analysed and put into context by creating a structure diagram. After finding the proper context, the parameters to measure the system by, also known as key performance indicators, where determined. Ideally, these K.P.I.'s are known before the design phase starts and incorporated in the decision-making process when choosing design elements. However, in this case, the K.P.I.'s were selected after starting work on the design. Implementation is a goal of a design, but for this thesis, the design was not implemented, this is mostly due to time constraints. The evaluation stage is done based on theoretical values created during and after the design process was completed. These values are rough and further research should be performed to improve the quality of these values. This will improve the quality and significance of the results. Ideally, this process is reiterated until the design satisfies all design and stakeholder requirements. However the time, for this thesis was limited and the cycle was, therefore only gone through once.

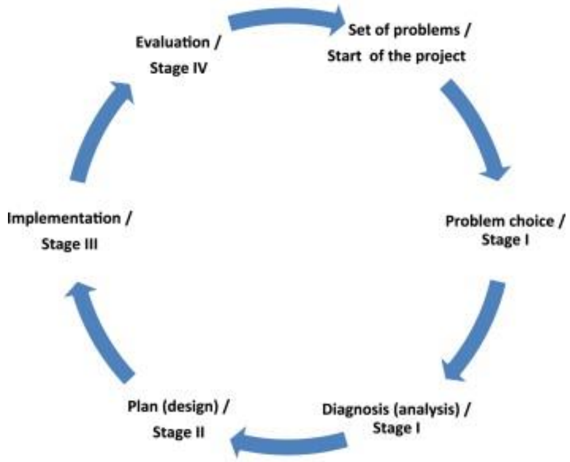

Figure 1: Design cycle van Strien (van Strien, 1997)

1.6.1 Used research tools

- **Literature research:** Sources like CBS data were gathered and used to correlate data gained from reports to the city centre. Besides this general knowledge was acquired about freight logistics and its real-world implications.
- **Interviews (found in Appendix B and D):** Two interviews were held to gain knowledge about already implemented canal based delivery systems as well as about the canals of Groningen. Interviews were held whit specifically these experts because most of this information they can provide is not written down. It also provided an opportunity to see such a system in action and determine good and bad practices. The interviews were not scripted and they were not sent to the interviewee to confirm the right interpretation of their words, this would have made the content more reliability and add to the reliability of the thesis.
- **Practical observations:** A tour of the city centre of Groningen was made, both on land and on the water to observe bridges and quays first hand. This method was chosen as it provides a real impression of the infrastructure which differs from the reports that are written about it. It revealed that in every quarter there are areas in which loading and unloading can take place, but it also illustrated the narrowness of some bridge heights. The results of these observations were used in determining the viability of the design.
- **Excel used for data correlation and extrapolation:** Very little data was pertaining specifically to the city centre, therefore excel was used to extrapolate from the regional or sometimes countrywide scale data to the city centre.

Chapter 2 Literature study: Freight consolidation, water-based transport and used tools

In this literature study, only two broader topics will be discussed and its relevant information applied throughout this thesis. Besides these two topics, many other documents and statistics were gathered and knowledge was gained through direct contact with experts. When applicable these sources will be cited in the relevant chapter or paragraph.

2.1 Freight consolidation: The key to reducing waste

Freight consolidation is the key to making more efficient use of the current transport vehicles and of possible alternative methods of transportation. Freight consolidation takes place at a logistics hub or consolidation centre. Freight consolidation, if done properly, means less freight traffic on the road while still delivering to everyone. If the delivery method used to get the freight to its end destination is emission-free, an emission-free last mile can be realized. Freight consolidation means that the goods which are coming to Groningen are caught outside of the city at a consolidation centre. The goods that go to a consolidation centre are often a small part of a load of a bigger truck, this truck would normally only deliver a small part of its load in the city centre. These Smaller and more scattered loads can be put together in one, preferably emission-free vehicle. This reduces the number of delivery vehicles that would need to go to and drive in the city centre. For example, instead of 20 trucks delivering 10% of their load to the city centre, 2 or 3 efficiently loaded trucks could be used to achieve the same objective.

Freight consolidation also has its detractors. As it would create an additional point of handling, it requires a physical location close to the city and personnel to unload and reload the goods. Besides that, it will also add a liability, who is responsible for the damages if something breaks during this process of unloading and reloading?

The figure below represents a future logistic system in which no emissions are created in the delivery process to the city centre and in which consolidation can be performed in the eco logistic hub. It also represents parts of the ideals of a circular economy as for instance waste streams can be returned to local hubs as a step in closing the loop.

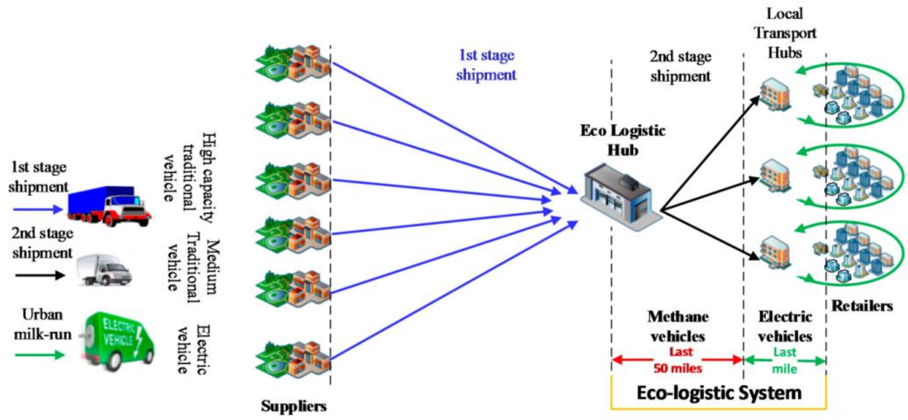

Figure 2: A description of a logistical hub (Faccio & Gamberi, 2015)

2.2 Canal based delivery platforms: Waterways - roads to the future

Freight consolidation is not the only method which has to be considered when looking to improve urban freight transportation. Alternate delivery methods must also be considered. The city centre of Groningen is completely surrounded by canals, if these canals can be used to deliver a part of the goods to the city centre, in a consolidated way, fewer vehicles would need to make the trip to and inside the city centre. The idea proposed and put in to practice in two Dutch cities, is a canal based delivery platform, which is electrically powered. These platforms are filled and refilled from the edges of the city and deliver to the sides of the canals, from where it is transported to the end customer. Often close by the canal.

Some research has been done about reusing the existing infrastructure of canals and waterways in such a fashion (Horvath & Wu, 2017; Rohács & Simongáti, 2007) Practical examples of this are 'Mokum Mariteam' in Amsterdam and the 'bierboot' in Utrecht (Horvath & Wu, 2017). These companies/organisations have created a canal based delivery system in an effort to combat the very problems stated in the problem description. However, Mokum mariteam has run into infrastructural problems, lack of applicable technology and a lack of tangible cooperation from their respective municipalities (Appendix B).

At the beginning of the research few comprehensive documents were found describing the state of the canal infrastructure in Groningen. Therefore a visual inspection was performed on both water and land. An expert in the canals of Groningen joined the visual inspection from the water: Maik van Heerd, who has broad knowledge about the canals of Groningen. He agreed to provide this information freely. An account of this conversation can be found in Appendix D. Appendix C contains a map of the centre of Groningen; this map was enhanced with knowledge from a document provided by Rijkswaterstaat (Rijkswaterstaat, 1988). This map was created to show the waterway infrastructure in the city centre of Groningen, with bridge locations, height, width and depth. Besides this, a map of the structure of the waterways around Groningen can also be found in Appendix C.

Figure 4: Sketch of a canal based delivery (Mokum mariteam.2018)

Figure 3: Picture of a canal based delivery (Mokum mariteam.2018)

Chapter 3 Structure diagram, the performance measurement of two freight transportation methods:

To compare the two systems and get a good overview of the current situation a structure diagram was created. This diagram gives an overview of the system and its relation to the world around it in the form of infrastructure, the inflow of goods, the outflow of waste and a measurement of the K.P.I.'s of the system.

3.1 Structure diagram:

Figure 5 is a structure diagram which represents the current and proposed transportation system embedded in the larger system that is Groningen's freight logistics. The flow of goods is, in this figure, a black box to simplify the structure and give a clear-cut overview.

In figure 6 the black boxes are filled in and a more complex but also more comprehensive picture emerges. Its relation to infrastructure and delivery vehicle types is added as well as a picture representing the proposed transportation method. Besides the aforementioned, two pictures were added, representing both the road and water infrastructure. In both figure 1 and figure 2, there is a clear relation between the systems and its measured K.P.I.'s.

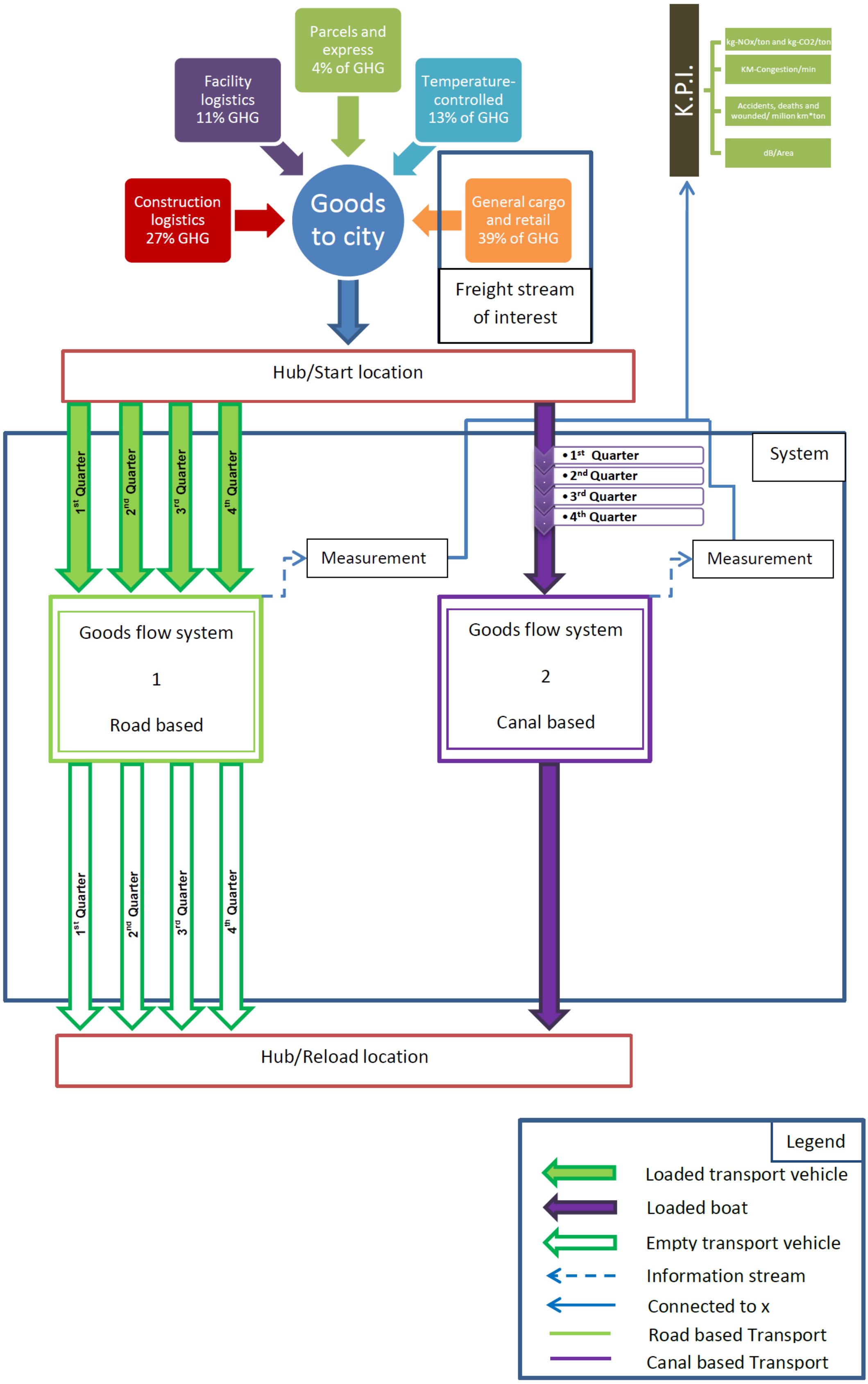

Figure 5: Simple system diagram (magnify to 250% for clear picture)

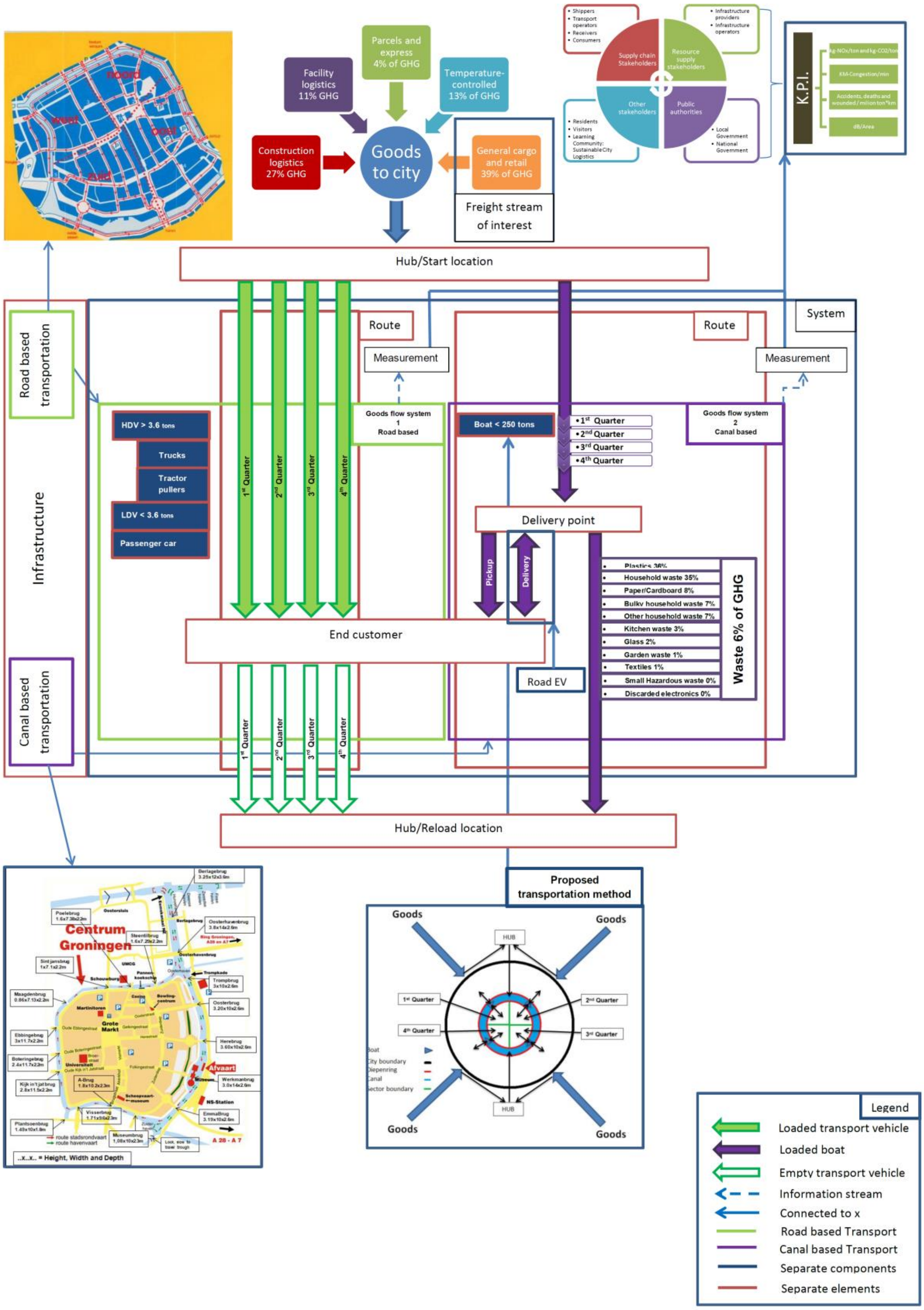

Figure 6: complex system description (magnify to 300% for clear picture)

3.2 Stakeholders and their stake in urban freight transport:

There are numerous stakeholders in this problem. I have not been able to meet with some of the following stakeholders in relation to their views on this goal and their related problems. The following is a combination of knowledge gained by studying literature, conversations with the team leaders, in the area of logistics, of the municipality as well as conversations with experts in the field.

Figure 7 gives a quick overview of the stakeholders in this system and their category. Bellow the most important ones are discussed.

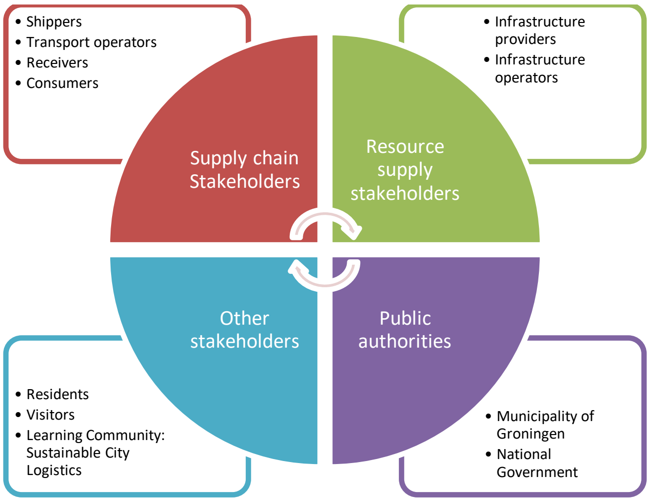

Figure 7: Stakeholders per category, an adaptation of (Horvath & Wu, 2017)

The 'Learning Community: Sustainable City Logistics', which is led by Dr. W. M. C. van Wezel and dr. ir. P. Buijs is currently researching the possible added value, of consolidation centres, in reducing the emissions and limiting freight movements, of in their view inefficiently loaded trucks. This group can be labelled a stakeholder as this research and design stop and start at a consolidation centre or 'hub'.

Transporting operators and shippers (for example Hanos, Post NL, Cycloon, DHL.): They are the ones actually delivering the goods in the current system. They are a big group of different companies which can have conflicting stakes amongst themselves (subject to more research). The proposed design would limit or in time eliminate their involvement, at least, in their current capacity. They could still transport goods to the hub and do the end delivery if they can do that emissions-free. They would have to adapt to a new way of working, with new rules and regulations to adhere to. They might not want to change as it will cost money and a certain amount of time to adapt, although adopting the new logistics scheme in the city, can make their businesses more future proof. They want to be able to deliver their goods to their customers within an agreed upon a window of time. Changing if or how they can deliver their goods to the centre will affect that. Their steak of delivering to the customer and being on time might also conflict with the inhabitants' need for clean air and good liveability.

Inhabitants of the city and visitors: They are a big group with most likely varying views on how transportation of goods will affect them and how it should be solved if they even consider it a problem. They by the very nature of the problem have conflicting stakes as they want clean air and less congestion, but also want quick, cheap and easy access to goods. Quick, cheap and easy can also conflict with each other.

Receivers in Groningen rely on deliveries from other companies to be able to operate and serve their customers. Their stake in this problem is that any change in delivery times or place might cause a problem for their company for example in their production process. The solution to this problem can directly impact the way they do business and their needs and wants should, therefore, be taken in to account. There need for on-time deliveries might conflict with their need for clean air and less inconvenience.

Any of the mentioned stakeholders can withhold or lie about the information they provide. All parties have different stakes and can, therefore, decide to omit or alter certain information as they think it might benefit their position. The municipality should be the least likely source of misinformation, but they are a political body that can change or omit certain facts to gain favour with voters or to not lose favour with voters. Information should, if possible, be checked for accuracy.

3.3 Key performance indicators:

Key performance indicators are used to measure the performance of the current system as well as the designed alternative. This data can, in turn, be used to make a comparison between both systems. Key performance indicators are inspired by the stakeholders and their different stakes. For this comparison cost and delivery times are, although very imported, neglected. This is done in the interest of time. Besides these parameters will only matter if the following K.P.I.'s are lower than or at least comparable to the current method. If they are not then a cost comparison will not be required.

3.1.1 Emissions: kg-NOx/ton and kg-CO2/ton

The K.P.I.'s on which emissions will be compared are KG-NOx/ton and Kg-CO2/ton. CO2 is a good measure of the amount of greenhouse gasses emitted and NOx is a good indicator of health damage due to emissions. Both indicators are calculated based on the driven kilometres and will be presumed stable. Future research might also consider KG-NOx/m3 and KG-NOx/m3 as this would better approximate the actual capability of the boat. Goods often use more of the maximum volume than maximum weight, due to for instance packaging of the goods. Another suggestion would be to compare these on a yearly bases to remove possible inconsistencies, because of different load factors per given day.

3.1.2 Congestion: KM-Congestion/min

KM-Congestion per minute is a known indicator for road-based transportation (Doppert, 2016). Therefore this K.P.I. was selected. The difference between the methods will be based on the tons of goods, and with that, transport vehicles that will be removed from the road and transported by boats. This number of vehicles, as a percentage of total amounts of vehicles, will be used as a percentage with which the congestion is reduced because of their absence.

3.1.3 Accidents: Accidents as a result of freight transport/year

Accidents per year as a result of freight transportation will be given for both water and road-based transportation. These methods will be compared based on the number of accidents, deaths and wounded per million ton*km (Dofferhoff, 2004).

3.1.4 Noise: decibels as a result of freight transport/Area

Noise pollution is underestimated as it comes to effects on the human body and with that the health of the person exposed to it. The effects can range from interrupting sleep to cardiac arrest when exposed to a large amount of noise over a protracted period. In the described situation the noise will not reach these levels, but it can interrupt sleep and irritate (*Voorontwerp-actieplan wegverkeerslawaai 2018-2023.*2018; Weber, 2013). Table 1 shows the effect of noise based on decibels.

Effect	Threshold			Time domain
	Dose[2]	***Threshold value in dB***	***Inside/ outside***[3]	
Annoyance	L_{den}	42	Outside	Chronic
Perceived health	L_{den}	50	Outside	Chronic
Sleep disturbance				Chronic
- (start of) movement	L_{max}	32	Inside	
- sleep structure	L_{max}	35	Inside	
- EEG awakenings	L_{max}	35	Inside	
- use of sleep medication	L_{night}	40	Outside	
- arousal	L_{max} and SEL	32 resp. 53	Inside	
- motility	L_{night}	42	Outside	
- subjective sleep quality	L_{night}	42	Outside	
- sleeplessness	L_{night}	42	Outside	
- mood	$L_{Aeq,06\text{-}22h}$	>60	Inside	
Hearing loss	L_{dn}	>75	Outside	Chronic
Heart- and vascular diseases				Chronic
- increased blood pressure	L_{den}	50	Outside	
- ischaemic heart diseases	L_{den}	>55 or 60[4]	Outside	
- myocard infarct	$L_{Aeq06\text{-}22h}$	>55	Outside	
Cognitive effects, learning and memory	L_{Aeq}	50	Outside	Acute, chronic

Table 1: Overview of health effects and noise thresholds (Weber, 2013)

Noise, in the current method, is a result of the combustion of fuel in a vehicle, the turning of axels and gears, combined with it applying the created momentum to the road.

For the proposed method the noise will be generated not by the combustion, but mostly by the application of the generated momentum on the water, this momentum results in cavitation, the creation of small air bubbles around the propeller. These bubbles are found to be the main source of noise in large vessels (Urick, 1975). Besides this, there is also the sound produced by the vibration of the hull, the movement of parts like axels and gears and the bubbles which are created by the exhaust gasses. (Seppänen & Nieminen, 2017; Urick, 1975)

Electric engines are in general, seen as quieter than combustion engines. The resulting, expected reduction of noise will be a combination of reduction of road born noise plus an addition of water born noise. This will be depicted as decibels (dB) and percentage of dB.

Chapter 4: Goods coming into the city centre and the waste leaving it

4.1 Good flows:

The goods flow coming into the city of Groningen is estimated to be 1,32 million tons of goods a year. Good flows into the city of Groningen were not found in the examined literature, as result of this, a top-down calculation was made to come to a reasonable estimate for the number of goods coming into the city centre. This estimate is based on population size as well as the number of businesses in the area of interest, compared to the known area. The known area, in this case, is The Netherlands as a whole. Table 2 below shows this calculation.

Method one: CBS data	Inhabitants	Inhabitants difference		Tons	Average tons
The Netherlands	16.829.289			639.692.000	1.022.681
The Province of Groningen	582.728	28,9		22.149.863	20.375.985
The city centre	18.695	31,2	900,2	710.609	
	Business	Business difference			
The Netherlands	1.363.490			639.692.000	
The Province of Groningen	39.650	34,4		18.602.108	
The city centre	2.845	13,9	479,3	1.334.754	
Method two: Monitor logistiek	Tons	Difference			
The Netherlands	1.112.833.000				
The Province of Groningen	43.326.000	25,7			
The city centre	1.921.033	22,6		Average tons: Method one and two	
Monitor-logistiek-goederenvervoer-voor-nederland-2016				Municipality	**28.025.990**
This source is less dependable as internal transport is counted double	The tons of freight for the city centre is based on the difference in population and number of business from method one.			City centre	**1.322.132**

Table 2: Tons of goods going to the city centre

4.2 Waste streams originating from Groningen:

The waste flow coming into the city is estimated to be around 77.715 tons per year. This does not, explicitly, account for the waste collected by private companies and are based on figures provided by both the municipality of Groningen and the CBS (central bureau for statistics). In Table 3 the calculations for this number are given.

Inhabitants (CBS 2014)	Total waste Groningen in Tons (2014)				
200.952	77.715				
		From CBS and Afval beheerplan Groningen	From OVAM		
Waste categories:	Percentage of waste (2014)	Tons of waste per year per category	Specific weight (ton/m3)	Volume (m3)	Percentage of total volume
Paper/cardboard	9,3%	7.189	0,40	17.973	7,7%
Glass	4,7%	3.622	0,9	4.024	1,7%
Textiles	1,1%	830	0,4	2.075	0,9%
Kitchen waste	8,3%	6.487	0,775	8.370	3,6%
Garden waste	1,0%	787	0,35	2.249	1,0%
Household waste	53,4%	41.488	0,5	82.976	35,4%
Bulky household waste	4,0%	3.129	0,2	15.645	6,7%
Small hazardous waste	0,3%	215	Not known		0,0%
Other household waste	10,3%	7.992	0,5	15.984	6,8%
Plastics	6,6%	5.113	0,06	85.217	36,3%
Discarded electronics and Electronic appliances	1,1%	863	Not Known, but a high specific weight		0,0%
Total	100%	77.715		234.513	100,0%

Table 3: Total weight and volume of waste leaving Groningen, per category

Plastic is by far the most appealing return stream due to its relatively low weight compared to its volume. This characteristic means that a lot of trucks are needed to take this specific type of waste out of the city. Household waste is not seen as a good stream to carry in a canal based method because the boot would require extensive cleaning in between trips as not to contaminate the new cargo (Appendix B). It is also relatively clean and won't leave much residue. The waste can be separated into 11 categories, of which plastics, paper, textiles and glass are interesting to consider. Business waste is not differentiated because waste pickup is also done by two private companies. The assumption is made that 50% of business waste is represented in these figures (Buck Consultants International, 2013).

Chapter 5 Road based transport:

5.1 Emissions: kg-NOx/ton and kg-CO2/ton

The road based emissions are 1,038 kg-CO2 per ton and 0,005447 kg-NOx per ton (table 4). To be able to calculate the road based emissions a number of values are needed. Appendix H holds the route description and its total length. This route is meant as an estimate of a delivery route a road-based vehicle might take to deliver packages to all quadrants of the centre. An average load per vehicle is also needed. A value of 12,8 tons per trip was calculated as the average between 2012 and 2015 (Monitor Logistiek & Goederenvervoer voor Nederland 2016). Furthermore, the estimated cargo load to the centre is needed. The calculations for this value can be found under chapter 4. The calculations can be found in table 3. The values used for kg-NOx per km and kg-CO2 per km were gained from the report 'transport en mobiliteit 2016' (*Transport en mobiliteit.*2016)

Average load per vehicle	12,80
Estimated cargo load to the centre	1.322.132
Estimated length of the route	33,20
kg-NOx per KM	0,00210
kg-CO2 per KM	0,40
Amount of trips to the centre	103.292
Kilometres travelled	3.429.280
kg-NOx per year	7.201,5
kg-CO2 per year	1.371.712
kg-NOx per ton	0,005447
kg-CO2 per ton	1,038

Table 4: NOx/CO2 per ton

The emissions could also be calculated for PM and SO2, this is not performed because CO2 is a good indicator of Greenhouse gas emission and NOx for health effects of the emissions.

5.2 Congestion: KM-Congestion/min

Road-based, freight-related, congestion is about 55 Km*minute. This is the conclusion of figures 5, 6 and 7, in which an estimate is made about the total congestion due to freight traffic, meant for the city centre of Groningen. In table 5 the congestion on province level is given (P.118 (Doppert, 2016)) and extrapolated using the 7,13% from the graph in Appendix I.

Provincial congestion in (km*min)	47.613
Freight-related Congestion in (km*min)	3397,1

Table 5: Congestion due to freight transport to city centre

Table 6 gives the total cargo transported to the province and to the city centre (Chapter 4). This percentage is in turn used to calculate the congestion is due to this transport.

Freight municipality	28.025.990
Freight city centre	1.322.132
percentage	4,72%

Table 6: Percentage of total freight to the province, going to city centre

Method one: Correction based on Inhabitants Source: CBS and Transport in cijfers	Inhabitants	Corrected congestion
The Province of Groningen	582.728	3.397
Municipality of Groningen	193.125	1.126
Method Two: Correction based on the number of businesses Source: CBS and Transport in cijfers	number of businesses	Corrected congestion
The Province of Groningen	39.650	3.397
Municipality of Groningen	14.025	1.202
Average municipality Freight related Congestion in (Kilometre*minutes)		1164
Congestion due to the transport of goods to the city centre (Km*minutes)		54,9

Table 7: Congestion due to the transportation of goods to the city centre in km*minutes

Table 7 is used to actually calculate the K.P.I. value for congestion. The congestion is corrected on both differences in population and businesses between the province and the municipality. This is then multiplied by 4,72% from Table 6 to get to the congestion due to the transport of goods to the city centre. This is 54,9 km*minute.

It stands to reason that the city would have significantly more congestion than the rest of the province, however, no supporting data could be found for this claim and therefore the above-mentioned method of extrapolation was used.

5.3 Safety: Accidents, wounded and deaths per million ton*km

To be able to compare the two methods table 8 can be used form this was derived from 'Dofferhoff,2014'(Dofferhoff, 2004).

Vrachtauto's en bestelauto's					
Ongevallen	1,74	1,63	1,56	1,42	1,30
Doden (inzittenden)	$0{,}98\times10^{-3}$	$1{,}44\times10^{-3}$	$1{,}40\times10^{-3}$	$1{,}36\times10^{-3}$	$1{,}13\times10^{-3}$
Gewonden (inzittenden)	$48{,}9\times10^{-3}$	$48{,}9\times10^{-3}$	$49{,}6\times10^{-3}$	$51{,}9\times10^{-3}$	$46{,}1\times10^{-3}$
Doden	$6{,}34\times10^{-3}$	$7{,}38\times10^{-3}$	$7{,}07\times10^{-3}$	$7{,}15\times10^{-3}$	$6{,}06\times10^{-3}$
Gewonden	$201{,}0\times10^{-3}$	$196{,}8\times10^{-3}$	$197{,}4\times10^{-3}$	$191{,}3\times10^{-3}$	$174{,}9\times10^{-3}$

Table 8: Accidents per million ton*km (Dofferhoff, 2004)

5.4 Noise: decibels as a result of freight transport/Area

The K.P.I. for noise, due to road transportation, could not be determined. Environmental sound charts made of the city of Groningen give values for noise pollution on buildings as a result of road noise. However, these values are not specified for the cause of this noise. Nor can the vehicle type be distinguished.

Chapter 6 Canal based transport:

6.1 Waterway infrastructure:

A boat can pass through the canals surrounding the centre of Groningen. This claim is based on a direct inspection as well as literature research and an interview with an expert. To make a comparison between the proposed transport method and the current method, fist the state of the infrastructure had to be ascertained. The result of this research is the following map (Big version in Appendix C)

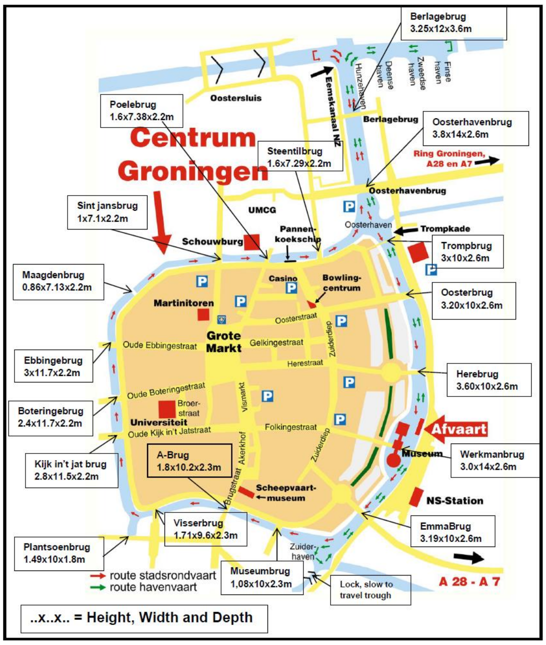

Figure 8: Map of the city centre with bridge names, depth, width and height (Zooming in helps legibility, 400%)

Besides the canal around the centre (Diepenring) the route from the hub to the centre also has to be considered. This canal is called the Noordwillemskanaal. The Lowest Bridge is 0,6 m high combined with a water depth of 2 m (Rijkswaterstaat, 1988). The Noordwillemskanaal leads to Eelde where a new hub is set to open soon. The distance from this hub to the Zuiderhaven is 11 Km. The maximum speed on both the Noordwillemskanaal and the Diepenring is 6 km/h, the Diepenring is about 4 kilometres long.

Currently, no infrastructure exists which could be used for unloading goods at the quay. In the design, an unloading method should be considered which can unload everywhere. For a practical implementation of such a method, spaces next to the canal will have to be reserved for unloading goods. These spots should also have space for light delivery vehicles and electric pump carts to facilitate the delivery to the end customer. Also, a type of lockbox system might be useful to store smaller to medium sized packages which could be retrieved by bike or pedestrian.

The distance from the hub to the water will also be useful in a design. This distance from ‘Flora Eelde’ to the water is approximately 150 meters.

6.2 Resulting boat design:

6.2.1 Boats maximum dimensions, cargo volume and load:

To calculate the maximum height of the ship, the lowest bridge must be added to the water depth at that point. This is 0,6+2=2,6 meters. After being in contact with Jan Pestoor (Appendix E), he is part of city management a department of the municipality of Groningen, some additional constraints were determined. Not just the guidelines provided by Rijkswaterstaat, need to be considered in the Diepenring. The vessel has to have an authentic appearance, and the total height of the vessel cannot exceed the quay with more than one meter. The most significant issue is the depth directly next to the quay as this is only one meter in some places. This would mean with a safety margin of 20 cm the maximum depth can be 80 centimetres. With the lowest bridge being 0,6 meter high and a safety margin of 0,1 m the maximum height of the vessel can be 0,5+0,8 is 1,3m. The vessel would fall under M0 class of boats. This can be seen in table 9.

CEMT-Klasse	Motorvrachtschepen (Motorvessels)						
	RWS Klasse	Karakteristieken maatgevend schip**				Classificatie	
		Naam	Breedte	Lengte	Diepgang (geladen)	Laad-vermogen	Breedte en lengte
			m	m	m	t	m
	M0	Overig				1-250	B<= 5,00 of L<= 38,00
I	M1	Spits	5,05	38,5	2,5	251-400	B= 5,01-5,10 en L>=38,01
II	M2	Kempenaar	6,6	50-55	2,6	401-650	B=5,11-6,70 en L>=38,01
III	M3	Hagenaar	7,2	55-70	2,6	651-800	B=6,71-7,30 en L>=38,01
	M4	Dortmund Eems (L < = 74 m)	8,2	67-73	2,7	801-1050	B=7,31-8,30 en L=38,01-74,00
	M5	Verl. Dortmund Eems (L > 74 m)	8,2	80-85	2,7	1051-1250	B=7,31-8,30 en L>=74,01
IVa	M6	Rijn-Herne Schip (L <= 86 m)	9,5	80-85	2,9	1251-1750	B=8,31-9,60 en L=38,01-86,00
	M7	Verl. Rijn-Herne (L > 86 m)	9,5	105	3,0	1751-2050	B=8,31-9,60 en L>=86,01

Table 9: Motor vessels dimensions per category (Koedijk, van der Sluijs, & Steijn, 2017)

This means that the ship cannot be larger than 5x38 meters. Giving the ship a maximum total volume of $1{,}3 \times 5 \times 38 = 247\ m^3$. However, also some room has to be left for the engine, batteries, crane and a wheelhouse. No exact data could be found about these dimensions. So a value of 20cm of height (more than the height of one 12V car battery), 1m of width and 8 m of length is considered to be large enough to accommodate everything the vessel needs besides cargo space. This would be part of future research if the boat is seen as competitive, based on the chosen dimensions. The proposed cargo volume is $1{,}1 \times 4 \times 30\ (D \times W \times H) = 132\ m^3$. This maximum value is chosen to continue to use for calculation. Other volumes can be investigated if the maximum value is deemed competitive. One other characteristic of the M0 class is that the maximum carrying capacity, this is 250 tons. This tonnage will in practice not be reached as freight is not 2 tons per m3 (Based on table 5 of (Faccio & Gamberi, 2015)). For this reason, a calculation was done based on 100 tons per trip, which can be found in table 10.

Boats	Load per trip in tons	trips per day	Total load per day	Total load per year (based on 5 day work week)	Percentage of total transport to the city
1	100	2	200	52.000	3,93%
2	100	2	400	104.000	7,87%
4	100	2	800	208.000	15,73%
8	100	2	1.600	416.000	31,46%
16	100	2	3.200	832.000	62,93%
25	100	2	5.000	1.300.000	98,33%

Table 10: percentage of total transportation to city centre done by boats

Delivery windows shown in Appendix A should not apply to a boat design as an exemption can be requested based on the fact that the delivery will be emissions free (for the city centre). This means that this will not have to be weighted in the decision-making process, but the question should be raised, with the municipality, if they will give this exemption.

6.2.2 Engine type and power:

The boat should be equipped with electric propulsion and batteries to power it. This is based on the recommendation in the interview with Mike van Heert, who has experience with a hydrogen-powered design. His rationale was that the inspections to receive a licence to operate these vehicles do not really exist yet and there is no recharging infrastructure in place. Besides from the interview with Mokum Mariteam the conclusion can be drawn that the range of an electric boat is more than sufficient for an 8-hour shift.

Based on data from Rijkswaterstaat (Appendix F (Koedijk, van der Sluijs, & Steijn, 2017)) an average engine power of 0,47 kW/ton is necessary. For a vessel which can hold a maximum of 250 tons, that would be 117,5 KW of engine power. This would have to be accurately determined in later research.

Load capacity (tons)	Engine power (kW)	kW/Ton
365	175	0,479452
535	240	0,448598
615	300	0,487805
910	490	0,538462
2900	1375	0,474138
3735	1750	0,468541
6000	2400	0,4
	Average	0,470999

Table 11: Average kW/Ton

6.2.3 Crane:

A crane would be necessary to load and unload the boat. To prevent redundancy and make infrastructure on the quay as small and easy as possible, the crane will be on board the vessel. Based on practical observations of Mokum Mariteam's operations and an interview with their expert, made it apparent, that a modified truck crane could be used for loading and unloading the vessel. They can be found in many different load capacities. In the detailed design stage, the best applicable crane design can be chosen. To be able to choose one stability calculations are necessary. This crane will also have to be modified with an attachment to carry roll containers as well as pallets and clothing racks.

6.3 Key performance indicator values based on boat design:

6.3.1 Emissions: KG-NOx/ton and Kg-CO2/ton

The generation of electricity is responsible for the created emissions for this method. This calculation will not account for emissions released in the construction of the boat. It is noteworthy to mention that these emissions will not be released inside the city centre and are, therefore, according to the definition of the boundary, not part of the discussed system. Still comparing them is an accurate way of comparing the two methods. In the Netherlands, the generation of 1 kWh is equal to 0,48 Kg-CO2 ((Harmelink et al., 2012), Appendix G)or 0,335 Kg-CO2 per kWh ((Otten & Afman, 2015), Appendix G), depending on the source. Both values have been calculated for the total energy mixture, the second value is more recent, however. Both values will be calculated with and of the resulting values one will be used as upper bound and one as lower bound. Besides CO2, NOx must be calculated, for the Dutch energy mixture, the amount of NOx released per kWh is 0,49g (Otten & Afman, 2015). A round trip is about 26km. At 6km per hour, two trips would take about 8 hours and 40 minutes, carrying a maximum load of goods of 250 tons per trip. This would be 500 tons or 264m3 per day per boat added to this is the waste stream, which is 64 tons per day. However the boat has a maximum volume and it is unlikely that 250 tons would fit in 132m3, therefore an estimate of 100 tons per trip is also calculated for. The engine at maximum power uses 117,5 kWh. For 8,66 hours a day 5 days a week, that result in, $5 \times 8{,}66 \times 117{,}5 = 5092\ kWh\ per\ week$.

Canal based transport results in 0,604-1,848 Kg-CO2 per ton and 0,000884-0,001887 Kg-NOx per ton. For the exact calculation see figure 11.

The emissions could also be calculated for PM and SO2, this is not done as CO2 is a good indicator of Greenhouse gas emission and NOx for health effects of the emissions.

	Based on a capacity of 250 tons	Based on a capacity of 100 tons
Estimated length of route (km)	26	26
Average speed (km/h)	6	6
Average time for two trips (hours)	8,67	8,67
Maximum load per day (tons)	564,44	264,44
Maximum load per week (tons)	2822,19	1322,20
engine power (kWh)	117,5	117,5
kWh per week	5091,7	5091,7
1 kWh = Kg-CO2 (cbs)	0,48	0,48
1 kWh = Kg-CO2 (Otten & Afman)	0,335	0,335
1 kWh = Kg-NOx (Otten & Afman)	0,00049	0,00049
kg-CO2 per week (CBS)	2444	2444
kg-CO2 per week (Otten & Afman)	1705,7	1705,7
kg-NOx per week (Otten & Afman)	2,5	2,5
Average Kg-CO2 per week	2074,9	2074,9
kg-CO2 per ton, CBS	0,866	1,848
kg-CO2 per ton, (Otten & Afman)	0,604	1,290
kg-CO2 per ton, average	0,735	1,569
kg-NOx per ton, CBS	0,000884	0,001887

	Waste per year (tons)	Waste per working day (for 260 workdays)
Plastic	5.113,00	
paper and cardboard	7.189,00	
Glass	3.622,00	
Textiles	830,00	
Total	16.754,00	64,44

Maximum goods per trip	250
Maximum waste per day	64,44

Table 12: Emissions per ton of transported goods

6.3.2 Congestion: KM-Congestion/min

Congestion can be described as the overcrowding of the road or in this case waterway, effectively jamming it. For roads, the congestion is calculated in Chapter 5.2, for the waterway congestion which could be created by adding boats on the water can be neglected. The waterways in the centre of Groningen don't currently experience congestion and due to the nature of the ship design the boat should be able to pass under the bridges, therefore it does not have to wait for bridges to open.

6.3.3 Safety: Accidents, wounded and deaths per million ton*km

Based on figure 13 bellow and figure 8 a comparison in accidents, deaths and wounded can be made. The data is form 2004, so relatively old, but it gives insight into the safety of water-based transport compared to road-based transport.

Jaar	1998	1999	2000	2001	2002
Vrachtvervoerende binnenvaart					
Ongevallen	0,0087	0,0093	0,0098	0,0093	0,0093
Doden (opvarenden)	0	0	0	$0{,}03\times10^{-3}$	$0{,}03\times10^{-3}$
Gewonden (opvarenden)	$0{,}15\times10^{-3}$	$0{,}03\times10^{-3}$	$0{,}18\times10^{-3}$	$0{,}06\times10^{-3}$	$0{,}09\times10^{-3}$
Doden	$0{,}09\times10^{-3}$	$0{,}03\times10^{-3}$	0	$0{,}03\times10^{-3}$	$0{,}03\times10^{-3}$
Gewonden	$0{,}38\times10^{-3}$	$0{,}9\times10^{-3}$	$0{,}21\times10^{-3}$	$0{,}11\times10^{-3}$	$0{,}26\times10^{-3}$

Table 13: Accidents per million ton*km (Dofferhoff, 2004)

6.3.4 Noise: decibels as a result of freight transport/Area

Noise could not be determined from the design parameters without more complex simulations on a more worked-out design. Therefore, this part of the comparison should be part of future research.

Chapter 7 Discussion: Canals versus Roads:

7.1 Canal or Road based transport:

7.1.1 Emissions: kg-NOx/ton and kg-CO2/ton

For road-based transportation, the amount of NOx and CO2 are 1,038 kg-CO2 per ton and 0,005447 kg-NOx per ton. This will be the baseline with which canal-based transportation can be compared, this comparison can be found in table 14.

Canal based delivery scores better on emission of NOx. However, on average it scores worse on CO2. There are cases in which a boat emits less CO2/ton; these instances are related to maximum cargo which can be carried per trip and the amount of CO2/kWh. It can be seen from table 12 that a 100 Tons of cargo is too little cargo to be competitive with road-based transport, even if the lower amount of CO2/kWh is used in the calculation. The only way for this to work is if more renewable energy is introduced into the grid. This is expected to be the future trend. The goal is to double the percentage of renewable between 2016 and 2020(Schoots, Hekkenberg, & Hammingh, 2017).

	kg-CO2 per ton	kg-NOx per ton
Road based transportation	1,038	0,005447
Canal based transportation	0,604-1,848	0.000884-0,001887
Difference with lower bound	41,81%	83,77%
Difference with upper bound	-78,03%	65,36%
Average difference	-10,98%	74,56%

Table 14: Comparison between road- and canal-based transport

One important note is that the emissions which are created by canal based delivery are not actually emitted in the city. This emission is released where the energy is generated. Canal base logistics would, therefore, be a better alternative to road-based transport in the context of this thesis.

7.1.2 Congestion: KM-Congestion/min:

Road-based congestion has been calculated to be 54,9 km*minutes (table 7). This is the congestion which is a result of the freight traffic meant for the city centre. However, this congestion can and will take place mostly outside of the city centre. As stated in Chapter 6 the assumption is made that the added congestion due to canal-based transportation, at least the boat part, is zero. This means that for every percentage of goods which is transported by boat the road based congestion will be reduced. This means that canal-based transportation is automatically better than road based congestion within the confines of this thesis.

An important note is that freight transport vehicles are only 7,13% of the total congestion (Appendix I). This means that the maximal reduction of congestion which can be reached in the municipality of Groningen is no more than 7,13%. If all freight transport to the city centre is done by boat. According to the calculations in table 10 this transport can be done by 26 vessels.

One boat could, based on 26 vessels and 54,9 km*minutes, realistically reduce the congestion with 2,1 KM*minutes.

7.1.3 Safety: Accidents, wounded and deaths per million ton*km

Based on table 15 and calculation in table 16 it can be concluded that current waterway transport is much safer than its road based counterpart. In two categories the number of victims is more than 500 times greater.

Jaar	1998	1999	2000	2001	2002
Vrachtvervoerende binnenvaart					
Ongevallen	0,0087	0,0093	0,0098	0,0093	0,0093
Doden (opvarenden)	0	0	0	$0{,}03\times10^{-3}$	$0{,}03\times10^{-3}$
Gewonden (opvarenden)	$0{,}15\times10^{-3}$	$0{,}03\times10^{-3}$	$0{,}18\times10^{-3}$	$0{,}06\times10^{-3}$	$0{,}09\times10^{-3}$
Doden	$0{,}09\times10^{-3}$	$0{,}03\times10^{-3}$	0	$0{,}03\times10^{-3}$	$0{,}03\times10^{-3}$
Gewonden	$0{,}38\times10^{-3}$	$0{,}9\times10^{-3}$	$0{,}21\times10^{-3}$	$0{,}11\times10^{-3}$	$0{,}26\times10^{-3}$
Vrachtauto's en bestelauto's					
Ongevallen	1,74	1,63	1,56	1,42	1,30
Doden (inzittenden)	$0{,}98\times10^{-3}$	$1{,}44\times10^{-3}$	$1{,}40\times10^{-3}$	$1{,}36\times10^{-3}$	$1{,}13\times10^{-3}$
Gewonden (inzittenden)	$48{,}9\times10^{-3}$	$48{,}9\times10^{-3}$	$49{,}6\times10^{-3}$	$51{,}9\times10^{-3}$	$46{,}1\times10^{-3}$
Doden	$6{,}34\times10^{-3}$	$7{,}38\times10^{-3}$	$7{,}07\times10^{-3}$	$7{,}15\times10^{-3}$	$6{,}06\times10^{-3}$
Gewonden	$201{,}0\times10^{-3}$	$196{,}8\times10^{-3}$	$197{,}4\times10^{-3}$	$191{,}3\times10^{-3}$	$174{,}9\times10^{-3}$

Table 15: Accidents per million ton*km (Dofferhoff, 2004)

	2002
Difference between accidents	139,8
Difference between Deaths (onboard/In-vehicle)	37,7
Difference between wounded (onboard/In-vehicle)	512,2
Difference between Deaths	202
Difference between wounded	672,7

Table 16: Congestion difference between both methods

7.1.4 Noise: decibels as a result of freight transport/Area

After many hours of research, the choice was made to not make a comparison based on noise as the figures for both methods cannot be determined without simulations of a more detailed boat design and a more detailed accounting for noise sources in current noise maps.

7.2 Design of the boat and its delimitations:

The boat design is made based on the allowed dimensions and characteristics of the canals in and around Groningen. The dimensions have been calculated to be $1{,}3 \times 5 \times 38$ (Height x width x length). The volumetric cargo space has been determined to be 132 m^3. However, how this exactly relates to the maximum volume, of 250 tons, is not completely known. This boat design has a floor space of 120 m^2, which is considerably more than a large truck, which has a floor surface of about 48 m2. The volume of such a truck is comparable though, being $2.55 \times 4 \times 12 = 122.4\ m^3$. The boat design could not carry anything higher than about 1,3 meters, this is a limitation that should be considered when determining the type of cargo this design will carry.

The length of the vessel will also mean it cannot turn around everywhere on the canal, this should be considered if a delivery rout outside the Diepenring is planned. Whit in the Diepenring the boat will be expected to complete circles around the city.

Besides the dimensions, the engine power was also calculated. 117,5 kWh should be sufficient to carry 250 tons. However, this is probably not the capacity the boat in real life will be able to handle. After revaluating the cargo streams coming into Groningen a study should determine the volume-Weight factor for these types of cargo to get a good idea about exactly how many tons can be carried. After this, the engine power should be revaluated.

7.3 Waste as a return flow:

Waste as a return flow makes the design more competitive. In this thesis, the assumption is made that trucks do not take a return flow with them on their way back. This essentially means that there load factor decreases per delivery until empty. For the ship design, the feasibility of return flows is considered. The calculations in table 3 show a return stream of 77.000 tons per year of which about 17.000 tons can be transported without any difficulty. This results in 65 tons of waste per day, which can be brought back. This would, however, need to be collected and stored close to the canals to make loading of this easy. To achieve this, waste should also be separated better. As plastics are now put in household waste and not collected separately. This should be changed for this return stream to work properly.

The return stream should be able to take 32 garbage truck trips off the road per week. An average garbage truck caries between 9 and 12 tons. For this argument, an average of 10 tons per truck is considered. For the total stream of 16.754 tons, this is 322 tons per week. This would result in 33 garbage truck trips less per week.

7.4 Recommendations to the municipality:

Based on the research done, the proposed method seems promising and could displace road based delivery as a form of competitive freight transportation. To achieve this, the recommendation of this thesis is to perform more research in areas described in chapter 9.1. Of these areas of future research, the inclusion of delivery to the end customer, in the design, should be first, followed by a cost analysis. Besides these, noise pollution should be included as a K.P.I. and measure for both methods. And the goods to the hub and city centre should be categorised and the collective weight should be measured.

Chapter 8 Conclusion: Canals versus roads

Water-based logistics is an innovative, interesting and promising transportation method, which deserves more research. There is enough data to support the conclusion that canal-based transportation of goods from a hub to the city centre could be done using a boat instead of a truck. The proposed method is safer and would relieve congestion in the city as well as significantly lower the amount of NOx generated by goods transportation to the centre, in turn reducing the freight transportation-related health risks. However, from the data concerning CO2 emissions, it can be concluded that a boat would result in more CO2 per ton than an equivalent amount of trucks. This would have a negative impact on global warming. The amount of CO2 produced by electricity production is expected to drop over the coming years as a larger percentage of the energy mix will be renewables. This will slowly but surely tip the K.P.I. in the direction of a breakeven point and eventually, it will be less polluting. Besides this, design changes could also lead to a less CO2 emitting boat.

There are parameters missing, such as the effects of end delivery methods on the calculated K.P.I. values. This makes an irrefutable conclusion difficult. Based on the finding of this thesis more research should be done to determine the practical viability of this method, especially the economic viability. However, this thesis provides an answer to almost all the posed research question and provides a design which can compare to the current system and even provide some advantages over it.

Chapter 9 Reflection, strengths and weaknesses of this thesis:

9.1 Implications for further research:

9.1.1 Goods:

More research has to be done into the good streams coming into the city. Currently, no direct separation in logistics categories could be made and therefore the goods which carry the most CO2 and NOx per ton could not be directly determined. Also, the number of tons were calculated in a top-down manner, this can vary greatly from the actual number of tons coming into the city centre. However, it should not affect the result, because both methods use the same number of Tons. For future research a bottoms-up analysis is recommended, to get a full inventory of the total weight and volume of goods going into the city centre per logistical category. And this should also be done for the whole of Groningen.

9.1.2 Waste:

More research should be conducted into the waste streams in Groningen. For this report, only data provided about the municipalities waste collection service was found and used. There are more businesses which collect company waste and these should be contacted and their data should be added to the current data. Besides this, more research should be done to find good conversion factors, from tons to cubic meters, for the different types of waste. This is useful for determining the exact load, both in cubic meters and tons of waste in the boat.

9.1.3 Canal based Transportation method:

In the design of the method, the delivery to the end-customer was not considered part of the design nor the calculations. This means that part of the; emissions, congestion, noise and accidents are not fully accounted for in the calculations. If the method is deemed worthy of future investigations this last part of the delivery should be accounted for and incorporated into the design and calculations. Besides this, the transport is only aimed at the city centre. Future research which is aimed at the other side of the water should be done to investigate the possible benefits of this increased volume and tonnage.

Furthermore, the boat design was based on documents pertaining to the infrastructure of the city's waterways. This data is dated and before a final design is proposed, if deemed wanted, then these parameters should be researched again, possibly by physically re-determining them. These results should, in turn, be discussed with an expert in boat design.

After such a redesign of the boat, the engine and its necessary power should also be recalculated. To make sure such a vessel would be able to move at the wanted speed and with the right behaviour.

Besides the outer diameter of the vessel also a more detailed calculation should be made for its carrying capacity in both cubic meters and tons. For the current design, the necessary space for wheelhouse, batteries, engines and a crane are estimated.

This method was envisioned around the hub 'Flora Eelde' it could be worthwhile to also research the competitiveness of this method for theoretical hubs or future hubs. This is due to the rather long distance from the hub to the inner city. This is a large factor in its emissions and it takes a lot of time, which makes the design less effective. With a hub closer to the city and directly on the water, will make this method much more competitive.

As stated under recommendations for Goods, the exact weight of goods coming into the city is not known, but even less is known about the volume this represents. This means that it is difficult to say exactly how many tons the design could carry based on its dimensions. To remedy this, a conversion number should be searched for and if it cannot be found it should be created based on the additional research suggested under goods.

For the K.P.I., noise, no literature could be found to help determine the noise output of the proposed design, based on its currently rough outline. A more detailed design should be developed and this design should be simulated to test the amount of noise it creates in operation.

9.1.4 Road based Transportation:

Most of the values obtained for the K.P.I.'s of the current method were calculated in a top-down fashion and make a wide range of assumptions about correlations between population, number of businesses, road length and more. Even though they are intuitive they remain assumptions and its validity should be checked with surveys under transporting companies and businesses. Besides this, experiments could be considered to evaluate some of these assumptions.

For the K.P.I. congestion, no clear distinction could be made between congestion in the city, compared to the rest of the province. Intuitively one would say congestion is more present in the busy city centre than in a small town, but no literature data was found to support this claim. Therefore calculations were made based on the difference of population and number of businesses in the municipality compared to the province. A recommendation for future research is to investigate the Km*minute for the city of Groningen.

For the K.P.I. noise, No clear data could be found that would allow for a separation of freight-related noise compared to the overall noise level. More research should be done into the percentage of noise caused by transportation traffic and this should be applied to the noise map of the city of Groningen. This data could also be gained by modifying the gathering of the data for the next sound map about environmental noise. This map is made every 5 years (*Voorontwerp-actieplan wegverkeerslawaai 2018-2023.*2018).

In the comparison, the assumption is made that road-based vehicles do not take any waste back on its way back out of the city. It is known that this is not true based on interviews with business owners in the city (buck international). But no weight or volume figures could be found for this phenomenon. For a future more detailed comparison the return stream of waste in road-based vehicles should also be considered.

9.1.5 K.P.I.’s:

To be more reliable, all values and methods of obtaining these values should be scrutinized by another expert to make sure everything important is accounted for. If errors are found these should be discussed and modified.

9.1.6 Cost:

The design has been tested in 3 key areas, but it has not been assessed on its cost. To determine economic viability the cost related aspects would have to be studied.

9.2 Reflection:

9.2.1 Problem analysis:

I was expecting a problem to be presented, by in this case the municipality, and I thought that I was supposed to find a solution to this problem. However, nothing was less true, the effects were presented and it was up to me to identify the causes and design my thesis around one or a few of these causes. This step took a while but was eventually overcome.

Besides this, I started considering solution very early on in the research and tried to reason backwards from there. In the last week, I learned that knowing your full problem and its context is far more important. Also how to get this in one overview was learned.

9.2.2 Literature:

Literature is, at the beginning of research, meant to gain a sense of the subject you are working on. Then a picture has to be made detailing this system. Only when the picture is complete, can an alternative be researched and can literature ones again be studied to find alternatives and backup for the stated claims. Literature is a tricky thing in this sense as reading more in not always knowing more. Literature research should start with a clear goal in mind as to identify useful from useless information. I mostly searched for literature in the first half of the second block. This kept me from making actual steps in the design and comparing process. In future research the picture described under chapter 3 will be made first; this will give a border and some preliminary elements. This figure will evolve over time, but it will give some grips on a project.

9.2.3 Results:

Due to the issues described under 9.1 and 9.2 and the described learning process, my results only started taking shape during the last weeks. As only then I had a structure from which I gained clarity. This has the effect that my results are not as complete as I would like them to be. However, I stand by my results and the work that has been done in this thesis.

9.2.4 General observations:

Working by one’s self on such a large project was a new experience. It presented many challenges in planning, motivation and feedback on ideas. Especially the last point was challenging because a conversation with a fellow student or an expert in the field working on the same problem usually helps clear the mind and focus on the more important aspects. Doing this by one’s self was more difficult for me. I solved this by discussing it with friends and family as well as experts I met along the way. This provided many of the more progress oriented steps I have taken in this thesis.

For future research, I should also keep in good contact with my supervisors as they can provide very valuable guidance. And I should create more deadlines for myself as I learned that I work best with a goal in mind and a timeline to achieve this goal.

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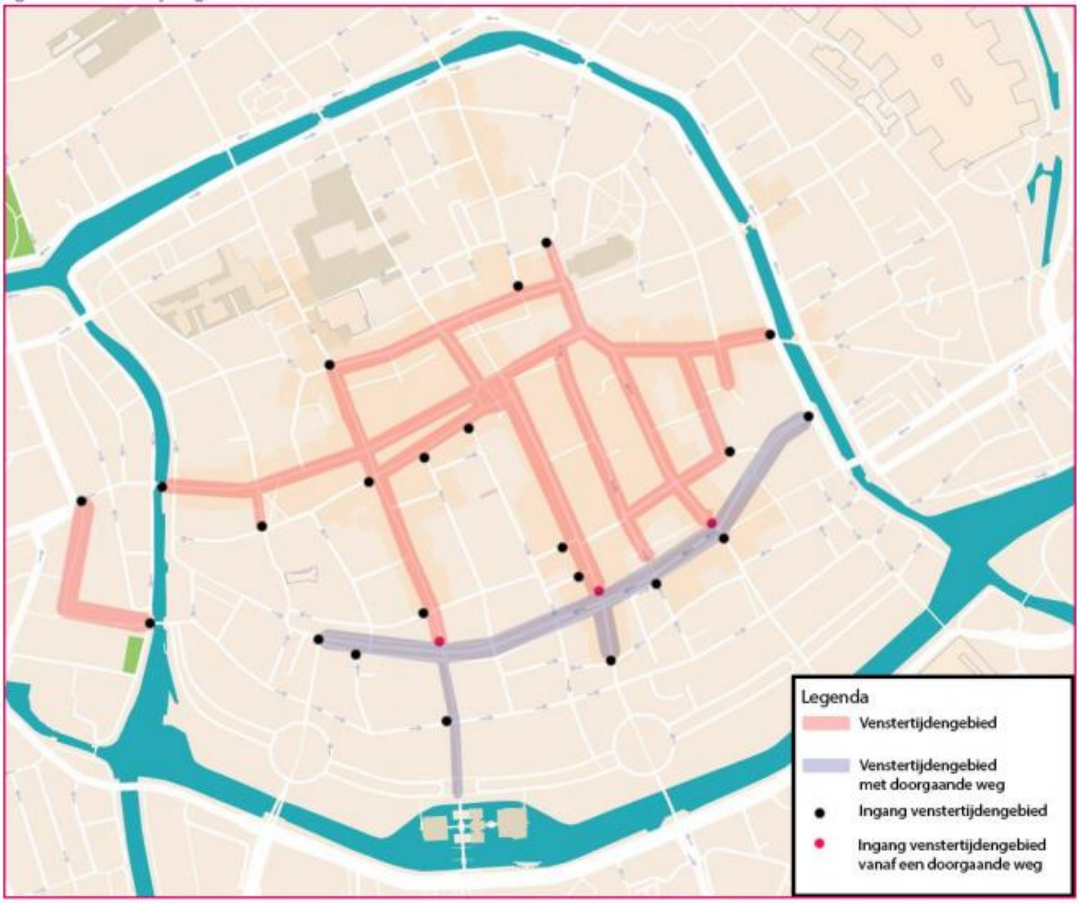
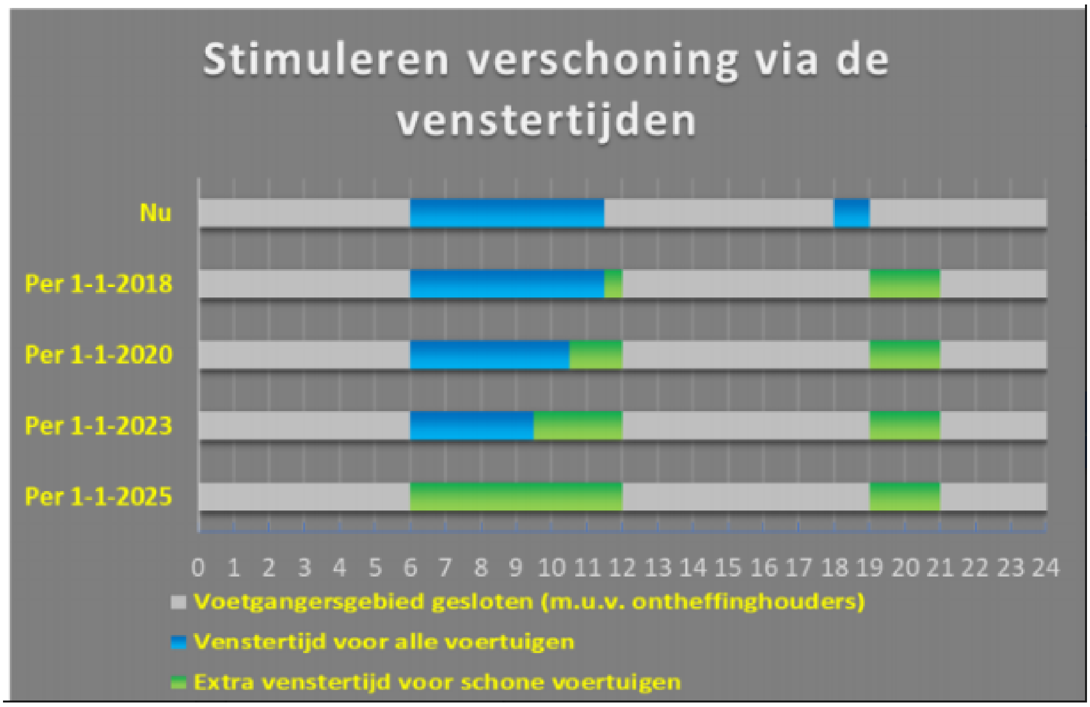
Appendices:

Appendix A:

Venstergebied (Delivery window area) map of the Groningen city centre as well as the proposed window times:





Appendix B: A day in the field with Mokum Mariteam

The day started at 6:45 with a trip to Mokum Mariteam in Amsterdam. I was able to join them on their delivery route through the canals of Amsterdam and I got to ask them a number of questions. The team consisted of a team of 3 men; a skipper, the manager of Mokum Mariteam and a driver of the electric tractor. Normally they operate in a team of two. The boat was delayed by 2 hours due to a truck driver being late with their cargo. So instead of starting at 7, they started at 9. This is the first problem that I spotted with their operation method. The cargo of the day was compression garbage containers, a load they transport four times a week. Besides this, they deliver construction materials, but this is not frequent enough yet.

Some key point:

- One delivery boat so far. This is not a good sign as they are operating sins 2010 and if it was going well they should have been growing.

- They have one main client. The client (Icova) is one of the original companies that set up Mokum Mariteam. This is troubling as having one big client leaves them open to a lot of risks. If the client decides to stop the business is effectively done. This is a lesson, the proposed design is capable of transporting a different kind of goods and can be easily transformed to deliver multiple kinds of goods. It can also be a tell-tale that no other clients are willing to consider water-based transport.

- Garbage is not shipped with food and cloth items because of fear of contamination. A clear division should be possible to prevent this if we want to transport waste and goods at the same time.

- They require about 150 euro's per hour to operate. The feasibility of this would have to be investigated. Operation cost would have to be far lower, in my opinion, to be able to be competition to traditional transportation methods

- They can lift objects up to 3000KG (crane capacity) this is interesting as it has all to do with boat design. The design creates stability and that determines the lifting capacity indirectly. But increasing stability and therefore being able to lift heavier load means the ship is less aerodynamic and is not that fast. The ship sails at a top speed of 6,5 KM/hour. The lesson should be here that the top speed in the canals of Groningen should be investigated and a design should be stable enough for the type and weight of the load that is envisioned, but also should make the craft as fast as is allowed. Losing time is money and this means less competitiveness against other transportation methods.

- With a crane, the height of the quay does not really matter. Accommodations can be reached. Fences do not really matter either.

- The municipality of Amsterdam shows enthusiasm but does not follow through on creating the necessary infrastructure (loading/unloading points) and they do not enforce regulations for parking in such a way that fast unloading can be achieved. Example; at the first unloading point there was a half hour delay due to an obstruction of an unloading area. The municipality also has to consider letting go of and creating new legislation unique to this new delivery method as the rules that apply to tourist boats or pleasure craft do not always apply to this type of transport. An example is a one-way canal that causes a detour of an hour to reach an unloading location, while the unloading location is not in the part of the canal for which it is made, one-way traffic. The boat can turn around before reaching that location and the added distance is therefore not necessary.

- The boat has enough battery for a 12-hour shift. So a design with enough battery capacity is technically feasible. Lead-acid batteries are used (relatively cheap). This is, in my opinion, a mistake as newer technologies are available. The reason was given that the newer batteries (lithium) are 4 times more expensive while only resulting in a two-folded increase in power storage. This claim has to be researched if boat design to this detail is required.

- Unloading areas are their main infrastructure problems so far. They can unload almost everywhere, but they need space and that is not yet reserved, mostly in the inner city.

- Technically the boat stability is an issue as the maximum load of the crane is limited by the stability. And to increase stability it seems that the maximum speed is reduced. As well unloading smaller items has proven to be difficult with the crane. As even standard ‘trolley' (roll containers) is seen as laborious to unload. To be an effective all-around delivery vehicle this would have to be addressed.

- They have a loading capacity of 85 m2 with a standard length of 20m and a width of 4,25m; this is equal to about 4 trucks.

- They use an electric battery for the last mile delivery. This has enough power for the entire delivery day and this machine moves through the city concurrent with the boat. That is in my opinion because it is just one boat. If this idea is scaled up one would be better at every unloading point.

- All data gathered from the field day can be used in the thesis along with taken pictures and movies.

- In Amsterdam, there are no area's they cannot reach, however, this might be a problem for Groningen.

- They would like to be kept up to date on my thesis results.

- Mokum Mariteam currently has no patented technology, so it can be freely duplicated.

- Use about 20/25 euros of electricity per day

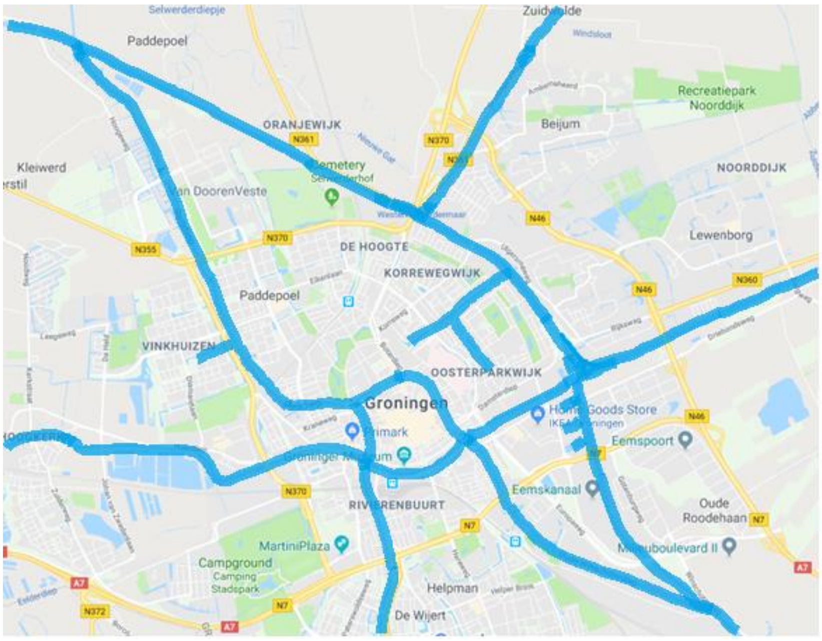
- The boat cost about 1 million and they think that they can now build a new one for 600.000.

- The batteries have an expected lifetime of 5 years, but they have already lasted for about 9 years

- The boat should have a lifetime of about 50- 80 years

Appendix C: Infrastructure waterways followed by roads

Waterways:



Paddepoel
ORANJEWIJK
Beijum
Recreatiepark Noorddijk
Kleiwerd
NOORDDIJK
DE HOOGTE
KORREWEGWIJK
Lewenborg
Paddepoel
VINKHUIZEN
OOSTERPARKWIJK
Groningen
Eemspoort
RIVIERENBUURT
Eemskanaal
Oude Roodehaan
MartiniPlaza
Campground
Helpman
De Wijert

Roads:

west
kijk in 't jatstraat
visserstraat
hoge der A
vismarkt
boteringestraat
universiteit (3)
stadhuis (1)
zuid
emmaplein
a-kerkhof
vismarkt
zuiderdiep
munnekeholm
museum (5)
bedum
winsum
noord
west
oost
zuid
hoogkerk
delfzijl
eelde
assen
haren
noord
ebbingestraat
grote markt
boteringestraat
kwinkenplein
martinikerk
V.V.V. (2)
stadhuis (1)
oost
hereplein
herestraat
grote markt
oosterstraat
zuiderdiep
politie (4)
stadhuis (1)
RHC Groninger Archieven

Appendix D: Sailing through the canals of Groningen with the owner of progress events

On the 7th of May, Mike van Heerd of progress events and me went for on a tour of the canals of Groningen to get a feel for the layout, see the obstacles, and bridges and to talk about the thesis in general. Mike van Heerd is the owner of progress events a business that is currently offering tours around the city of Groningen and the company has a choice to do this in an emission-free and sustainable way. Mister van Heerd has, due to his business's activities, become somewhat of an expert on the canals of Groningen.

The tour started at 13:00 on a small electrically powered boat. This is relevant as it proves that an electrical boat works and can perform for longer periods of time. At the end of the trip, the battery was still 92.5% full. In 1.5 hours we used about 3% of the battery (2 persons). And 4,5 % was used in a trip of, also, about 1.5 hours with 9 people. This principle is also true for larger boats with heavier loads as is proven by their tour boats and by the boat of Mokum mariteam. Range and duration should if properly taken into account, not be any problem. The boat has a 4x32 ampere battery.

First, the bridges on the Diepenring were discussed. Heights and widths known to mister van Heerd will be sent in an email and have sins been received (see updated canal map). A new bridge is in the works. The Kattenbrug, this is relevant as this bridge is higher than the lowest bridges, however, it cannot be opened. This reveals a trend in which future development, of the Diepenring, as a real waterway is not top of mind in the current government of the city. In a design it would be most likely that the boat would have to be able to pass under the bridge without it opening first, this to prevent waiting time at bridges.

Mister van Heerd also showed me two boats he has in mind to be used for goods distribution over the channels. These boats are 11x3x0.5 m (LxBxD), about 15m3 cargo volume. In my opinion, these boats do not optimally use the space in the canals as the canals are at least 2 meters deep (mike, check with harbour master) and the lowest bridge is 0.84m high (check with harbour masters). Also, boats can have a maximum length of 26 meters and conservatively 5 meters wide (VOV 2006, Artikel 7, see notes in IP notes). Getting to a cargo volume of 26x5x2.8= 364m3, there also has to be room for batteries, propulsion and a wheelhouse. This would have to be exactly designed an calculated, but assuming 2 of the 26 meters length being a wheelhouse and 2 for the engine, as well as half a meter of the depth for battery space. This would leave 22x5x2.3= 253m3 which would be 17 times more volume than the smaller boat. A typical truck can carry 122,4m3 (see notes and confirm). A boat with maximum dimensions would, therefore, be able to carry a load twice as big. To be most competitive, the boat would have to carry as much load as possible, this means returning less often which is a limiting factor as the speed limit is fixed at 6.5 km/h, making it far slower than a delivery truck.

The Oude Windschoterdiep might not be reachable anymore, contact harbour masters about this. Mister van Heerd knows a man trying to save this channel, might be able to learn more about it through him if required.

Visiting the Noordwilhelmskanaal showed that the bridge connecting the Diepenring with this canal is has a limiting factor. There is a train bridge present with a height of 0.84 m this can open and is operated by Prorail (provides train infrastructure). This canal would be of interest as it is going directly past Eelde and with that the new to be built hub at Flora Eelde. Using it as a supply line to the city might be invaluable.

There are house boots present on part of the Diepenring. Some of these will in time be removed due to age and state. I should research what the future plans for houseboats are. (See bestemingsplan openbaar vaarwater 2009.) On part of the Diepenring, moving them would make unloading of goods easier and create access to parts of the canal side.

Appendix E:

Correspondence with Jan Pestoor:

Vester,

Hierbij gegevens van de kanaalvakken die bij ons in beheer en onderhoud zijn. Gegevens van de doorvaart hoogtes en breedte van de bruggen. Overzicht wegwijzer voor de binnenscheepvaart kun je zien op de site: http://publicaties.minienm.nl/documenten/wegwijzer-voor-de-binnenscheepvaart

Vanaf blz 146 in bijlage deel 1 staan de vaardieptes en breedtes van de vaarwegen

Groeten Jan

Beste Vester,

Niet alleen de voorwaarden uit de richtlijn gelden in de diepenring er zijn voor ligplaatsen aanvullende eisen. Zoals b.v. en authentiek uitstraling, totale hoogte mag niet hoger dan x m1 boven de kade zijn. De Noorderhaven (lopendediep, Spilsluizen etc) heeft een vaarweg met een maximale diepte van 2,2 m1 (diepgang toegestaan 2 m1). Maar de diepte voor de kademuren is ca. 1 m1. Als veiligheidsmarge aanhouden 20 cm1 diepte hoogte 10 cm.

Is dit zo voldoende?

GroetenJan

Appendix F

CEMT-klasse	breedte (m)	lengte (m)	diepgang (m)		strijkhoogte (m)	laadverm. (ton)	motorverm. (kW)	boegschroef (kW)
			geladen	leeg				
I	5,05	38,5	2,5	1,2	4,25	365	175	100
II	6,6	50 - 55	2,6	1,4	5,25	535 - 615	240 - 300	130
III	8,2	67 - 85	2,7	1,5	5,35	910 - 1250	490 - 640	160 - 210
IV	9,5	80 -105	3,0	1,6	5,55	1370 - 2040	750 - 1070	250
Va	11,4	110 - 135	3,5	1,8	6,40	2900 - 3735	1375 - 1750	435 - 705
VIa	17,0	135	4,0	2,0	8,75	6000	2400	1135

(Koedijk et al., 2017)

Appendix G: CO2 emissions per kWh CBS 2013

Tabel 1. CO_2-emissiefactor, fossiel energieverbruik en rendement voor elektriciteit bij gebruiker

-	Integrale methode [1)]			Referentieparkmethode [2)]		
	-			-		
	CO_2 emissiefactor	Primaire fossiele energieinput (LHV)	Rendement op primair fossiel (LHV)	CO_2 emissiefactor	Primaire fossiele energieinput (LHV)	Rendement op primair fossiel (LHV)
-						
	kg/kWh	*MJprim/kWh*	*%*	*kg/KWh*	*MJ/kWh*	*%*
2000	0,55	8,3	43,5	0,64	9,0	40,0
2001	0,56	8,5	42,6	0,65	9,1	39,4
2002	0,55	8,4	43,0	0,65	9,1	39,4
2003	0,55	8,4	43,0	0,64	9,1	39,6
2004	0,53	8,1	44,2	0,62	9,0	40,2
2005	0,51	7,9	45,5	0,62	8,9	40,3
2006	0,50	7,7	47,0	0,61	8,7	41,2
2007	0,50	7,7	46,8	0,60	8,7	41,5
2008	0,49	7,6	47,5	0,61	8,8	40,8
2009	0,48	7,4	48,6	0,59	8,6	41,6
2010	0,46	7,2	49,8	0,57	8,4	42,7
2011	0,44	7,0	51,7	0,56	8,2	43,6
2012	0,47	7,1	50,4	0,61	8,5	42,1
2013	0,48	7,1	50,7	0,62	8,5	42,6

(Harmelink et al., 2012)

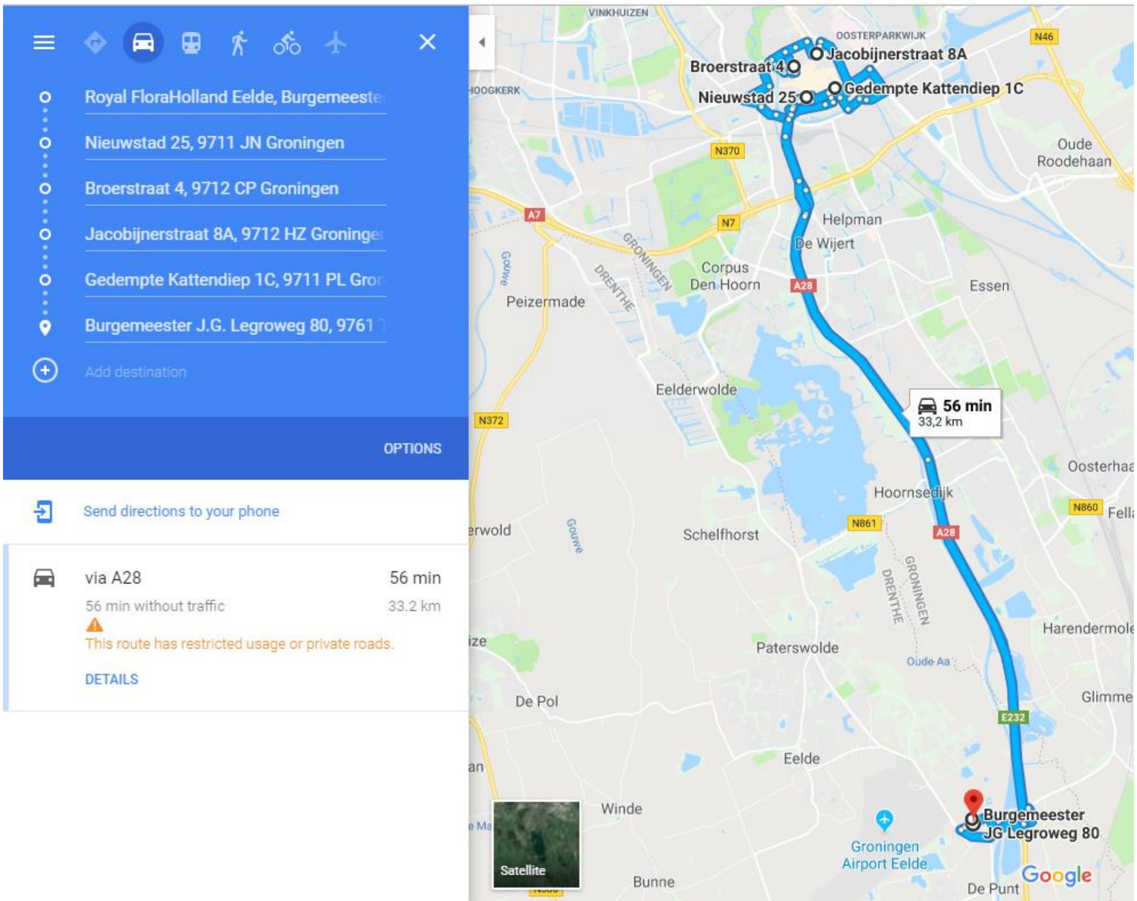
CO2 and air pollution for Dutch power generation in 2013

	CO_2	***NO_x***	***PM***	***VOS***	***SO_2***
	g/kWh	***g/kWh***	***g/kWh***	***g/kWh***	***g/kWh***
Grijze stroom	526	0,71	0,03	0,56	0,39
Niet-geoormerkte stroom	355	0,49	0,02	0,62	0,26

(Otten & Afman, 2015)

Appendix H:

Total length of route = 33.2 KM



Appendix I:

	% transport traffic	Length of Congestion in hours	Length of Congestion due to transportation
Day			
Monday	7,76%	6.418	498,0
Tuesday	7,44%	8.675	645,4
Wednesday	7,38%	5.704	421,0
Thursday	7,14%	8.697	621,0
Friday	7,17%	5.783	414,6
Saturday	4,25%	1.456	61,9
Sunday	2,37%	862	20,4
Total		37.595	2682,3
		Percentage of total	7,13%