Reconnecting Rotterdam Port

How the physical and mental connections between the port and its surroundings can be restored by extending the regional public transport system, in order to enhance the competitive position of the Port of Rotterdam.

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Reconnecting Rotterdam Port

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Preface

This report contains my graduation research for the master degree of Urbanism at the faculty of Architecture and the master degree of Transport & Planning at the faculty of Civil Engineering, both at Delft University of Technology.

This research resulted from a collaboration between Delft University of Technology and the Port of Rotterdam. This collaboration contains two studies about public transport in the Port of Rotterdam: My study about the regional design of public transport and another study about the possibilities of Personal Rapid Transit in the Cityports area, executed by a group of researchers.

During the length of this graduation research, I was an intern at the Port of Rotterdam. This internship enabled me to receive first-hand information and include those aspects relevant for successful passenger transportation design in the Rotterdam port area.

Since I am a pioneer in combining the master studies of Urbanism and Transport & Planning this report contains new insights in regional public transport design. These insights provide new opportunities when designing regional public transport and should therefore be taken into account when designing such public transport.

I consider it a big responsibility, and therefore a real privilege to be able to think about the spatial layout of the world we are living in. Therefore, I am very grateful for the opportunity that was given to me: To think about public transportation in the Port of Rotterdam. I would like to thank all people involved in this study for their input and their continuous support.
Summary

Problem and approach

The Port of Rotterdam used to be embedded in the city. Yet, when the port grew, the port became more automatized, and public reluctance to the port emerged, the port grew apart from its surroundings. Several problems emerge from this poor connection, that damage the competitive position of the Port of Rotterdam. Changes in the port industry have brought about an increased level of competition among seaports. Therefore, the Port of Rotterdam should actively put forward proposals to attract port related companies. The most important elements that should be improved to attract these companies are: Accessibility of the area, a strong labour pool, innovative character of the port, sustainability and the availability of a sufficient amount of space.

Several infrastructure interventions are proposed in the area, but these are all car oriented. Since 75% of the traffic on the A15 consists of passenger cars, public transport could be used to reconnect the port with its surroundings. Furthermore, the port company aims at creating a strong relation between accessibility, sustainability and space. Public transport has the incentive to do so, since the system can be made sustainable, development can take place around station areas and the accessibility of the port area may improve.

A problem with public transport in the port area is cost-efficiency. Low densities and an uneven distribution of travelers throughout the day make the creation of a cost-efficient system difficult. Therefore, external flows should be included in the network design. This way, the passenger distribution during the day will be more even and loads on the transit lines will be higher. Another way of enhancing the cost-effectiveness of the transit system is by changing the spatial layout of the port area, adding densities around the station area to generate more travelers.

The following hypothesis is tested throughout this research: Cost-effective public transport can be created to restores physical and mental connections between the port and its surroundings, thereby enhancing the competitive position of the Port of Rotterdam.

Methodology

Within this research, several network alternatives are designed and tested by making use of the RVMK model. The networks will be evaluated on travel behavior & cost-efficiency, socioeconomic relevance and transit oriented development opportunities.

Analysis

An analysis is made, in order to enable the creation of different network alternatives and to simulated the different networks, in order to test the hypothesis. The analysis started by performing an elaborate SWOT analysis on the port area and the region surrounding it. This SWOT analysis resulted in different design opportunities for the transportation network and the transit oriented development opportunities in the port. The design opportunities are used to perform a spatial analysis in order to define the areas that should be connected to enhance the competitiveness of the Port of Rotterdam. The following findings are the most striking:

The biggest portion of A15 car trips, about 35% start/end around Rotterdam and start/end in Voorno-Putten or the port area, congesting the highways surrounding the port area. In order to decrease this amount, public transport should be created between the areas.

Most port employees dwell in the area South of the port, the Voorne-Putten area (about 40%). Between 2009 and 2025 the working population of this area is expected to decrease with 12%, causing a shortage of port employees. This shortage is strengthened by the growth of Maasvlakte, causing a higher demand of port employees in the future. Potential new employees should be attracted to solve this shortage. Different municipalities North of the port house potential new employees, with The Hague as biggest potential facilitator of new labour. The areas should be connected to ensure a strong labour pool in the long run.

Furthermore, available types of public transport are researched, as well as the current travel behavior of people living in South Holland.
Synthesis

The spatial analysis is used to create the ideal network from a point of view of the competitiveness of the Port of Rotterdam. This ideal network is translated into three different public transport network designs: A network that makes use of the port railway, a network that is based on a new tunnel connecting the East and West bank of the new Waterway, and a network that makes use of the water available in the area.

Simulation

The different networks are evaluated on travel behavior & cost-efficiency, socioeconomic relevance and transit oriented development opportunities. Based on this evaluation, the Rivercrossing alternative performs best: It scores best on socioeconomic relevance and transit oriented development potential, while the different network score equally good on the evaluation on investment costs & cost-efficiency.

In order to test this network preference, the different outcomes of my simulation are evaluated and compared with other research on public transport in the port area. The conclusion is that the network preference is valid and indeed performs best regarding the competitiveness of the Port of Rotterdam.

Transit oriented development and local transport

A way of enhancing the cost-effectiveness of the transit system is by changing the spatial layout of the port area, adding densities around the station area to generate more travelers. This spatial development is shown for two different scenarios: One scenario where sufficient space for port development is available in 2035 (Steady Growth) and a scenario where a shortage of space is expected (Prosperous Port). In the Prosperous Port scenario, industries with high employee density are moved towards the regional transit stops and additional densities are created. Applicable local transportation is designed for the different transit stops.

For a station in Maasvlakte, in Botlek and in Cityports, a functional design is made to show the opportunities of transit oriented development at the transit stops. For the station in Botlek, a spatial design is made, combining new infrastructure with new development: Parking spaces and a hotel for truck drivers, basic amenities for employees and visitors, offices for innovative companies, a beacon building to improve the image of the Botlek area, and apartment buildings that emphasizes the boundary between the port and the village of Rozenburg. These buildings are situated along the border between port an village, but they open up at the station area where the port and the urban area come together.

Final network design

Some adaptations are made to the Rivercrossing network alternative, to make the system more cost-efficient. The final network is shown of the following page.

The network is designed in such a way that the different transit lines benefit from each other, by creating transfers between them. The network includes a fast train between Dordrecht and Hellevoetsluis, to transfer people into the port area and to provide an alternative for car drivers between Voorne-Putten and Rotterdam. A lightrail is proposed between The Hague and Maasvlakte, which will mainly be used by new port employees dwelling in The Hague. A part of this line runs on the existing port railway, since capacity is available on this part of the railway. A busline is proposed between Spijkenisse and Maasvlakte for port employees bound to Maasvlakte. In Cityports, a PRT network is proposed, which functions as a driverless taxi system which fits the layout of the area.

Enhancing the competitive position

This network can enhance the competitive position of the port area in the following ways:

- The system can reduce daily car traffic on the A15 and the Beneluxtunnel with 5%, which will give trucks a better passage when passing trough the port area.
- The number of port employees within 60 minute public transport travel time from their work in the port increases with approximately 66%, which will reduce car traffic.
Link 1: Rotterdam-Hellevoetsluis
Link 2: The Hague-Port area
Link 3: Spijkenisse-Maasvlakte

Spatial development potential

Legend

- Link 1: Rotterdam-Hellevoetsluis
- Link 2: The Hague-Port area
- Link 3: Spijkenisse-Maasvlakte
- Spatial development potential
- New infrastructure

Existing infrastructure

- Existing stop
- New stop

Type

Frequency

*The part between Maasvlakte and Botlek runs only between 6.00-9.00 h, 14.00-19.00 h and 22.00-24.00 h, to match the shift times of port labour.
The new transit system dramatically increases the amount of potential new employees that dwell within 60 minute travel time from the port area (an additional 173,000). The expected shortage of port employees in 2025 is 7,000 employees (table 7.1). If only 4% of these potential new employees start working in the area, the expected employee problem can be solved.

The number of youngsters within 60 minute public transport travel time from port related knowledge institutes increases with about 20%, increasing the chance of attracting qualified personnel.

More leader firms are connected to port related knowledge institutes (about 30% extra), which enables students to take internships and visit companies which may enhance the innovative nature of the companies.

CO2 emission reduction will be caused by the public transport system. This amount is estimated at 36,000 tons/year, which fits in with the sustainability objective of the Port Company of Rotterdam.

Transit oriented development in the port area can enhance the competitiveness in various ways, like providing amenities for port employees, improving the image of the port area and stimulating innovation by attracting innovative companies.

**Cost effectiveness of the system**

For the cost estimations only the fast train, the lightrail and the busline are taken into account, because they are beneficial for the entire port, while the PRT and metro system only serve the Cityports area. Those parts are therefore not crucial in the regional network design.

The system as proposed has a benefit/cost ratio of 77% and needs an investment in infrastructure of 1.7 billion euro. In this benefit/cost ratio, changes in travel demand are not taken into account. The system may influence the socioeconomic relations and generate more travelers this way. Furthermore, transit oriented development may increase the amount of public transport travelers. In case these effect are taken into account the benefit/cost ratio of the system is estimated at 93%.

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*Enhancing the competitive position of the Port of Rotterdam*

I conclude that cost-effective public transport can be created that restores physical and mental connections between the port and its surroundings, thereby enhancing the competitive position of the Port of Rotterdam. Therefore, the port company should seriously consider regional public transport in their long-term strategy.
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Part 1
Problem and approach

Contents

In the first chapter of this part the state of the art of the port industry is explained. Changes in the port industry have enlarged the competition among seaports. As described in chapter 2, The port has gotten disconnected from its surroundings. Several problems rise because of this poor connection, harming the competitive position of the Port of Rotterdam. In chapter 3, the approach that I want to use to tackle these problems is given: By making use of Public Transport as integral problem solver.

Results of this part:

This part gives insight in the different problems in the port area, affecting the competitive position of the Port of Rotterdam. Furthermore, an approach is presented to tackle these problems: Public transport as integral problem solver for the area. The following hypothesis will be tested throughout this research:

Cost-effective public transport can be created to restores physical and mental connections between the port and its surroundings, thereby enhancing the competitive position of the Port of Rotterdam.
1. Introduction: State of the art of the port industry

The Port of Rotterdam is important for the Dutch economy...

Ports are often seen as engines behind regional economic development. They are considered to be more than just part of a transport system: They also serve as a cluster for economic activity (de Langen & Chouly, 2004). Furthermore, they provide unique establishment locations for companies. Both roles are very important for the Dutch economy; almost 7% of the national income and 25% of the regional income is earned in the Port of Rotterdam. The port accounts for 16% of the region’s employment and when indirect labour is added to this, 5.4% of the national employment (Port of Rotterdam, 2004). Figure 1.1 shows the current layout of the Port of Rotterdam. Figure 1.2 and 1.3 show the cargo flows for the biggest European ports.

...but is threatened by increased competition...

Further economic growth in China will lead to a boost in shipping of goods. Since China ships mainly processed goods and will continue to do this in the future, growth projections for the container market are much higher than those of Bulk goods (Stopford, 2001). This increased growth brings prosperity, but also new threats: As Zhang (2008) points out, containerization has dramatically increased competition among ports. The intermodal movement of freight by containers through ports has reduced port-handling costs and increased the reach of markets served from a given port (figure 1.4). One of the places in the world experiencing the most fierce port competition is the West of Europe, especially in the range between Hamburg and le Havre (figure 2.3). All ports in this area share the same consumption and industrial target market and have quick access to the inland ways and modalities to serve them (hinterland connections) (Cap Gemini, Ernst & Young, 2003).
Figure 1.3. Flows of cargo in the Hamburg- Le Havre range (Bureau Voorlichting Binnenvaart, 2007)

Figure 1.4. When the catchment area of ports increased, the competition became more fierce.

... and port related companies becoming footloose.

Port companies used to be embedded in the city and were bonded to the port because of the hinterland they could serve from this port (van der Lugt & de Langen, 2005). Nowadays the loyalty of port related firms can no longer be taken for granted. Clients have become more international and have low binding with the port itself. Distribution centres have evolved over into European distribution centres. They distribute their goods from one port to several countries. Because of this they are likely to leave if conditions elsewhere appear more attractive (Notteboom & Rodrigue, 2005). Because of this internationalization, ports also face competition to attract new entrants, in particular container carriers, railway companies, logistics companies and investment groups (Notteboom, 2004).

This could have economical consequences for Holland...

Research from the Nationale Havenraad (2004) shows that Hamburg and Antwerp have gained on Rotterdam in terms of container handling and may surpass Rotterdam as nr.1 container port of Europe. According to Jones and Jacobs (2006) the need for economic growth in the most developed countries is no longer a need for more products to consume. Instead, this growth is needed to compensate for the loss of jobs because of productivity improvement. Also, economic growth should keep up with neighboring countries in order to preserve prosperity.
Therefore a proactive attitude is needed...

Frankel (1992) observed that ports have historically been inward-looking monopolies and because of this they failed in accomplishing quality and efficiency of services. De Langen and Pallis (2006) state that port competition obliges port companies to think about their position in the global economy and to react with proposals to successfully adapt to this change.

...with focus on the port related companies.

The demands of port related companies have become more important because of their footloose character. The five most important characteristics of a certain port, that may be improved with spatial interventions, are the accessibility, a strong labour force, the innovative character, available space and sustainability. These factors are determined as described below. The five factors are shown on figure 1.5.

A survey among over 100 port experts, conducted by de Langen & Chouly (2004) shows the importance of five predefined factors, important in the port selection process. It shows that hinterland access is the most important aspect when choosing a certain port. Training & education, marketing & promotion and innovation are also important and should not be undervalued. Another research shows criteria to attract distribution companies (van der Lugt and de Langen, 2005). A selection of the most important factors are availability of space close to the markets, good hinterland connections, a well developed labour pool and an attractive business climate. Another important but rather new development is sustainability. Due to pressure from governments and clients, companies aim at environmental friendly production and minimal negative externalities (Naniopoulos et al., 2006).

From the surveys listed above can be concluded that port related companies consider Hinterland access to have the highest priority. Yet, a well developed labour pool and the availability of space are important boundary conditions for a flourishing port economy. Also, the innovative character of the present companies can be a reason to choose a certain port. Increased attention to sustainability is a new development and may become a boundary condition for development, as well as a strong tool for image building.

Figure 1.5. The five most important aspects in the port selection process, that may be influenced with spatial interventions.
2. Problem: The port is physically and mentally detached from its surroundings

The port used to be embedded in the city. Yet this connection withered away because of enormous growth and automation of the port industry, combined with increasing public reluctance towards the port industry.

How the port got disconnected from its surroundings

At the beginning of the 19th century, the Port of Rotterdam flourished being a transit harbor between Germany and England. Goods were mainly handled by hand and the port was embedded in the city (figure 2.1). In 1930 Shell started an oil refinery next to Pernis. This development marks the start of the port and the city growing apart. After the Second World War, shipping gained a gigantic boost. In 1955 Rotterdam surpasses London and becomes the biggest harbor of Europe. Congestion on the quays and the waterways is a result of this enormous growth, where most handling is still done by hand (figure 2.2). At the beginning of the 1960s the container is introduced. This innovation leads to faster and cheaper handling. International shipping increases dramatically, enabling gigantic port growth up to the year 1970, making the port physically disconnected from the city (figure 2.3). (Huurman et al., 1982). Up to the year 1960, the Dutch lived in the era of public support for the port. After this, action groups emerged and the community gained influence on spatial planning. (Pinder, 1981). It was the Avant Garde era, where the new credo of planning became human, natural and free, making the port not only physically, but also mentally
disconnected from its surroundings. This mental disconnection is strengthened by the high degree of automation in the port industry (figure 2.3) and is indicated by the removal of port area at Kop van Zuid, replaced by city development.

**Competitive position is at stake because of poor connections**

Several problems are caused by the detachment of the port from its surrounding, all related to the five factors important in the port choice for port related companies.

**Congestion on the A15**

Only one highway connection is present in the port area: The A15. This makes the system very vulnerable for congestion and calamities. The road network around the port area is tormented with daily congestion in both directions. Apart from trucks, many passenger cars use the A15 (about 70%) (Ministry of Transport, Public Works and Water management, 2007). According to Nijdam (2008) total handling costs of containers are increased with 1-3% because of congestion, making the Port of Rotterdam less attractive for port companies. Figure 2.4 shows the biggest congestion problems in the vicinity of the port.

**Future shortage of labour**

The port area is totally detached from the lives of Dutch inhabitants. Young people tend to be unaware of the work of the port and the industry. They do not have a good image of the port, and, as a result, the influx of young people is stagnating (Port of Rotterdam, 2004). On top of that, future prognosis show that the Dutch working population is expected to decrease in the future (CBS, 2005), This in confirmed by the CPB (2008) which states that between 2008 and 2025 the Dutch working population will decrease by 9%. Figure 2.5 shows the decrease in working population between 15-65 years. This decrease is especially present in the area South of the port: Voorne-Putten. This area provides almost 40% of the port employees (Port of Rotterdam and Deltalinqs, 2007). Ageing of the population can bring about problems for port companies.

**Lack of innovation**

Innovation in the port industry is very limited (CBS, 2007) because:

- The number of highly educated employees in the industrial sector is relatively low
compared to other fields (CBS, 2007)

- Internships can be used to improve the collaboration between knowledge institutes port companies (Ministry of Economic Affairs, 2002). Figure 2.6 shows the regional public transport infrastructure in South Holland, which is defined as public transport with operational speeds over 40 km/h. No regional public transport is present in the port area, therefore public transport connections between port related knowledge institutes and the port area are nonexistent. These poor connections hinder such internships.

**Shortage of space and limited sustainability**

In 1996, the CPB has made different forecasts for growth in the port sector. They included three scenarios, all with different growth potentials. In two of these scenarios, the capacity of the second Maasvlakte is exceeded. The port may miss out on business in that sense. Research by the Vrije Universiteit of Amsterdam (2007) shows, rents in the port are expected to be low, based on the accessibility of the area. Low rents hinder space efficient measures. Furthermore, space productivity and sustainability can be stimulated with innovative measures. Since innovation in the port area is poor, such measures hardly take place.

Legend
- University offering port related education
- HBO and MBO with port related education
- High speed train
- Train
- Randstadrail
- Bus lane
- Stop

Figure 2.6. Public transport connections between port related knowledge institutes and the port area are nonexistent

Problems strengthen each other

The different problems are visualized in figure 2.7-2.10. It clearly indicates how the different problems influence each other. Therefore, a solution should be sought that tackles the problems in an integral manner.
3. Approach: An integral design solution to tackle the different problems

A fitting approach should be sought, in which the different problems can be tackled within one design, in order to improve the competitive position of the Port of Rotterdam. I start by evaluating the existing plans in the area, in order to find out what is lacking in the area. Based on this evaluation I define a strategy for the Port of Rotterdam.

Existing plans

Port planning policy

The port company and the Dutch government work together in creating a strong port area. Spatially, the port company of Rotterdam aims at creating a strong relation between accessibility, sustainability and space (Port of Rotterdam, 2009) (figure 3.1).

Nota Ruimte (ministry of VROM, 2004) describes the spatial development strategy of the Dutch government up to the year 2020. One of the key principles is creating a strong relation between economy, infrastructure and urbanization, which is considered mandatory for a strong region. These approaches are interrelated with each other and seem applicable to tackle the different problems in an integral manner.

Spatial projects in the vicinity of the port

The government determined a budget of 1 billion euro, within the Nota Ruimte framework. The MIRT (Ministry of Transport, Public Works and Water Management, 2009), contains the projects that the government has selected for the Nota Ruimte budget. The goal of the MIRT is to create more coherency between spatial projects in Holland.

Randstad Urgent (Ministry of Transport, Public Works and Water Management, 2009) is another program executed by the Dutch government, which contains spatial projects, aiming to create a strong and viable Randstad region. When budget is available, the project is included in the MIRT. Figure 3.2 shows the projects included in the MIRT and Randstad urgent in the vicinity of the port area.

Emphasis on the road network

In the province of South Holland big investments are made in the existing public transport system, like the redevelopment of Rotterdam Central station and the creation of a railway tunnel through Delft. These projects are (partly) executed on behalf of the project

Figure 3.1: The relation between economy, infrastructure and urbanization; mandatory for a strong region.

Figure 3.2: Spatial projects that are intended to be executed by the Dutch government, derived from Nota Ruimte, MIRT and Randstad Urgent.
Stedenbaan: A plan to increase the amount of trains in the Randstad to accommodate traveling without timetable. Yet, around the port area, the emphasis seems to be on the expansion of the road network. MAVA (expansion of the A15), NWO (A new tunnel under the New Waterway) and A4 South, all projects that use the accessibility of the port as (part of their) argumentation to explain the necessity of the intervention. This is not intrinsically logical, because three quarter of the traffic on the A15 consists of passenger cars. (Ministry of Transport, Public Works and Water Management, 2007)

No relation between spatial projects and infrastructure projects

Different projects are proposed within the port area. Maasvlakte 2 is a project to create an additional 1000 ha of industrial plots for new port development, mainly in the container sector. Cityports is a collaboration between the city and the Port of Rotterdam, to create a symbiosis between city and port in this area. Existing port area (BRG) is a projects that aims at intensification of port functions, in order to improve space efficiency. Unfortunately, there seems to be no relation between these projects and the infrastructure projects in the vicinity of the port area.

Public transport as integral problem solver for the Port of Rotterdam

There is a need for an approach that includes space, accessibility and sustainability and solves the different problems caused by poor connections between the port and its surroundings. Public transport could be a good design solution to improve the competitiveness of the Port of Rotterdam because:
- It has the potential to reduce congestion on the highways around the port area.
- It could attract labourers with and without a car to work in the port area.
- It could improve the relation between knowledge institutes and port companies and thereby stimulate innovation, which may bring about space efficiency and may stimulate sustainable measures.
- Public transport may improve the accessibility of the area, may provide a sustain-able alternative for car and has the potential to stimulate spatial development (transit oriented development, Cervero, 2002) and thereby fits into the strategy of the port company of Rotterdam.

An attempt at cost-effective public transport

Some public transport lines are available in the port area, but the quality is not nearly enough to attract many port employees: Only 1 % of the travelers in the port area (Cityports excluded) makes use of public transport (Port of Rotterdam & Deltalinqs, 2007). Creating high quality, cost-effective public transport for the port area proves to be difficult, because:
- Flows to and from the port are very unbalanced (figure 3.5).
- Employee densities in the port area are generally low and high densities are randomly distributed throughout the area (figure 3.4).
Instead of just focusing on the port area, it is important to focus on a combination of flows. Flows between the Port area and Rotterdam are out of balance: In the morning peak people travel to the port area and in the evening peak people travel back to Rotterdam. Yet, traffic between Voorne-Putten (the area South of the Port) and Rotterdam is in opposite direction: towards Rotterdam in the morning peak and towards Voorne-Putten in the evening peak (figure 3.6 and 3.7). Combined, these flows give a even distribution for morning and evening peak. Therefore, by combining the two flows, a cost-efficient system may be created.

Reorganizing densities around transit stops

Employee densities in the port area are generally low and high densities are randomly distributed throughout the area (figure 3.4). By creating high densities around transit stops (figure 3.8), more people are likely to choose public transport over their car. Furthermore, internal traffic is minimized.
Different scenarios for port development

In an uncertain world it does not suffice to simply extrapolate present growth trends. Scenarios may be used to scan different futures (Schwartz, 1996). Therefore, two scenarios for port development are created; the Steady Growth scenario and the Prosperous Port scenario. These scenarios are based on growth projections up to the year 2035. More information about the scenarios can be found in chapter 15.

In the Steady Growth scenario, the amount of space in the port area is sufficient until after the year 2035, while for the Prosperous Port scenario the amount of space is insufficient in 2035 (figure 3.9). Therefore, the land-use strategy differs between the scenarios, as shown on figure 3.10. Redistribution of port activity is only a legitimate intervention when a shortage of space is present in the port area. A redistribution of port activity can be combined with space innovations, like stacked distribution or co-siting of chemical industry (see Chapter 2 of the Analysis document for more information). Plans are to gradually remove port activity from the Cityports area to create space for urban development. This is acceptable when the amount of port area is sufficient, but unacceptable when there is a shortage of space. In the Prosperous Port scenario, a symbiosis between port and city should be created where the available space is used in an effective manner.

The public transport system will initially be designed according the Steady Growth scenario, but will be simulated for the two different scenarios.

Hypothesis:

Now that the approach is set and specified, I am able to generate the hypothesis that will be tested throughout this research: Cost-effective public transport can be created that restores physical and mental connections between the port and its surroundings, thereby enhancing the competitive position of the Port of Rotterdam.

Chapter 4 contains the methodology I will use throughout this research. Chapter 5 shows the derived research questions that need answering to test the hypothesis.
A multi level design with transfer at regional nodes.

A regional public transport system usually calls for a multilevel, multi modal network (Van Nes & Bovy, 2008). The regional network has limited accessibility and high speed to provide fast transport into the area. The local network has high accessibility and low speed, to transport people from transfer points to the place they need to be (figure 3.11). Apart from functioning as transit station, the stations can be used as catalyst of spatial development. This way, the area benefits from the transit station, and the transit station benefits from the area, since the availability of amenities makes the transfer more comfortable.

**Figure 3.11. Illustration of multi-level network (Van Nes & Bovy, 2008)**

**Scope**

**Year 2025 as target**

Because the realization of new infrastructure usually takes several years between planning and actual realization, I have to design for several years ahead. I choose the year 2025 as target year because of the following reasons:
- In 2025 Maasvlakte will be filled up for the biggest part, revealing the challenges this has for the future.
- 2025 is the year that the Port of Rotterdam wants to have its carbon dioxide emission reduced by 50%.
- The capacity of the A15 is expected to be exceeded regularly after the year 2020.
- The capacity of the port railway is expected to be exceeded at some points, so adaptations to the network may be necessary then.
- Long lasting contracts require a long term strategy.
- CBS prognosis data on the municipal scale only go so far as 2025. It will be very hard to generate this data for after 2025.

**Focus on province of South Holland**

The scope of this research is limited to the area where the conditions of the 5 aspects important in the port selection process can be improved significantly, (figure 1.5). Therefore, the scope will be the Province of South Holland:

Nijdam (2007) states that only the part of 50 – 100 km from the port determines the difference in Hinterland accessibility between Rotterdam, Antwerp and Hamburg, because for the remainder the other ports use the same connections. Furthermore, The biggest portion (3/4) of port related road traffic has destinations inside Holland (Bureau voorlichting Binnenvaart, 2007). Therefore, the scope will be on the highways in the proximity of the port, with emphasis on the congested areas.

About labour force, around 7% of the people working in the port area come from outside the Province of South Holland (Port of Rotterdam & Deltalinx, 2007). This is not a considerable amount to include the areas in the scope. Yet, by including the major public transportation hubs, like The Hague, Dordrecht and Gouda, portals where these people enter the area are included.

Sustainability and innovative character are limited to the port area, since they are characteristics of the port. Port related knowledge institutes are all situated in the vicinity of the port, therefore, using the province of South Holland as scope seems to be sufficient.

Availability of space could be assessed together with other ports and industrial clusters. Yet, I choose to limit the scope to the Port of Rotterdam, in order to keep the project within boundaries and since optimal space productivity will benefit the port, regardless of development in other ports. Availability of space should be sought within the port boundaries, because of the SER-ladder (SER, 1999) determined by the Dutch government: Intensification and restructuring are desired, before new development locations are sought.
Now that the approach is set, I go deeper in the methodology of this research. Not only will the networks be simulated on travel behavior and cost-efficiency, but also on socio-economic relevance and transit oriented development potential.

The IRVS methodology will be used to create different network alternatives, while the RVMK model will be used to simulate the network alternatives.

Several research questions arose while defining the methodology and are summarized in chapter 5.

Results of this part

The methodology described in chapter 4 will be used in later chapters in order to answer the research questions derived in chapter 5. The goal of answering these research questions is to test the hypothesis of this research:

*Cost-effective public transport can be created that restores physical and mental connections between the port and its surroundings, thereby enhancing the competitive position of the Port of Rotterdam.*
4. Methodology

A methodology has to be sought in order to test the hypothesis. Different networks will be designed and tested, according to various criteria.

General approach

The general approach in network design is often executed by formulating the design problem as a bi-level programming model (Boyce et al., 1990) (figure 4.1). In a bi-level model two problems are distinguished:
1. The upper problem describing the design problem for the road authorities: Which links should be included and with which capacities in order to optimize a certain objective?
2. The lower problem describing the user’s problem also called the assignment problem: in which way will travellers actually use the network?

Yet, Straatemeier (2004) states: ‘For economic activities it is not the transport system itself that is important, but the fact that the transport systems provides them with access to spatially en temporally dispersed resources”. Therefore, the network alternatives will be designed on socioeconomic relevance, as well as travel behaviour & cost-efficiency. This is sufficient for the Steady Growth scenario (see Chapter 3). Yet, in the Prosperous Port scenario, the spatial development possibilities generated by the transit system are very important and should be part of the network simulation. Therefore, Transit oriented development potential is added as part of the simulation of the network alternatives (figure 4.2 and 4.3).

Since this is a double graduation project of Urbanism and Transport & Planning, both fields should be represented in the methodology. The travel behaviour is covered by the field of Transport & Planning, while the transit oriented development potential are covered by the field of Urbanism. Both field are used to design the networks and to evaluate to what extend the networks improve the connections between port and its surroundings. (figure 4.4)

The basic design cycle is used in both the field of Urbanism and Transportation Planning (figure 4.4) and will be used throughout this research.

Figure 4.1, The general network design approach (Boyce et al., 1990)

Figure 4.2. The general design approach, adapted for this project

Figure 4.3. Transit oriented development is particularly important in the Prosperous Port scenario

Figure 4.4. How the fields of Urbanism and Transportation planning cover the general approach

Figure 4.5. Basic design cycle (Eekels and Rozenburg, 1991)
Synthesis: Network design through IRVS

For the synthesis of the different network designs, the IRVS method (TNO, 2002) is used. This chapter describes the choice for this method and the different steps the method prescribes.

Choice for the IRVS method

A method is needed for the generation of public transport alternatives, that is not only focussing on travel behaviour, but includes which socioeconomic relation should be established and what transit oriented development opportunities result from the system. IRVS, developed by TNO (2002) seems to be a fitting approach for the task, because of the following reasons:

- The method is very flexible and can be adapted to the design case.
- It is an interactive planning instrument that is easy to use by policy makers and stakeholders in the field of traffic and transport, spatial planning and the environment.
- The method includes a vision on network structure in its entirety.

Design steps of the IRVS method

The method starts without taking the existing transportation network into account, by building up the entire network from scratch. Then, the ideal network is adapted to the existing situation, proposing new links where none were available.

I will follow three major design steps, which are adaptations to the IRVS design steps:

1. Define the socioeconomic relations to establish for the Port of Rotterdam.
2. Define which areas to connect in order to establish the socioeconomic relations.
3. Design realistic networks, based of existing network and the socioeconomic relations to be established.

Step 1: Define socioeconomic relations to be established and transit oriented development opportunities for the Port of Rotterdam

This analysis is executed in SWOT format, based on the five factors important in the port selection process (Figure 1.5). This analysis provides the design opportunities for what socioeconomic relations should be established by the public transport network and the land use planning opportunities (Chapter 6). The complete SWOT analysis can be found in chapter 2 of the analysis document.

Step 2: Define what areas to connect in order to establish the socioeconomic relations

The design opportunities from step 1 will be made spatial by using ArcGIS. Data from different sources is used in order to define what areas should be connected for the different design criteria. Chapter 7 contains these this synthesis.

Step 3: Design realistic network(s)

One or more modes of public transport are taken as basis for the design. The ideal network defined in step 2, the existing network and the characteristics of different public transport modes are taken into account.

Necessary analysis

The following analysis is needed in order to start the synthesis phase:

- Which design opportunities and design criteria can be derived from the functional, spatial and demographic analysis of the scope area?
- Connections between which areas should be established, in order to establish the desired socioeconomic relations?
- What are the characteristics of different modes of public transport available for the network design?

These analysis are performed according to the 5 aspects that are important in the port selection process (Figure 1.5). The results and methodology can be found in chapter 6, 7 and 8.
Simulation: Travel behaviour

The travel behaviour for the different networks is simulated in order to predict the future use of the new transport variants. A different method to predict the travel behaviour is by means of a sampling enquiry (survey) combined with stated choice analysis. However, this method is very time consuming and out of reach for this thesis. The performance of the new public transport variants is preferably estimated with a simulation environment that already encompasses the networks and social economic data of the region. Therefore, the RVMK model will be used for this simulation, since:

- The model is in use by one of the major stakeholders (city region of Rotterdam) and has been developed especially for the region of this study.
- The model is detailed in the Rotterdam area and abstract in the regions further away, which increases the models speed.
- The model is able to simulate multi-modal environments.

Mode choice modelling with logit model

The simulation model of the RVMK is based on the tradition four-stage approach of transport planning. This four-stage approach is a model that distinguishes between trip generation, trip distribution, modal split and route choice. (Bovy et al. 2006). Unfortunately, the social economic data and the use of the trip distribution and mode-choice function within the RVMK is restricted for internal use by Goudappel Coffeng and the department of traffic and transport of the municipality of Rotterdam and therefore not available for this research. The current trip distribution is present in the form of OD-matrices of the modality bicycle, public transport and car. Based on this trip distribution and the characteristics of the available travel options the modal split can be determined. A commonly used approach is to distribute the total travel demand for a given OD-pair over the available modes using the logit model (Bovy et al., 2006). Figure 4.6 shows this logit function. Figure 4.7 shows the different steps in estimating travel behaviour in case of a new network. Appendix C contains an example of the total calculation from original data to the loads for the new network.

\[
P_i = \frac{\exp(V_i)}{\sum_{n} \exp(V_i)}
\]

with:

- \(P(i)\) = probability alternative i
- \(V(i)\) = utility for mode i
- \(B_{ki}\) = weight for explanatory variable k for mode i
- \(x_{ki}\) = explanatory variable k for mode i
- n = number of alternatives

Figure 4.6. Logit function in modal choice modelling, based on Bovy et al., (2006)

Explanatory variables and utility factors

Different variables influence the modal choice, like travel time, travel costs, comfort, waiting time, congestion time etc. (Bijlsma et al, 2002). Omnitrans (the program used to make simulations based on the RVMK model) is unable to generate all the explanatory variables. Travel time covers most factors, since factors like travel costs and distance are related to travel time. Therefore travel time will be used as main explanatory variable.

Empirical evidence shows that the time people spend outside the vehicle of choice is more inconvenient than in vehicle time (Ben-Akiva and Lerman, 1985). Therefore, waiting time is included as explanatory variable for public transport to cover initial waiting time and transfer discomfort.

Additional congestion time for car is included in the total travel time for car and cannot be generated independently by Omnitrans. Therefore, no additional explanatory variable will be added for congestion time for car.

Furthermore factors like travel experience and reliability can influence the mode choice. The impact of these non-observable factors and mode related thresholds can be summarized in one or two demand sensitivity variables and a mode specific constant.
Utility for different modalities is described as follows:

\[ V_{\text{car}} = A_{\text{car}} - B_{\text{car}} \times T_{\text{travel,car}} \]
\[ V_{\text{PT}} = A_{\text{PT}} - B_{\text{PT}} \times T_{\text{travel,PT}} - C_{\text{PT}} \times T_{\text{wait,PT}} \]
\[ V_{\text{bike}} = A_{\text{bike}} - B_{\text{bike}} \times T_{\text{travel,bike}} \]

The explanatory variables can be calculated with the Omnitrans software in so-called skim matrices.

**Estimating utility parameters**

Utility parameters (weight for the explanatory variables) are needed to estimate the travel behaviour in case of a new public transport network. The utility parameters are unknown for the province of South Holland. Yet, the behaviour is known for 5100*5100 cases (the amount of zones in the RVMK model). The utility parameters that have the best fit for the behaviour cases is estimated with an iteration program (Appendix I.1). For the iteration, only a selection of RVMK zones is used (figure 4.8). OD (origin/destination) data and skim data from the RVMK model is merged into area data and exported with Omnitrans (appendix II.1). Zonal data is aggregated into area data in order to:

- make the iteration possible with less OD pairs
- remove outliers

The results of the iteration process can be found in chapter 8. The iteration process is elaborated on further in Appendix A. The iteration is weighted, meaning that each OD pair has a weight factor in the iteration, according to its total OD flow.
Shadow OD calculation

As can be read in appendix A, the reference OD data (from the RVMK) and the data calculated with the logit model show significant differences. Weighted, 68.6% of the OD flows per mode are within 25% difference of the real OD flow. Therefore, shadow ODs and a shadow factor are introduced.

Shadow ODs for each OD pair and each mode are calculated with the logit function, both for the reference situation (SODorg) and the situation with the new network (SODnew). A growth factor is calculated by dividing the SODnew by SODorg. The new ODs are calculated by multiplying the ODorg with the growth factor, for each mode and each OD pair. (The jobs can be found in appendix II.2)

Adapting the OD data for Port areas

Making use of shadow calculations doesn't work for areas with limited or no public transport in the reference situation. Since the new public transport OD is calculated by multiplying the reference situation with a growth factor, and the reference situation has zero public transport trips, the new situation will have zero public transport trips as well, regardless of the scaling factor. Therefore, the data from the shadow matrix is imported into the new OD matrix for Maasvlakte, Europoort, Botlek and Vondelingenplaat. (Appendix II.3)

By making use of the shadow OD calculation, the total OD for each pair changes. Therefore, a scaling factor is introduced for each OD pair. (Appendix II.4)

Effect of the new network on total travel demand between zones

The method I use includes the assumption that the total origin/destination data between A and B do not change when a new network is introduced, only the modal split between A and B changes. In reality, social-economic patterns will change eventually (Egeter et al., 2002). For instance, if a good public transport connection between Maasvlakte and The Hague is realized, inhabitants from The Hague are more likely to start working on Maasvlakte. Since this effect is not included in the model, the effect should be considered when evaluating the different network designs, as shown in chapter 14.

Validating the RVMK data

The RVMK origin/destination data is validated based on the survey on the origin of port related employees (Port of Rotterdam and Deltalinqs, 2007). The origin/destination of trips towards Botlek and Maasvlakte is evaluated in appendix B. Some differences can be found, but these are not significant enough to alter the RVMK data. Furthermore, the travel times of some bus lines have been altered, because they carried unrealistic operational speeds.

Simulation: Cost-efficiency

The costs of the different network design are estimated based on the characteristics of the public transport modes and the loads defined in the simulation on travel behaviour. Distinction is made in investment costs, yearly operational costs, yearly revenues and revenues loss on existing public transport system. Based on these numbers a benefit/cost ratio can be calculated for the different transportation lines of the different network variants. More information on the methodology can be found in chapter 12. An example of such a calculation can be found in appendix D.

Simulation: Socioeconomic relevance

The different network designs will be tested on their socioeconomic relevance, based on the ArcGIS analysis from chapter 7. The public transport travel time skims are used to calculate what areas are within 60 minute travel time from a certain destination. By combining this data with the socioeconomic data, the socioeconomic relevance of the different networks can be calculated. Because the socioeconomic data (figure 4.9) is in a different format than the RVMK data (figure 4.10), the socioeconomic data is translated into the RVMK zoning division. How this calculation is executed can be found in appendix E.
Simulation: Transit oriented development opportunities

Transit oriented development opportunities inside the port

The relevant land use development opportunities inside the port area are defined in the SWOT analysis from chapter 6. The transit oriented development opportunities range from amenities for tourists and visitors to co-siting and space innovations. These developments ask for good connections to other businesses, to visitors, to port employees, to knowledge institutes etc. In other words: Accessibility to urban densities. As indicator for urban densities, the total working population within 60 minutes public transport travel time to a certain port area is chosen. The results from the socioeconomic relevance simulation is used for this calculation (appendix II.5)

Transit oriented development opportunities outside the port

The relevant land use development opportunities outside the port can be found in figure 13.2. These development comprise dwelling programs to house new port employees and park & ride facilities to reduce car use. Future housing development in South Holland follows the SER ladder (Province of South Holland, 2009), meaning that intensification and restructuring are desired, before new development locations are sought. Therefore, the existing future housing programs are identified (Atelier Zuidvleugel, 2008) (figure 2.14 of the analysis document). Omnitrans and ArcGIS are used to calculate the amount of hectares of housing programs within 60 minute travel time from Botlek and Maasvlakte. Chapter 13 show the results from this simulation.
5. Research questions

Based on the problem, approach and methodology, I am able to write down the questions that need answering in order to test the hypothesis:

Cost-effective public transport can be created that restores physical and mental connections between the port and its surroundings, thereby enhancing the competitive position of the Port of Rotterdam.

Main research questions:

1. Can cost-effective public transport be created that restores physical and mental connections between the port and its surroundings, thereby enhancing the competitive position of the Port of Rotterdam? This research question will be answered in chapter 18, conclusions.

Secondary research questions:

In order to answer the main research question, several secondary questions should be answered, based on chapter 4:

Analysis

2. What design opportunities and design criteria can be derived from the functional, spatial and demographic analysis of the scope area?
3. Connections between what areas should be established, in order to establish the desired socioeconomic relations?
4. What are the characteristics of different modes of public transport available for the network design?
5. What is the current travel behaviour of people traveling in South Holland, relevant for this design project?

Synthesis

6. What connections are desirable to be established the socioeconomic relations, in order to enhance the competitive position of the Port of Rotterdam?
7. What network alternatives can be generated based on the desirable connections?

Simulation & Evaluation

8. How do travelers behave in case of the new transportation networks?
9. What is the cost-efficiency of the different network alternatives?
10. What is the socioeconomic relevance of the different network alternatives, based on the design criteria?
11. What transit oriented development opportunities do the network alternatives offer, relevant for the competitive position of the Port of Rotterdam?
12. What network fits the different design criteria best, based on travel behaviour & cost-efficiency, socioeconomic relevance and transit oriented development opportunities?
Part 3

Analysis

Contents

Different research questions have to be answered in order to start the synthesis and simulation phase. This chapter contains different design criteria; network design criteria, socioeconomic criteria and transit oriented development criteria. These criteria are derived from a SWOT analysis, found in chapter 2 of the Analysis booklet. Chapter 7 goes in depth of the socioeconomic relations that should be established. In this chapter, the criteria are made spatial in order to define what areas should be connected by the new public transport system. Chapter 8 contains the available modes of public transportation available for the design, as well as how travelers behave currently in South Holland.

Results of this part

This part provided the data necessary for the design, simulation and evaluation of different network alternatives. The areas that should be connected, derived in chapter 8, are used to define the ideal network from the point of view of the Port of Rotterdam in the Synthesis phase. The design criteria from chapter 7 and the available modes of public transport from chapter 9 are used to translate this ideal network into several network alternatives. The current travel behavior in South Holland is used to simulate the network alternatives in the simulation part of this research, while the criteria from chapter 7 are used to evaluate the network alternatives.
An analysis is made, in order to answer research question 2. What design opportunities and design criteria can be derived from the functional, spatial and demographic analysis of the scope area?

**Design opportunities**

This analysis is executed in SWOT format, based on the five factors important in the port selection process (figure 1.5 and 6.2). First, the weaknesses and threats for each factor are defined, threatening the competitive position of the Port of Rotterdam. Then, strengths and opportunities that may be used to take away the weaknesses and to avoid the threats are analyzed. These strengths and opportunities provide the design opportunities for what socioeconomic relations should be established and what land use planning may enhance the competitiveness of the Port of Rotterdam (figure 6.1). The complete SWOT analysis can be found in chapter 2 of the analysis document.

**Socioeconomic design criteria**

In chapter 12, the different network designs will be tested according to the following design criteria derived from the design opportunities:

- The daily car usage reduction on the om the A15 and in the Beneluxtunnel.
- The amount of port employees within 60 minutes public transport travel time from Botlek and Maasvlakte.
- The amount of potential new port employees that are within 60 minutes public transport travel time from port related knowledge institutes*.
- The amount of youngsters within 60 minutes public transport travel time from port related knowledge institutes.
- The amount of CO2 emissions in metric tonnes.
- The amount of leader firms within 60 minutes public transport travel time from port related knowledge institutes.
- The reduction of yearly CO2 emissions in metric tonnes.
- The amount of potential new port employees that are within 60 minutes public transport travel time from Botlek and Maasvlakte.
- The amount of leader firms within 60 minutes public transport travel time from port related knowledge institutes.
- The amount of youngsters within 60 minutes public transport travel time from port related knowledge institutes.
- The amount of potential new port employees that are within 60 minutes public transport travel time from Botlek and Maasvlakte.
- The amount of leader firms within 60 minutes public transport travel time from port related knowledge institutes.
- The amount of youngsters within 60 minutes public transport travel time from port related knowledge institutes.
- The amount of CO2 emissions in metric tonnes.

*knowledge institutes as found on figure 2.13 of the analysis booklet.

---

**Figure 6.1. Design opportunities to enhance the competitiveness of the Port of Rotterdam**
Transit oriented development criteria

These criteria only apply to the Prosperous Port scenario. The development opportunities inside the port are tested as follows:

- How much working population in 2025 resides within 60 minutes public transport travel time of Maasvlakte, Botlek an Cityports?
- The development opportunities outside the port area tested as follows:

  - How much hectares of dwelling program can be reached within 60 minute travel time from Maasvlakte or Botlek?

More information about these criteria can be found in chapter 13.

Network design criteria

Information on the network design criteria can be found in chapter 7 and chapter 10.
7. The areas to be connected

Research question nr. 3 will be answered in this chapter: 3. Connections between what areas should be established, in order to establish the desired socioeconomic relations? The design opportunities derived in chapter 6 will be made spatial by using ArcGIS. The sources used for this analysis and the procedure I followed can be found in chapter 4 of the analysis document. Furthermore, the criteria for these connections are derived in this chapter, based on chapter 4 from the analysis document.

Relieve the car network around the port area to give trucks a better passage.

By providing public transport, car drivers may choose to leave their car at home. This means that truck drivers have a better passage and less costs of congestion are added to the total handling costs. Kentekenqueste Regio Rotterdam 2007 (Ministry of V&W, 2007) was used to locate the origin and destination of people traveling on the A15 (figure 7.1). Interesting is the fact that about 35% of the car trips on the A15 start/end around Rotterdam and start/end in Voorne-Putten or the port area. This goes for 13585 of the daily 38826 passenger cars on the A15. Figure 7.2 shows what the A15 car driver density for each area. The reason I translated total car drivers into car driver density is that the areas are different in size. Therefore, calculating car driver density gives a genuine image of what areas should be connected.

Table 7.1, Amount of workers needed and shortage in 2020 and 2025, (Maasvlakte 2 projectorganisation 2009; CBS statline, 2009; Province of South Holland, 2008)
Part 3. Analysis

Provide public transport for port employees

A survey was executed by the Port of Rotterdam and Deltalinqs (2007) about the origin of employees of the Port of Rotterdam. Figure 7.4 shows the origin of the 25257 people working in the port area, Cityports excluded. Most people (about 40%) originate from the area South of the port: Voorne-Putten. Ageing will influence the labour pool for the Port of Rotterdam. Figure 7.3 shows the expected decrease in working population between 2009 and 2025. Decrease in working population is very high in the Voorne-Putten area (12%), which may cause problems in the future. Table 7.1 shows the need and decrease of port employees for the different port areas. Based on this data, Maasvlakte and Botlek will have priority to be connected with public transport over Europoort and Vondelingenplaat, since Botlek has the highest employee density and Maasvlakte will have the highest shortage of port employees. Figure 7.5 shows the expected port employee density in 2025, the effect of ageing included.
Provide public transport to attract new port employees

A shortage of port employees is expected, because of the expected ageing of the port labour force. Also, an increased demand of port employees is expected, because of port growth. Therefore, new municipalities should be connected to the port, in order to attract new port employees. Two sources may be used:

- Municipalities with high unemployment rates (figure 7.7).
- Municipalities where the effect of ageing is limited or where the working population is expected to grow between 2009 and 2025 (figure 7.6). The assumption is made that 90% of the working population in 2009 is needed to run the local economy in 2025. This means that only the top 10% may become port employees. If the working population in a certain municipality decreases with more that 10%, no potential workforce is left. If the working population increases with 10%, the potential workforce doubles. To this number is added half the unemployed of each area to calculate the total potential workforce. Figure 7.8 shows the potential workforce density in 2025. The calculation can be found in chapter 4 of the analysis booklet.
Connect youngsters with port related knowledge institutes

By connecting youngsters with port related knowledge institutes, these youngsters are more likely to choose port related education. This way, these people are likely to become port employees after they finished education. The prognosis of the amount of youngsters between the age of 15-25 in each municipality in 2025 is extracted from CBS (2005). Figure 7.9 shows the youngster density in 2025. Since they should be connected to the port related knowledge institutes, those are included in this figure.

Connect leader firms and port related knowledge institutes

De Langen & Nijdam (2006) made an analysis on leader firms in the Port of Rotterdam. The definition of a leader firm is as follows: "A leader firms is a company that has the capacity and the incentive to do investments with positive spill over effects to other companies in the cluster, because of their size, market position, knowledge and entrepreneurship".

By connecting these companies to the port related institutes, internships and visits from students become possible. This improved relation between the knowledge institutes and leader firms may also bring about innovative interventions, which may spill over to the rest of the port area. Figure 7.10 shows the leader firms density and the knowledge institutes.

Network criteria and boundary conditions

The criteria for the characteristics of the new network are based on the conclusions in chapter 4 of the analysis document. The system should be fast enough to seduce car drivers to use public transport instead. Therefore, the operational speed should be ≥40 km/h and the minimal frequency should be 4 vehicles/hour/direction. Also, travel times for port employees should not exceed 60 minutes. Otherwise, they will use their car, or will not become an employee for the Port of Rotterdam. Furthermore, the system should be nearly 100% punctual, with comfortable seats and with minimal transfers in a door-to-door trip. Finally, the system should run from 6.00 h - 24.00 h to adapt to shift times.
<table>
<thead>
<tr>
<th><strong>Regional line bound</strong></th>
<th><strong>Urban system line bound</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Train</strong></td>
<td><strong>Metro</strong></td>
</tr>
<tr>
<td>Vehicle on rail infrastructure, track has to be fenced.</td>
<td>Underground system</td>
</tr>
<tr>
<td>Operational speed: 70 km/h²</td>
<td>Operational speed: 40 km/h¹²</td>
</tr>
<tr>
<td>Stop frequency: 9 km/stop²</td>
<td>Stop frequency: 1.3 km/stop¹²</td>
</tr>
<tr>
<td>Capacity/vehicle: 350 seats³</td>
<td>Capacity/vehicle: 200 passengers¹²</td>
</tr>
<tr>
<td>CO2 emission: 60 g/passenger km⁸</td>
<td>CO2 emission: 65 g/passenger km⁸</td>
</tr>
<tr>
<td>Infrastructure costs: 18.000.000 €/km⁹</td>
<td>Infrastructure costs: 75.000.000 €/km¹¹</td>
</tr>
<tr>
<td>Vehicle costs: 3.000.000 €/vehicle¹</td>
<td>Vehicle costs: 1.800.000 €/vehicle¹</td>
</tr>
<tr>
<td>Operational infrastructure costs: (7,5%)¹</td>
<td>Operational infrastructure costs: 815.000 €/km/year¹¹</td>
</tr>
<tr>
<td>Operational vehicle and employee costs: 300 €/vehiclehour²⁰</td>
<td>Operational vehicle and employee costs: 200 €/vehiclehour¹</td>
</tr>
<tr>
<td><strong>Hovercraft</strong></td>
<td><strong>Tram</strong></td>
</tr>
<tr>
<td>Floats on water, thereby minimizes problematic wave production</td>
<td>System on rails, no fences needed</td>
</tr>
<tr>
<td>Operational speed (no stop): 75 km/h⁶</td>
<td>Operational speed: 20 km/h¹³</td>
</tr>
<tr>
<td>Stop time: 5 minutes/stop⁹</td>
<td>Stop frequency: 0,5 km¹³</td>
</tr>
<tr>
<td>Capacity/vehicle: 90 passengers⁶</td>
<td>Capacity/vehicle: 150 passengers¹³</td>
</tr>
<tr>
<td>CO2 emission: 530 g/passenger km⁶</td>
<td>CO2 emission: 42 g/passenger km⁸</td>
</tr>
<tr>
<td>Infrastructure costs: 1.000.000€/stop⁵</td>
<td>Infrastructure costs: 11.000.000€/km⁹</td>
</tr>
<tr>
<td>Vehicle costs: 6.500.000 €/vehicle⁶</td>
<td>Vehicle costs: 1.500.000€/vehicle¹</td>
</tr>
<tr>
<td>Operational infrastructure costs: (7,5%)¹</td>
<td>Operational infrastructure costs: 500.000 €/km/year¹¹</td>
</tr>
<tr>
<td>Operational vehicle and employee costs: 300 €/vehiclehour⁴</td>
<td>Operational vehicle and employee costs: 175 €/vehiclehour¹</td>
</tr>
<tr>
<td><strong>Bus on buslane</strong></td>
<td><strong>City bus</strong></td>
</tr>
<tr>
<td>Maintains speed because of uneven crossings, part in city</td>
<td>Operational speed: 15 km/h¹⁴</td>
</tr>
<tr>
<td>Operational speed: 60 km/h⁷</td>
<td>Stop frequency: 0,5 km¹⁴</td>
</tr>
<tr>
<td>Stop frequency: 1,5 km⁷</td>
<td>Capacity/vehicle: 100 passengers¹⁵</td>
</tr>
<tr>
<td>Capacity/vehicle: 150 passengers¹⁰</td>
<td>Capacity/vehicle: 70 g/passenger km⁸</td>
</tr>
<tr>
<td>CO2 emission: 70 g/passenger km⁸</td>
<td>CO2 emission: 15.000 €/stop¹⁶</td>
</tr>
<tr>
<td>Infrastructure costs: 6.000.000 €/km¹</td>
<td>Infrastructure costs: 190.000 €/vehicle¹</td>
</tr>
<tr>
<td>Vehicle costs: 430.000 €/vehicle¹</td>
<td>Vehicle costs: 1.100 €/stop</td>
</tr>
<tr>
<td>Operational infrastructure costs: 80.000 €/km/year¹</td>
<td>Operational infrastructure costs: (7,5%)¹</td>
</tr>
<tr>
<td>Operational vehicle and employee costs: 140 €/vehiclehour¹</td>
<td>Operational vehicle and employee costs: 77 €/vehiclehour¹</td>
</tr>
<tr>
<td><strong>Lightrail</strong></td>
<td><strong>Ferry</strong></td>
</tr>
<tr>
<td>System on rail, that acts differently in- and outside the city</td>
<td>Operational speed (no stop): 20 km/h⁹</td>
</tr>
<tr>
<td>Operational speed, stop frequency in city: 20 km/h, 0,75¹¹</td>
<td>Stop time: 5 minutes/stop⁹</td>
</tr>
<tr>
<td>...outside city: 55 km/h, 2,5¹¹</td>
<td>Capacity/vehicle: 150 passengers⁹</td>
</tr>
<tr>
<td>Capacity/vehicle: 200 passengers¹¹</td>
<td>Capacity/vehicle: 115 g/passenger km²</td>
</tr>
<tr>
<td>CO2 emission: 65 g/passenger km⁸</td>
<td>CO2 emission: unknown</td>
</tr>
<tr>
<td>Infrastructure costs: same price train/tram</td>
<td>Infrastructure costs: 1.000.000€/stop³</td>
</tr>
<tr>
<td>Vehicle costs: 1.650.000 €/vehicle¹</td>
<td>Vehicle costs: unknown</td>
</tr>
<tr>
<td>Operational infrastructure costs: same price train/tram</td>
<td>Operational infrastructure costs: (7,5%)¹</td>
</tr>
<tr>
<td>Operational vehicle and employee costs: 200 €/vehiclehour</td>
<td>Operational vehicle and employee costs: 75.000€/stop/year</td>
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</tbody>
</table>

**38**
Urban system semi on demand

**Parkshuttle**
On demand, line bound system without a driver
Operational speed: 14 km/h
Stop frequency: 0,5 km
Capacity: 20 people/vehicle
CO2 emission: unknown
Infrastructure costs: 6.300.000 €/km
Vehicle costs: 300.000 €/vehicle
Operational infrastructure costs: unknown
Operational vehicle and employee costs: 18 €/vehiclehour

**ULTRA PRT**
On demand taxi system, elevated on own track without a driver.
Operational speed: 35 km/h
Stop frequency: 0,5 km
Capacity: 4 people/vehicle
CO2 emission: unknown
Infrastructure costs (half double track): 8.300.000 €/km
Vehicle costs: 140.000 €/vehicle
Operational infrastructure costs: 550.000 €/km/year
Operational vehicle costs: 37 €/vehiclehour

**Watertaxi**
On demand taxi system, elevated on own track.
Operational speed: unknown
Stop density: unknown
Capacity: 8 people/vehicle
CO2 emission: 115 g/passenger km
Infrastructure costs: unknown
Vehicle costs: unknown
Operational infrastructure costs: unknown
Operational vehicle and employee costs: unknown

**Vipre Collective transport**
On demand taxi system, elevated on own track.
Operational speed: 40 km/h
Stop frequency: 3-12 km
Capacity/vehicle: 100 passengers
CO2 emission: 60 g/passenger km
Infrastructure costs: 0
Vehicle costs: 190.000 €/vehicle
Operational infrastructure costs: 0
Operational vehicle and employee costs: unknown

**Car**
Operational speed: 30-120km/h
Capacity: 4 seats/vehicle
CO2 emission: 133 g/passenger km
Infrastructure costs: -
Vehicle costs: -
Operational infrastructure costs: -
Operational vehicle and employee costs: -

**Bike**
Operational speed: 15 km/h
Stop density: -
Capacity: 1
CO2 emission: 0 g/passenger km
Infrastructure costs: -
Vehicle costs: -
Operational infrastructure costs: -
Operational vehicle and employee costs: -

**Walking**
Operational speed: 5 km/h
Stop density: -
Capacity: -
CO2 emission: 0 g/passenger km
Infrastructure costs: -
Vehicle costs: -
Operational infrastructure costs: -
Operational vehicle and employee costs: -

1. CVOV, 2005
2. Based on fast train Haarlem-Dordrecht
4. Based on Hanzelijn, including 1 bridge
5. EDBR, 2007
6. Australian hovercraft, 2009
7. Based on bus 101, Spijkenisse-Hellevoetsluis
8. CO’nnect, 2008
9. Based on Aqualiner Rotterdam
10. Enkel gelede bus
11. Based on lightrail green, Denver
12. Based on Erasmuslijn Rotterdam
13. Based on HTM tram 1, The Hague
14. Based on bus 72, Rotterdam
15. Niet gelede bus
16. Based on a Dudok bus stop in Hilversum
17. Estimation, based on other figures
18. Based on Parkshuttle at Kralingse Zoom
19. Based on ULTRA in Heathrow
- Not relevant for this project
8. Available types of public transport and travel behaviour

Research question nr. 4 and 5 will be answered in this chapter: 4. What are the characteristics of different modes of public transport available for the network design? 5. What is the current travel behaviour of people traveling in South Holland, relevant for this design project?

Available modes of public transport

Different modes of public transport can be found on the previous two pages. Different sources are used to find the characteristics of the different types. They are divided in different categories: Regional system line bound (with speeds over 40 km/h), urban system line bound, urban system (semi) on demand and local system to reach the final destination. This analysis will be used while designing the different networks in the synthesis phase.

Travel behaviour in South Holland.

The modal choice for a person traveling from O to D is described with the formula in figure 9.1. The Utility is described as follows and is calculated as described in chapter 4:

\[
\begin{align*}
V_{\text{car}} &= 1 - 0.0779 \times T_{\text{Travelcar}} \\
V_{\text{PT}} &= 0.2967 - 0.0207 \times T_{\text{TravelPT}} - 0.0895 \times T_{\text{WaitPT}} \\
V_{\text{bike}} &= 1.0861 - 0.0697 \times T_{\text{Travelbike}}
\end{align*}
\]

Figure 4.6 shows the \(\exp(V)\) for the three modes with different travel times. For this graph \(T_{\text{WaitPT}}\) is included in \(T_{\text{TravelPT}}\) and the scale parameter for this combination is -0.0379. The division of the \(\exp(V)\) for each mode for a certain OD pair is the division of mode choice. An example: For a certain OD pair counts: \(T_{\text{Travelcar}}=20\), \(T_{\text{TravelPT}}=30\) and \(T_{\text{Travelbike}}=60\). Then \(\exp(V_{\text{car}}) = 0.75\), \(\exp(V_{\text{PT}}) = 0.45\) and \(\exp(V_{\text{bike}}) = 0.01\) (from the graph). This means that 62% will choose car, 37% will choose public transport and just 1% will choose bike.

These values are defined by looking at the current travel behaviour in the vicinity of the port (figure 4.6). Traffic within areas (municipalities) is excluded for this analysis. Therefore the formula’s fit best on traffic between areas.
Part 4
Synthesis

Contents

Three different network alternatives are generated in this part, based on the analysis from part 3. Chapter 9 describes the ideal network for maximum socioeconomic relevance from the point of view of the Port of Rotterdam, without taking into account the existing public transport network. This ideal network is translated into three more realistic networks in chapter 10.

Results of this part

This chapter delivers three network alternatives that may prove the hypothesis to be true, as set in chapter 3. These network alternatives will be simulated and evaluated in part 5 of this research.
9. Desirable connections

For the synthesis of the network variants, the IRVS methodology is used. More information about this method can be found in chapter 4. The first step in the IRVS method is to define what areas should be connected, without taking into account the existing public transport network. This question is answered in chapter 7. In this chapter the ideal network will be defined. Based on the existing network, the links that should be added are created. Research question nr. 6 will be answered in this chapter: What connections are desirable to be established, in order to enhance the competitive position of the Port of Rotterdam?

Defining the ideal network

In chapter 7, the areas that should be connected are defined. For each design criteria, the ten most important areas are chosen and connections between these zones are established, as directly as possible. For example, figure 9.1 shows the density of the origin and destination of car drivers on the A15. The 10 zones with the highest density are defined (figure 9.2) and connected as directly as possible in such a way, that the number of links equals the number of areas. This is done for each design criteria, and is shown on figure 9.1-9.10.

Figure 9.1. Density of A15 car drivers

Figure 9.2. Top 10 areas to be connected to reduce car use on the highways surrounding the port area
Figure 9.3. Density of port employees in 2025

Figure 9.4. Top 10 areas to be connected to connect port employees with the port area.

Figure 9.5. Potential port employees density

Figure 9.6. Top 10 areas to be connected to attract new employees to work in the port area.
**Figure 9.7. Youth density**

**Figure 9.8. Top 10 areas to be connected to connect youth to port related knowledge institutes.**

**Figure 9.9. Leader firm density**

**Figure 9.10. Top 10 areas to be connected to connect port related knowledge institutes and leader firms.**
Part 4. Synthesis

From ideal network to realistic network.

Figure 9.11 shows all the desirable connections from figure 9.1-9.10. In order to define what links should be added for a more realistic network, this chaos of connections should be consolidated. The existing transportation network will be part of this consolidation process (figure 9.12), as well as the lines under discussion to be built in the future (Appendix F). The consideration behind these discussed lines, together with the consideration for the Port of Rotterdam may be enough to create public transport with speed >40km/h and with minimal frequency’s of 4 vehicles/hour/direction.

The following rules are used for the consolidation. A link should:
- follow existing public transport
- follow future pubic transport that is likely to be created
- bundle with at least one other desirable link

Figure 9.13 shows the consolidated desirable links.
Four new proposed connections

What links should be added to the existing network to gain the consolidated desirable network? That question will be answered in this sub-chapter. Figure 9.14 shows these links to be added. They consist of four different connections: A connection between Hellevoetsluis and Rotterdam, going through Botlek, a connection between The Hague and the port area, a connection between Spijkenisse and Maasvlakte and a connection between Schiedam and the Drechtsteden, through Rotterdam and Cityports.

10. Network alternatives

Now that the desirable connections are found, research question nr. 7 can be answered in this chapter: What network alternatives can be generated based on the desirable connections? The network criteria derived in chapter 7 are used in the network design as well as the characteristics of different types of public transport, found in chapter 8. First, the network conditions and criteria are shown.

Network conditions and criteria

Network boundary conditions
- Operational speed ≥40 km/h.
- Minimal frequency of 4 vehicles/hour/direction.
- The maximum amount of transfers for a door-to-door trip is 3.
- The vehicles should have comfortable seats.
- The system should run from 6.00 h - 24.00 h.

Network criteria
- The system should be as punctual as possible.
- The amount of transfers should be minimized.

![Figure 9.14. Connections to be added to establish the desirable connections.](image)

![Figure 10.1. Summary of the network criteria and boundary conditions.](image)
Network concepts

Three network variants are created, based on three different network concepts, making use of the port railway, creating a Meuse river crossing and making use of the existing waterways for public transport. In these thee network variants, the desired links from figure 10.14 are translated into real network variants.

1. Port railway variant

The port railway is currently in use for goods only. Yet, capacity is still available for additional trains. In this variant the capacity will be used for people transportation instead of goods. If the capacity is reached in the future, a new railway can be built parallel to the existing port railway. The network design can be found on figure 10.2. Only part of the port railway is used in this design, yet in a scenario with limited port growth, the entire port railway between Rotterdam and Botlek may be used for passenger transportation. Rather than connecting to Rotterdam Central, the lightrail runs to Rotterdam Alexander station. This is done because the network attract considerable more travelers this way. For more details I refer to appendix G.

To make the connection between the port area and The Hague, a lightrail connection through Greenports is created. A ferry is used to make the crossing to the South bank of the Meuse. The existing buslane in Voorne-Putten is extended towards Maasvlakte, to create a busservice between Spijkenisse and Maasvlakte. The connection between Schiedam and Drechtsteden is created with a metro on an elevated track and connected to Dordrecht Central station. The system runs trough Barendrecht, in order to make a connection with the lightrail station in the South of Cityport, to create a transit hub in this area.

2. River crossing variant

Plans are to create a new river crossing under the Meuse (figure 3.2). Yet, this tunnel is planed solely for cars. Bundled development of a car tunnel and a railtunnel can cut costs considerably. When the Beneluxtunnel in Rotterdam was build, a metrotube was constructed with it. This resulted in 50 million euro extra costs for the metrotube, while building a separate tube was estimated at 120 million euro (Trouw, 1992). The combined development of a car- and railtunnel may reduce the costs of the railtunnel with over 50% and is therefore identified as an opportunity for public transport development.

The network design for this variant can be found on figure 10.3. A fast train will run from Dordrecht to Botlek and Hellevoetsluis, going trough the tunnel near Rozenburg. The location near Rozenburg is chosen, because it is a serious variant to be built as new river crossing tunnel and because it fits best with the connections to be added from figure 10.14. A lightrail between The Hague and the port runs trough the same tunnel, and ends up at Maasvlakte. The existing buslane in Voorne-Putten is extended towards Maasvlakte, to create a busservice between Spijkenisse and Maasvlakte. The connection between Schiedam and Drechtsteden is created with a metro on an elevated track and connected to Dordrecht Central station.

3. Water bound variant

The port and city of Rotterdam are cut trough by waterways. Making use of these waterways seems to be a cheap solution for providing public transport in these areas. A fast moving vessel, with limited wave hindrance is chosen for this task, a hovercraft. The network design can be found on figure 10.4. The service runs from The Hague over the Northsea to Maasvlakte, meets Hoek van Holland, Maassluis, Botlek, Spijkenisse, Cityports, Rotterdam and runs to the Drechtsteden. A buslane is created to connect Hellevoetsluis to this hovercraft service. The existing buslane in Voorne-Putten is extended towards Maasvlakte, to create a busservice between Spijkenisse and Maasvlakte. A metro is created in Rotterdam between Rotterdam Alexander and Schiedam Central station. In between this metro attaches to the ferry service twice.

Operational hours.

All systems, except the lightrail on the port railway in the River crossing variant run from 6.00-24.00h. This way, the schedule fits with the shift times of the port industry. Shifts start and end around 7.00 h, 15.00 h and 23.00 h. About half of the port employees work in shifts, the rest starts around 8.00 h and ends around 17.00 h.
Legend

- Connection 1: Rotterdam-Hellevoetsluis
- Connection 2: The Hague-Port area
- Connection 3: Spijkenisse-Maastricht
- Connection 4: Schiedam-Drechtsteden

- Existing infrastructure
- New infrastructure

Legend

- Existing stop
- New stop

Figure 10.2. Port railway network variant
Legend

- Link 1: Rotterdam-Hellevoetsluis
- Link 2: The Hague-Port area
- Link 3: Spijkenisse-Maasvlakte
- Link 4: Schiedam-Drechtsteden

- New infrastructure
- Existing infrastructure
- Existing stop
- New stop

**Figure 10.3. River-crossing network variant**

*The part between Maasvlakte and Botlek runs only between 6.00-9.00 h, 14.00-19.00 h and 22.00-24.00 h, to match the shift times of port labour.*
Legend

- Link 1: Rotterdam-Hellevoetsluis
- Link 2: The Hague-Port area
- Link 3: Spijkenisse-Maasvlakte
- Link 4: Schiedam-Drechtsteden

New infrastructure
Existing infrastructure

Existing stop
New stop

Figure 10.4. Water bound network variant
Part 5
Simulation and evaluation

Contents

The different network alternatives will be tested and evaluated in this part of this research. In chapter 11, travel behavior and cost-efficiency are evaluated. The different networks are simulated with the RVMK model, as described in chapter 4, to estimate the loads (revenues) on the different public transport lines. I estimated the investment costs and operational costs, based on the analysis from chapter 8 about the characteristics of different public transport systems.

In chapter 12, the different network alternatives are tested according to the socioeconomic design criteria from chapter 6. Socioeconomic data is combined with output from the RVMK model to make the socioeconomic relevance of the different network alternatives explicit.

Chapter 13 contains an analysis on transit oriented development opportunities derived for different stations within the port area.

In chapter 14 a network of preference is chosen, based on the simulation from part 11,12 and 13. To validate whether this choice is legitimate, the results from previous chapters are evaluated on their reliability. I conclude that the results are reliable.

Results of this part

This part gives insight in the performance of the different network alternatives. I conclude that the Rivercrossing network alternative has the best prospect of supporting the hypothesis, since it performs best based on the criteria I set in chapter 6 and.

This chosen network will be used to when giving shape to the transit oriented development opportunities in chapter 15 and 16 and will be finalized in chapter 17.
11. Travel behavior and cost-efficiency

The different network alternatives have been simulated as described in chapter 4. Two research questions will be answered in this chapter:

8. How do travelers behave in case of the new transportation networks?
9. What is the cost-efficiency of the different network alternatives?

The networks are simulated for the Steady Growth scenario. In the Prosperous Port scenario, the amount of travelers on the different transit lines will increase.

Travel behaviour with the different network variants

Origin/destination data from the RVMK model is used to estimate the future use of the different network variants. RVMK data for 2020 is used for this simulation. The used method includes the assumption that the total origin/destination data between zones does not change, only the modal split may be altered.
**Loads on the transit lines**

Figure 11.1-11.3 shows the loads on the different elements of the network variants. The width of the line shows the load on the transit element. The color shows the occupation degree of the different elements. The loads are highest in the vicinity of big cities like The Hague and Rotterdam.

**Effect of a new car river crossing**

The simulation is executed for two variants, one where a new tunnel for cars is included and one where this tunnel is not included. The location of this tunnel is the same as the public transport tunnel near Rozenburg and Botlek. The effect is significant on the transit lines between Rotterdam and the port area. This is a logical effect, since the new car tunnel enhances the connections by car between Rotterdam and the port area.

The same effect is expected for the connections between The Hague and the port area but the effect of the car tunnel seems to be limited for the transit lines in this area. A explanation for this limited effect is the limited amount of traffic between The Hague and the port area in the existing situation. Loads on the transit lines between The Hague and the port are mainly used to travel between Greenports and The Hague, or to transfer to the Hoeksche lijn (connection between Hoek van Holland and Rotterdam). If the social-economic relations would change, the effect would be much higher. Yet, these changes are not included in the RVMK model.

**Cost-efficiency of the different network designs**

Now that the loads on the different public transport line are estimated, the cost-efficiency of the different network design can be calculated. Data from chapter 8 on the development and maintenance costs on different public transport types is used to make the calculations as described in chapter 4.

**Three variants for cost estimations**

The costs for each network variant are calculated in three variants: A variant as designed and shown on figure 10.2-10.4, a variant where the port railway is used for passenger transport wherever possible and a variant as designed and shown on figure 10.2-10.4 where a car tunnel is added to the design. Appendix IV.1 contains the calculations made for this simulation and figure 11.4 shows the different cost estimations.

**Investment costs**

The investment costs contain the costs of the infrastructure and the purchase costs of the vehicles. For the port railway variant, costs are cut considerably when the port railway is used, instead of the creation of a new passenger railway parallel to the port railway. The same goes for the River crossing variant. For the River crossing variant, costs are also cut with the creation of the car tunnel, since the combined development of a car-and railtunnel may reduce the costs of the railtunnel with over 50% (see chapter 10). For the water bound system, investment costs do not change for the different variants.

The investment costs will be paid back in 20 years with an interest-free loan from the government. This way, the investment costs are included when estimating the cost-benefit ratio, but a contribution from the government is included as well.

Elements like bridges and tunnels bring about extra costs. Building the metro tube near Beneluxtunnel cost 120 million euro back in the year 1992 (Trouw, 1992). Nowadays I estimate the costs of such a tunnel at 150 million euro. For an underground connection near Rozenburg, costs rise significantly, because a protected landscape has to be crossed. Costs for such a connection are estimated at 750 million euro (Comán, 2007).
**Yearly operational costs**

The yearly operational costs include operational vehicle costs (including driver and overhead) and operational infrastructure costs. When the port railway is used, the operational costs decrease for the port railway variant and river crossing variant, since less railway has to be maintained.

**Yearly revenues**

The calculation of the yearly revenues is based on the loads from figure 11.1-11.3. The tariff system of the OV chipkaart charges 75 cents per trip and 11.8 cents per kilometre. The average length of the trips that are added is about 30 km/trip, and is calculated by dividing the additional public transport kilometers by the additional public transport trips for each network variant (appendix IV.1). The revenues per passengerkilometer become $\frac{75}{30} + 11.8 = 14.3$ cents/passengerkilometer. Since many travelers have public transport discount, the final revenues per km are $14.3 \times 0.75 = 10.7$ cents/passengerkm.

**Revenues loss on existing public transport**

The new public transport lines attract existing car drivers, but also people from existing public transport lines. This revenue loss should be included in the revenues and cost-efficiency of the new networks.

**Evaluation: Benefit/cost ratio of the different network designs**

The benefit/cost ratio is calculated by dividing the yearly revenues by the yearly operational costs + 5% of the investment costs. The river crossing variant shows the highest benefit/cost ratio, even though the investment costs are also the highest. A benefit/cost ratio of 50% is desired, yet this amount often does not include the investment costs. Interesting is the difference in benefit/cost ratio for the busline between Maasslakte and Spijkenisse, since the busline is identical in the different variants. The higher the quality of the alternative West-East connection, the worse the benefit/cost ratio for the busline.

Most public transport lines show acceptable benefit/cost ratios, except for the hovercraft service and the metro between Schiedam and Drechtsteden. This makes the realization of these public transport lines unlikely. As a system, the River crossing variant shows the best cost/benefit ratio, but also comprises the highest investment costs.

**Benefit/costs excluding the yearly depreciation**

The yearly depreciation of infrastructure is included in the benefit cost/ratio, in order to evaluate which network is most cost effective. Yet, in reality, the government pays for the investment costs of the infrastructure as well as about 50% of the yearly operational costs. The other 50% has to be financed by ticket revenues. Figure 11.5 shows the cost benefit ratio excluding the depreciation. It shows that the Rivercrossing alternative has the best benefit/cost ratio for each variant. Furthermore, the effect of building a car bridge has considerable effect on all alternatives. The average amount is included in figure 14.1 for the evaluation of the network designs.
Public transport as designed  | Making use of the port railway  | Including a new car-waterway connection

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Investment costs (million euro’s)</th>
<th>Yearly operational costs (million euro’s)</th>
<th>Yearly revenues (million euro’s)</th>
<th>Benefit/cost ratio</th>
<th>Yearly revenue loss on existing public transport (million euro’s) and the new benefit/cost ratio</th>
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<td><strong>55</strong></td>
<td><strong>12%</strong></td>
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<td>Port railway</td>
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<td><strong>2381</strong></td>
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<td><strong>55</strong></td>
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<td></td>
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<td><strong>98</strong></td>
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<tr>
<td></td>
<td></td>
<td><strong>4</strong></td>
<td><strong>4</strong></td>
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<td><strong>20</strong></td>
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<td></td>
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</tbody>
</table>

* Runs between 6.00-9.00 h, 14.00-19.00 h and 22.00-24.00 h.

Figure 11.4. Cost estimations for the different network variants.
Robustness

The following network criteria are shown in chapter 10:
- The system should be as robust as possible.
- The amount of transfers should be minimized.

The criteria on minimisation of the amount of transfers is implicitly included in the travel behaviour simulation, since transfers generate a big penalty for public transport utility. Robustness of the network is not taken into account and should be evaluated in this chapter. A way of checking the robustness is by performing a worst case scenario (Meepetchdee and Shah, 2007). For each scenario, the worst blockade is determined (figure 14.2-14.4). No blockade is possible with the bus on buslane, since the busses can choose to drive on the public roads. Elements that can be blocked are rail elements and landing stages of the hovercraft. When a landing stage is blocked, the public transport line can still function. When a rail element is blocked, the vehicle cannot continue and the line is blocked.

When the Blankenburg tunnel is blocked, port employees from Rotterdam and The Hague will have difficulties to reach their destination in the port area. When the port railway is blocked, only port employees from Rotterdam are affected. When the ferry stop is blocked in the Waterbound network alternative, only Maasvlakte employees from The Hague are seriously affected. Therefore, the Waterbound network alternative is most robust, while the Rivercrossing alternative is least robust (Figure 14.1).

Figure 14.2. The worst blockade possible for the Port railway variant: No rail traffic possible between Voorne-Putten and Botlek.
Figure 14.3. The worst blockade possible for the Rivercrossing variant: No rail traffic possible in the tunnel between Maassluis and Botlek.
Figure 14.4. The worst blockade possible for the Waterbound variant: No possibility to anchor at Maasvlakte because the landing is destroyed.
12. Socioeconomic relevance

Not only the travel behaviour and cost effectiveness of a transportation network is important, but also the socioeconomic relevance of the network designs. Therefore, research question nr 10 is answered in this chapter: What is the socioeconomic relevance of the different network alternatives, based on the design criteria?

Design criteria

The different network designs will be tested on the following design criteria derived from chapter 6:
1. The daily car usage reduction on the A15 and in the Beneluxtunnel.
2. The amount of port employees within 60 minutes public transport travel time from Botlek and Maasvlakte.
3. The amount of potential new port employees that are within 60 minutes public transport travel time from Botlek and Maasvlakte.
4. The amount of leader firms within 60 minutes public transport travel time from port related knowledge institutes*.
5. The amount of youngsters within 60 minutes public transport travel time from port related knowledge institutes*.
6. The reduction of yearly CO₂ emissions in tons.

Simulation by combining socioeconomic data with transit reach data

The RVMK model is used to calculate what areas can be reached within 60 minutes travel time from Maasvlakte (figure 12.2-12.5), Botlek (12.6-12.9), the RDM campus (12.10-12.13) the Scheepvaart and Transport college, The Technical University of Delft and the Erasmus University. The methodology is described in chapter 4. Based on this information, and the socioeconomic data from chapter 7 the different networks can be tested on criteria 2-5. The results are found in figure 12.1 and the data in appendix IV.2. The calculations can be found in appendix E.

Car usage reduction and CO₂ emission reduction

The results from the travel behaviour simulation from chapter 11 are used to estimate the amount of car usage reduction and CO₂ reduction. The reduction of cars is done by letting the Omnitrans program calculate the loads on the highway links for the different network variants.

Calculating CO₂ emissions is more elaborate. The total calculations can be found in appendix D. Data from chapter 11 is used to estimate the change in passengerkilometers for the different modalities. The characteristics from chapter 8 include parameters for CO₂ emissions for different modalities. Appendix IV.1 contains the calculations. They are performed for two different situations, one where a car tunnel near Rozenburg is present and one where the car tunnel is not created. CO₂ reduction for the total transportation network differs for as shown on figure 12.1. Since the utilisation rate of the public transport vehicles is not taken into account, the CO₂ emission calculation contains errors. Yet, for indication and comparison purposes the data can be used.

Evaluation: Socioeconomic relevance of the different network designs

Figure 13.1 shows the performance of the different networks on the network design criteria. Both the Port railway and the River crossing variant reduce car use on the A15 and beneluxtunnel considerably, while the effect from the water bound system is limited. For criteria 2, 4 and 5 the scores of the different networks do not differ much. Most potential workforce dwells at the North side of the port area. Therefore, the River crossing variant scores significantly better on criteria 3 than the other variants.

For the reduction of CO₂ emissions the River crossing variant scores best. The water bound system shows reverse effects: The total CO₂ emissions increase with the new public transport system. This has to do with the high CO₂ emission/passengerkilometer for water bound public transport. To conclude, the River crossing variant scores best on most criteria and is therefore preferable when considering socioeconomic relevance of the networks.

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*knowledge institutes as found on figure 2.13 of the analysis booklet.
<table>
<thead>
<tr>
<th>Current situation</th>
<th>Port Railway</th>
<th>River crossing</th>
<th>Water bound</th>
<th>CO2 emission in tonne/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily amount of cars on the A15 and in the Beneluxtunnel (two directions)</td>
<td>Employees from Maasvlakte &amp; Botlek within 60 minutes public transport travel time from Maasvlakte &amp; Botlek</td>
<td>Potential employees within 60 minutes public transport travel time from Maasvlakte &amp; Botlek</td>
<td>Leader firms within 60 minutes public transport travel time from port related knowledge institutes</td>
<td>Youngsters within 60 minutes public transport travel time from port related knowledge institutes</td>
</tr>
<tr>
<td>Total: 309000 in peak hours: 34%</td>
<td>Total: 7000 within 45 minutes: 59%</td>
<td>Total: 40000 within 45 minutes: 31%</td>
<td>Total: 110 within 45 minutes: 45%</td>
<td>Total: 880000 within 45 minutes: 60%</td>
</tr>
<tr>
<td>Total: -9600 in peak hours*: 37%</td>
<td>Total: +3900 within 45 minutes: 63%</td>
<td>Total: +50500 within 45 minutes: 30%</td>
<td>Total: +46 within 45 minutes: 76%</td>
<td>Port ambition: yearly reduction of 20,000,000</td>
</tr>
<tr>
<td>Total: -13500 in peak hours: 35%</td>
<td>Total: +4500 within 45 minutes: 66%</td>
<td>Total: +172700 within 45 minutes: 41%</td>
<td>Total: +37 within 45 minutes: 35%</td>
<td>Total: +185200 within 45 minutes: 84%</td>
</tr>
<tr>
<td>Total: -4670 in peak hours: 37%</td>
<td>Total: +2800 within 45 minutes: 36%</td>
<td>Total: +23100 within 45 minutes: 38%</td>
<td>Total: +41 within 45 minutes: 97%</td>
<td>Total: +190500 within 45 minutes: 85%</td>
</tr>
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</tr>
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<td>Total: +190500 within 45 minutes: 85%</td>
</tr>
</tbody>
</table>

Figure 12.1. Socioeconomic relevance of the different network designs on different design criteria.
Part 5. Simulation and evaluation

Legend
- < 15 minutes
- 15 - 30 minutes
- 30 - 45 minutes
- 45 - 60 minutes
- Destination

Figure 12.2. Public transport travel times to Maasvlakte in the original situation.

Figure 12.3. Public transport travel times to Maasvlakte in the Port railway variant.

Figure 12.4. Public transport travel times to Maasvlakte in the River crossing variant.

Figure 12.5. Public transport travel times to Maasvlakte in the Waterbound variant.
Figure 12.6. Public transport travel times to Botlek in the original situation.

Figure 12.8. Public transport travel times to Botlek in the River crossing variant.

Figure 12.7. Public transport travel times to Botlek in the Port railway variant.

Figure 12.9. Public transport travel times to Botlek in the Waterbound variant.
Figure 12.10. Public transport travel times to Botlek in the original situation.

Figure 12.11. Public transport travel times to Botlek in the Port railway variant.

Figure 12.12. Public transport travel times to Botlek in the River crossing variant.

Figure 12.13. Public transport travel times to Botlek in the Waterbound variant.
13. Transit oriented development potential

Transit oriented development opportunities can provide benefits for the port in both the Steady Growth scenario and the Prosperous Port scenario. Yet in the Prosperous Port scenario, the amount of space in the port area is insufficient in 2035. Therefore the necessity of space redistribution may only be acknowledged by the Port Company in this scenario. Therefore, the transit oriented development potential should only be used as evaluation criteria in the Prosperous Port scenario. Research question 11 is answered in this chapter. What transit oriented development potential do the network alternatives offer, relevant for the competitive position of the Port of Rotterdam?

Transit oriented development opportunities inside the port

The relevant land use development opportunities inside the port area are defined in the SWOT analysis from chapter 6 and can be found in figure 13.1. The transit oriented development opportunities range from amenities for tourists and visitors to co-siting and space innovations. These developments ask for good connections to other businesses, to visitors, to port employees, to knowledge institutes etc. In other words: Accessibility to urban densities. As indicator for urban densities, the total working population within 60 minutes public transport travel time to a certain port area is chosen. Figure 13.7 shows the transit oriented development opportunities inside the port area.

Transit oriented development opportunities outside the port

The relevant land use development opportunities outside the port can be found in figure 13.2. These development comprise dwelling programs to house new port employees and park & ride facilities to reduce car use. Future housing development in South Holland follows the SER ladder (Province of South Holland, 2009), meaning that intensification and restructuring are desired, before new development locations are sought. Therefore, the existing future housing programs are identified (Atelier Zuidvleugel, 2008) (figure 2.14 of the analysis document). The data from figure 12.2 - 12.9 is used to find what housing programs are situated within 60 minutes public transport travel time from Maasvlakte or Botlek. Figure 13.3-13.6 shows these housing programs, where dwellings for port employees can be created. Figure 13.7 shows the total amount of hectares of housing program within 60 minutes public transport travel time from Maasvlakte or Botlek.

Evaluation: Transit oriented development opportunities for the different network designs.

Figure 14.1 shows the transit oriented development opportunities, in- and outside of the port area. The River crossing variant scores best in development opportunities for Maasvlakte and Botlek. Furthermore, it attaches to most dwelling programs in South Holland. The network alternatives score equal in development opportunities for Cityports. Therefore, the River crossing variant scores best in transit oriented development opportunities.

Figure 13.1. Transit oriented development opportunities inside the port area.

Figure 13.2. Transit oriented development opportunities outside the port area.
Figure 13.3. Housing development locations accessible with public transport from Botlek and Maasvlakte in the original situation

Figure 13.4. Housing development locations accessible with public transport from Botlek and Maasvlakte and proposed Park & Ride facilities in the Port railway variant.

Figure 13.5. Housing development locations accessible with public transport from Botlek and Maasvlakte and proposed Park & Ride facilities in the River crossing variant.

Figure 13.6. Housing development locations accessible with public transport from Botlek and Maasvlakte and proposed Park & Ride facilities in the Waterbound variant.
## Socioeconomic relevance

<table>
<thead>
<tr>
<th>Current situation</th>
<th>Port Railway</th>
<th>River crossing</th>
<th>Water bound</th>
<th>CO2 emission in tonne/year</th>
</tr>
</thead>
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<tr>
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<td>total: 7000 within 45 minutes: 59%</td>
<td>total: +4500 within 45 minutes: 66%</td>
<td>total: +2800 within 45 minutes: 36%</td>
<td>no car tunnel: -20000 car tunnel: -15600</td>
</tr>
<tr>
<td>Potential employees within 60 minutes public transport travel time from Maasvlakte &amp; Botlek</td>
<td>total: 40000 within 45 minutes: 31%</td>
<td>total: +172700 within 45 minutes: 41%</td>
<td>total: +23100 within 45 minutes: 38%</td>
<td>no car tunnel: -36400 car tunnel: -30500</td>
</tr>
<tr>
<td>Leader firms within 60 minutes public transport travel time from port related knowledge institutes</td>
<td>total: 110 within 45 minutes: 45%</td>
<td>total: +37 within 45 minutes: 35%</td>
<td>total: +41 within 45 minutes: 97%</td>
<td>total: +185200 within 45 minutes: 84%</td>
</tr>
<tr>
<td>Youngsters within 60 minutes public transport travel time from port related knowledge institutes</td>
<td>total: 880000 within 45 minutes: 60%</td>
<td>total: +196000 within 45 minutes: 74%</td>
<td>total: +190500 within 45 minutes: 85%</td>
<td>total: +190500 within 45 minutes: 85%</td>
</tr>
</tbody>
</table>

Figure 14.1. Evaluation of the different network designs on the different network criteria
<table>
<thead>
<tr>
<th>Travel behavior and cost effectiveness</th>
<th>Transit oriented development potential (only of importance in the Prosperous Port scenario)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs of the system in billion euro. (Average of figure 12.5)</td>
<td>Transit oriented development potential of Maasvlakte. (Working population within 60 min PT travel time)</td>
</tr>
<tr>
<td>Benefit/cost ratio of the network. (Average of figure 12.5)</td>
<td>Transit oriented development potential of Botlek. (Working population within 60 min PT travel time)</td>
</tr>
<tr>
<td>Impact of a worst case calamity on the network performance (figure 14.1-14.3).</td>
<td>Transit oriented development potential of Cityports. (Working population within 60 min PT travel time)</td>
</tr>
<tr>
<td>Housing development location within 60 minute public transport travel time from Botlek or Maasvlakte (hectare)</td>
<td></td>
</tr>
<tr>
<td>2.3 billion euro</td>
<td>0</td>
</tr>
<tr>
<td>41%</td>
<td>357700</td>
</tr>
<tr>
<td>medium</td>
<td>449500</td>
</tr>
<tr>
<td>+176500</td>
<td>5757</td>
</tr>
<tr>
<td>+315900</td>
<td></td>
</tr>
<tr>
<td>+910700</td>
<td>+6873</td>
</tr>
<tr>
<td>2.9 billion euro</td>
<td>53%</td>
</tr>
<tr>
<td>big</td>
<td>+441200</td>
</tr>
<tr>
<td>+796200</td>
<td>+15290</td>
</tr>
<tr>
<td>+983200</td>
<td>+15290</td>
</tr>
<tr>
<td>1.1 billion euro</td>
<td>40%</td>
</tr>
<tr>
<td>small</td>
<td>+164500</td>
</tr>
<tr>
<td>+81900</td>
<td>+2329</td>
</tr>
<tr>
<td>+996900</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
14. Evaluation and validation of the results

In this chapter, the network of preference is chosen. Then, the data is validated, to see if the network choice is legitimate. This validation will also be used when designing the final network, in chapter 17.

Network preference by evaluating different criteria

The networks are evaluated on the three aspects important for public transport network design for the Port of Rotterdam (figure 4.2), investment costs & cost-efficiency, socioeconomic relevance and transit oriented development potential. The latter is only important in the Prosperous Port scenario, while the other two are important for both scenarios. Figure 14.1 shows the results of the simulations.

Investment costs & cost-efficiency

As can be seen on figure 14.1, the investment costs of the Rivercrossing variant are highest. Yet, the benefit/cost ratio is also highest. This means that creating the Rivercrossing variant involves the highest risk, but is also expected to be most benefit/cost-efficient. Based on this analysis, no best performing network can be identified.

Socioeconomic relevance

As described in chapter 12, the River-crossing variant performs best in most socioeconomic relevance criteria. Therefore, the Rivercrossing variant is preferred from a socioeconomic point of view.

Transit oriented development potential

As described in chapter 13, the River-crossing variant performs best in the criteria on transit oriented development potential. Therefore, the Rivercrossing variant is also preferred when regarding spatial development opportunities.

Best performing network

Based on this evaluation, the Rivercrossing alternative performs best: It scores best on socioeconomic relevance and transit oriented development potential, while the different network score equally good on the evaluation on investment costs & cost-efficiency. This result will be validated in the following sub-chapters.

Validating my results

Poor performance of the water bound public transport

The main reason why the Rivercrossing alternative attract more travelers than the other alternatives is because of the poor performance of the public transportation over water. As figure 11.1 and 11.3 show, the load on the ferry lines are very limited, even though the operational speed is around 45 km/h (including 5 minute waiting time/stop, see chapter 8). While designing the ferry network, I encountered several problems:

- Areas with high population density are often not situated next to the water (figure 2.17 and 2.18 in the analysis document). Therefore, attaching the water bound network to areas with high traveler density is often impossible difficult.
- Existing public transport stops are often situated away from the water, to maximise transit attractiveness (figure 14.1). Therefore, attaching the water bound lines with the exist-
ing public transport network proves very difficult. As can be read in chapter 8, the penalty for waiting times and transfer times are very high (four times as high as in vehicle time). Walking between transit stations is considered waiting time and weighs heavily on the attractiveness of the transit line.

With the poor functioning of the hovercraft system, the only alternative providing areas public transport network is the Rivercrossing alternative. With a transfer at Botlek/Rozenburg, different areas are interconnected; Rotterdam, Botlek, Maasvlakte, Voorne-Putten and The Hague.

Comparison with other graduation research

A research is carried out on public transport over water in the Port of Rotterdam (Piet, 2008). The conclusions of this research are that a waterbound system can be designed with a cost/benefit ratio of 59% that improves the accessibility of the port area (figure 14.2). Since the waterbound legs of my alternative show poor benefit/cost ratio, and the accessibility of the port area is not improved significantly this research contradicts the results of my evaluation. Therefore, I make a comparison to see if my results are reasonable.

The best performing network of the research of Piet is the network shown on figure 14.2. It is the best performing network because it has a benefit/cost ratio of 59% and gives the best improvement of the accessibility of the port area. The yearly operational costs are estimated at 4.5 million. This number includes the depreciation of the investments. The yearly revenues are estimated at 2.7 million. The waterbound transit line of the network I simulated has a benefit/cost ratio of only 11% (depreciation of the investment cost included, derived from appendix D). The yearly costs are estimated at 26.9 million euro while the yearly benefits are only 3.8 million euro.

Since the lengths of the transit lines are different and the loads are distributed equally among the line (figure 11.3) the costs and benefits can be calculated per km (figure 14.3).

Cost differences

The difference in yearly costs is a factor 1.4 between the research by Piet and me. In the study of Piet, about 3/4th of the costs come from operational costs (fuel and personnel). In my study, this portion is also 3/4th of the total costs, so the portion is the same. I based my cost calculation on a study done for DS+V (CVOV, 2005) on the operational costs of different types of public transport. This data is based on the total operational costs derived from cases that are operational, whereas the study by Piet is based on separate elements of the operational cost calculation. In the analysis of Piet some elements are not taken into account, like overhead costs and ship layover time (waiting time at the end of the transit line). The difference in cost estimations can be explained in this way.

Benefit differences

The benefits per kilometer differ with a factor of 3 between the research by Piet and me. We both make use a logit model for OD estimations and use of the same RVMK data, so the results should be similar. The following reasons contribute to this difference:

- Piet uses the maximum fare of 11 cents/km for calculating benefits, while I include people traveling with public transport discount and use a fare of 8.3 cents/km.

<table>
<thead>
<tr>
<th>Designer</th>
<th>Yearly revenues</th>
<th>Yearly costs</th>
<th>benefit/cost</th>
<th>transit line length</th>
<th>revenues/km</th>
<th>costs/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piet</td>
<td>2.7</td>
<td>4.5</td>
<td>0.59</td>
<td>25</td>
<td>0.108</td>
<td>0.180</td>
</tr>
<tr>
<td>de Koning</td>
<td>3.8</td>
<td>26.9</td>
<td>0.14</td>
<td>105</td>
<td>0.036</td>
<td>0.254</td>
</tr>
</tbody>
</table>

Figure 14.2. Longitudinal waterbound variant (Piet, 2008)

Figure 14.3. Difference between the transit line from Piet and de Koning
I include waiting time as an explanatory variable for public transport utility, whereas Piet included the waiting time in the total travel time. The weight of waiting is four times as high as in vehicle time. As I point out in the beginning of this chapter, waterbound transit contains relatively large waiting times when compared to other types of public transport. Therefore, waterbound transit will be less attractive if waiting is weighted separately.

In my research, loss on existing transit lines is included in the cost-efficiency of the transit system, while Piet neglects this effect while calculating the benefits.

The stop density of the network designed by Piet is higher, therefore more travelers may use the transit line.

I introduce a busline that provides competition for the waterbound transit.

Conclusions

The difference in benefits and costs between the two research studies can be explained by flaws in the research executed by Piet. I conclude that between these two studies my benefit/cost estimations are more realistic and no adaptations have to made. Therefore, the conclusion that the Rivercrossing network alternative scores best still stands.

Modal split

Modal split numbers are generated (figure 14.4), in order to know for what areas the new transport system has most impact. The biggest percentile change in public transport trips occurs on Maasvlakte, from 9.7% to 29.3%. The biggest total change in public transport trips occurs in The Hague, where an additional 4000 people make use of public transport for trips between areas.

Port bound flows and external flows

At the beginning of this research I made the assumption that a cost-effective system can be created when both port bound and external flows are combined in one system. The portion of port bound transit loads can be calculated in Omnitrans. First the demand from and to the port areas is set to 0 in the RVMK model and the loads are calculated. Then, this data is compared with the total loads (figure 14.5). Figure 14.4 shows the port bound flows and external flows.

The train between Botlek and Rotterdam contains many port bound travelers and external travelers, so this line really benefits from the combination of flows. The same goes for the busline between Spijkenisse and Maasvlakte.

The metro between Schiedam and Drechtsteden does not contain many travelers for the Western port areas and is therefore not important for these port areas.

Logit model explanation

The original 9.7% public transport share for Maasvlakte seems to be very high, since no public transport is available in the original situation. This high percentage is the result of the method I used, where modal split is estimated with a logit model. Maasvlakte is situated far away from most areas and travel times for the different modalities are therefore large. When travel times are high, the utility of public transport is relatively large in comparison to other modalities. The utility functions are most reliable for distances between 5 and 50 km, since the utility iteration is executed for areas within these distances (figure 4.8). Therefore, calculations on high travel times may be inaccurate.

The purpose of this research is to estimate whether the creation of cost-effective transit is possible for the port area of Rotterdam. The modal split of Maasvlakte influences the cost-efficiency and should therefore be attended to more elaborate in further research. For the network preference choice however, the calculations give good indication of the difference in travel behaviour between alternatives, and a network of preference can be determined based on these calculations.

Port areas are Maasvlakte, Europoort, Botlek and Vondelingenplaat.
The lightrail in The Hague contains much external load for the part outside the port and only port bound load inside the port. If new employees would be attracted from The Hague, this line would really benefit from the combination. Yet, since this simulation did not include total demand estimations, this was not included thusfar.

Changes in travel demand

The method I use includes the assumption that the total origin/destination data between zones does not change when a new network is introduced, only the modal split changes. In reality, social-economic patterns will change eventually (Egeter et al., 2002). Especially the transit line between The Hague and Maasvlakte will benefit from this change, since most potential new port employees dwell in The Hague (figure 7.8). What this effect could be explained with an example.

The effect of additional port employees

The expected shortage of port employees is 2025 is 1000 employees in Botlek and 5000 employees in Maasvlakte (table 7.1). I assume that all these new employees dwell in The Hague, since the amount of potential new port employees is highest in The Hague. Based on the modal splits from figure 14.4, Botlek will have an additional 250 public transport travelers and Maasvlakte an additional 1500 public transport travelers. The average load on the lightrail between The Hague and Maasvlakte will increase with approximately 3000 trips per day (in two directions). The benefit/cost ratio of the lightrail between The Hague and Botlek changes from 0.88 to 1.03. The benefit/cost ratio between Botlek and Maasvlakte changes from 0.26 to 0.37. The benefit/cost of the total system changes from 0.52 to 0.57.

The change in travel demand can influence the travel behavior and thereby the cost effectiveness of the new system. Therefore, in further research the change in travel demand should be examined further.

The effect of transit oriented development

When development takes place around station areas, more people are likely to use the transit system. This effect is elaborated on in chapter 18.

Reliability of the cost estimations

Investment costs

The biggest part of the investment costs are new infrastructural elements. The cost estimations are done based on a study from DS+V (CVOV, 2005), that gives statistical indicators for the creation of public transport systems. Additional costs like bridges and tunnels are excluded from these indicators and are added based on reference projects. A big portion of the investment costs comes from these additional costs. If these costs turn out to be much higher, the investment cost can easily be twice as high as estimated in this research.
Operational costs

The operational costs are also estimated based on indicators provided by DS+V (CVOV, 2005). Since the layout of the public transport system will not influence the operational costs much, I consider my operational cost to be reliable.

Revenues

The revenues of the system have been validated according to research by Piet (2008). Since his and my research use the same method, the revenues may be over- or underestimated. As is indicated in the subchapter ‘modal split’ (previous spread), some loads may be overestimated.
Part 6
Transit oriented development and local transport

Contents

The transit oriented development opportunities are described rather abstract in the previous chapters of this report. This part will give shape and will visualize what these development opportunities could mean for the Port of Rotterdam. Furthermore, the local transportation between regional transit stop and the actual work locations have to be designed.

As described in chapter 3, the development opportunities are dependent of the growth perspectives of the port area. Chapter 15 shows the different land-use strategies for the different scenarios and the local transportation resulting from this land-use proposal for Maasvlakte, Botlek and the Cityports area.

In chapter 16, the local development around the station areas will be visualized with visual impressions and a spatial design for the Botlek transit node. The implications of this spatial development are explained and taken into account when designing the final network design.

In chapter 17, the final network is designed by adapting the Rivercrossing network alternative, based on the evaluation from chapter 14 and the spatial development implications from chapter 15 and 16.

Results from this part

This part gives shape to the transit oriented development opportunities, described abstract in part 5. Furthermore, the final network design is determined. This final network will be used to test the hypothesis in part 7, Conclusions and recommendations.
15. Land-use proposal for optimal passenger transportation in different scenarios

The transit oriented development opportunities are described rather abstract in the previous chapters of this report. In this chapter the long term land-use choices in the port area are explained from the point of view of optimal passenger transportation. Also the local transportation is designed for the different transit stations.

Different growth projections for the Port of Rotterdam

The necessity of different scenarios

Availability of space has everything to do with growth projections and the space-efficiency of companies. In an uncertain world it does not suffice to simply extrapolate present growth trends. Scenarios may be used to scan different futures (Schwartz, 1996).

Growth projections for the Port of Rotterdam

In 1996, the CPB has made different forecasts for growth in the port sector. They included three scenarios, Divided Europe, European Coordination and Global Competition, all with different growth potentials. In 2001, they translated this growth into a long term demand for space (CPB, 2001). The latest development, the global crisis, also has huge impact and has uncertain outcomes. De Pers (2009) shows that the first 9 months of 2009, total shipping tonnage decreased with 11.9% in comparison to the first 9 months of the year 2008. Still when looking at the land-use development of the Port of Rotterdam, the scenario with biggest growth, the Global Competition scenario was followed between 1996 and 2009 (Appendix J). Therefore, I choose the European coordination and the Global Competition growth scenarios as likely possible futures. These scenarios, derived in 1996 are adapted to new insights (Appendix E). Two new growth scenarios are created, the Steady Growth scenario and the Prosperous Port scenario (figure 15.1). In the Steady growth scenario, space is still available in 2035, while in the Prosperous Port scenario, a shortage of space is expected in the port area. A more detailed image of the demand of space for the different scenarios is found on figure 15.2.

Land-use in of the Port of Rotterdam

Principles for land-use in the different scenarios

In the Steady Growth scenario, the amount of space in the port area is sufficient until after the year 2035, while for the Prosperous Port scenario the amount of space is insufficient in 2035 (figure 15.2). Therefore, the land-use strategy differs between the scenarios as shown on figure 15.3. Redistribution of port activity is only a legitimate intervention when a shortage of space is present in the port area. A redistribution of port activity can be combined with space innovations, like stacked distribution or co-siting of chemical industry. Co-siting is a way of improving the space efficiency: Two companies that make use of each others residual products are situated on one plot. This saves space and stimulates residual product use, which fits into the sustainability intensions of the Port of Rotterdam. In the

<table>
<thead>
<tr>
<th>Steady Growth scenario 2035, sufficient amount of space in the port area.</th>
<th>Prosperous Port scenario 2035, shortage of space in the port area.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space innovations are not important.</td>
<td>Space innovations are very important.</td>
</tr>
<tr>
<td>Redistribution of port activity is not a legitimate way to minimize internal traffic.</td>
<td>Redistribution of port activity is a legitimate way to minimize internal traffic.</td>
</tr>
<tr>
<td>The Cityports area is slowly taken over by urban development.</td>
<td>A Symbiosis has to be created between city and port in the Cityports area.</td>
</tr>
</tbody>
</table>

Figure 15.3. Land-use strategy for the different growth scenarios
<table>
<thead>
<tr>
<th>Year</th>
<th>Containers and breakbulk</th>
<th>Liquid bulk</th>
<th>Dry bulk</th>
<th>Distribution</th>
<th>Fruit</th>
<th>Other</th>
<th>Urban development (excl. the existing Cityports plans)</th>
<th>Available space (incl. MV II, excl. Merve-Vierhaven)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>1152</td>
<td>2626</td>
<td>388</td>
<td>170</td>
<td>60</td>
<td>420</td>
<td>0</td>
<td>1076</td>
</tr>
<tr>
<td>2035</td>
<td>Steady growth</td>
<td>+258</td>
<td>+102</td>
<td>+20</td>
<td>+0</td>
<td>+47</td>
<td>200</td>
<td>221</td>
</tr>
<tr>
<td>2035</td>
<td>Prosperous Port</td>
<td>+493</td>
<td>+113</td>
<td>+85</td>
<td>+0</td>
<td>+75</td>
<td>200</td>
<td>-297</td>
</tr>
</tbody>
</table>

Figure 15.2. Demand of space for different growth scenarios and the existing layout of the port area.

Figure 15.1. Growth projection for the Steady growth and Prosperous Port scenario up to the year 2035.
prosperous port scenario, the same types of industry have to be bundled together, in order to enable this co-siting to happen.

In order to minimise internal transportation and to make the regional transit system more cost effective, density with high employee density have to be moved towards the transit stops (figure 15.6). This only goes for the Prosperous Port scenario, since the Steady Growth scenario does not allow such redistribution of port activity.

Plans are to gradually remove port activity from the Cityports area to create space for urban development. This is acceptable when the amount of port area is sufficient, but unacceptable when there is a shortage of space. In the Prosperous Port scenario, a symbiosis between port and city should be created where the available space is used in an effective manner.

Figure 15.4 and 15.5 show the different principles of the two scenarios. Figure 15.7 and 15.8 show the land-use proposal for the different scenarios, that will be explained in the following sub-chapters. Figure 15.9 shows the land-use for each port area separately.

**Steady Growth scenario: Growth on Maasvlakte**

**Industry**

In the Steady Growth scenario, the new industry is placed on Maasvlakte. Since the Merwe-Vierhavens will be used for urban development, the Fruitports and other functions are moved to Cityports. This means that some container trans-shipment has to move to Maasvlakte. No organized space innovation is needed for this scenario, since the amount of port area is sufficient to manage the predicted growth.

**Urban functions**

Combining port industry and urban functions is difficult, mainly because of safety contours that block urban development. The easiest way of coping with this problem is by simply replacing the port industry with urban functions. This means that the existing hazardous industry from Eemhaven has to move to Waalhaven (figure 15.10)

**Prosperous Port scenario: Redistribution of port activity**

**Industry**

In order to stimulate space efficiency, the different types of industry have to be bundled together, so they can make use of each others facilities and residual products. Maasvlakte will be home for containers mostly, while Europoort, Botlek and Vondelingenplaat contain mostly liquid bulk. The liquid bulk will be made more space efficient by stimulating co-siting and by strict agreements when new contracts are admitted. This makes the Botlek area more labour intensive (figure 15.9). Fruitports from Merwe-Vierhavens is moved to Botlek, to enable quick access between Greenports and Fruitports. The labour intensive distribution activity in Botlek will be moved to the South of Rozenburg. Not only does this decrease internal traffic, it also relieves pressure on the Calandbridge: Distribution activity generates no sea bound ships and therefore minimizes the frequency of opening the bridge.
Figure 15.6. Land-use in the port in 2009

Figure 15.7. Proposed land-use in the Steady Growth scenario in 2035

Figure 15.8. Proposed land-use in the Prosperous Port scenario in 2035

Figure 15.6. Characteristics of different types of port activity.
Port functions and the main public transport system

Steady Growth

Prosperous Port

Legend
- Containers/breakbulk
- Liquid bulk
- Dry bulk
- Distribution
- Fruit
- Other
- Urban area

Figure 15.9. Proposed port land-use and regional transportation network.

Figure 15.10. Safety contours in order to accommodate the proposed land-use.
Urban functions

To prevent the cityports area from filling being taken over by urban development, a symbiosis between port and city has to be created in this area. Therefore, the port should be considered an urban quality, and should be integrated with the city. Not only gives this port activity in the Cityports area a chance of survival, it also improves the image people have of the port area. The large amount of water in the Cityports area gives opportunities for new urban development, without using any space. As boundary condition, hazardous industries should move from the Cityports area, in order to enable such an integration to take place (figure 15.8). Hazardous industries from Cityports should therefore move to Botlek or Maasvlakte.

Local transportation

Local transportation is the trip from the regional public transport stop to the actual work location. Figure 15.11 shows the possible means of local transportation, based on the information from chapter 8. Figure 15.14 shows the proposed local transportation for the two scenarios.

**Steady Growth scenario: Adapting the local transit system to the existing layout of the area.**

In the Steady growth scenario, basis for land-use division is the existing industry. The corresponding employee division is shown on figure 15.12. Local transport on Maasvlakte can be organized with collective transport, since the plot sizes in this area are large (figure 15.13). Local transport on Botlek can be arranged with a combination of bicycle and collective transport. Some areas cannot be served with any of the local transit systems from figure 15.11, since plot sizes are too small for collective transit, the distance is too large for bicycle and densities are too low for other types of local transportation. For the Cityports area, the metro already serves the north side of the area, where densities are high because of new urban functions. Tramline 2 in Rotterdam South will be extended in order to serve the...
dense areas (the urban areas). For the rest of the port area, densities are too low to create any of the transit systems. Therefore, the bicycle will be used for local transportation in the port area.

**Prosperous Port scenario: Redistribution of port activity to optimize local passenger transportation**

In the Prosperous Port scenario, the land-use will be adapted in such a way that the local passenger transportation is optimized. On Maasvlakte, big plots are proposed, to make the collective transport even more feasible. For Botlek, the distribution cluster and Fruitports are located in the vicinity of the regional transit stop. This way, the dense areas can be reached by foot or bicycle. Outside the 2.5 km range of the bicycle the plots should be bigger, to enable collective transit for these areas.

In the Steady Growth scenario, the North and East side of the Cityports area where considerably more dense than the rest of the area and therefore, public transport is only created in these areas (figure 15.14). In the Prosperous Port scenario high densities can be found throughout the area. A system should be found that can cope with the high densities and the branched structure. The only public transport system capable of serving such an area is the PRT system. The system functions like a taxi on its own elevated track. When called, a vehicle comes to a station in about 2 minutes and brings its passenger to any station he/she chooses. Because of the lightweight structure, the system can be implemented easily in the area (figure 16.5) and is capable of serving the urban functions located in the water (figure 16.4).

**Differences and similarities**

The local transportation is similar for Maasvlakte and Botlek. For the Cityports area the system really differs, because of the different distribution of densities in the area.

![Density](image)

**Figure 15.12. Employee density resulting from the proposed land-use.**
Plot sizes

Figure 15.13. Employee density resulting from the proposed land-use.

Figure 15.14. Proposed local transportation network.
16. Design and visualization of the transit oriented development

In this chapter the local development around the station areas will be visualized. For the Maasvlakte, Botlek and Cityports. For Maasvlakte and Cityports, the program around the station areas is explained and the local development is visualized with visual impressions. For the Botlek area, a spatial design is made. This area is chosen since the station design is very complex. It includes connections to a new highway, several new development possibilities and should provide good access for both inhabitants of Rozenburg and port employees. Furthermore, since the Botlek station will become a transit node in the regional network, the design of this station area is important on the regional scale.

Transit oriented development opportunities

Figure 16.1 shows the development opportunities derived from the SWOT analysis is chapter 6. Some development opportunities are more applicable in the Prosperous Port scenario, while others can be applied for both scenarios.

Transit oriented development on Maasvlakte

The transit oriented development opportunities on Maasvlakte are limited in comparison to other port areas, because of limited accessibility of the area (figure 14.1), therefore development around the transit stop is limited to parking spaces for truckers and basic amenities for port employees. The development is the same for the two scenarios. Figure 16.2 shows how the node could look: A transit stop within the distribution centre.
Transit oriented development in Cityports

The transit oriented development opportunities in Cityports are considerable, because of the good accessibility of the area (figure 14.1).

**Transit oriented development in the Steady Growth scenario**

In the Steady Growth scenario, the Cityports area is divided in a part with urban development and a part with port activity (figure 16.3). Therefore, a symbiosis between port and city is difficult to create. The RDM campus provided port related education and may attract innovative companies. This innovation may spill out to the rest of the port area.

**Transit oriented development in the Prosperous Port scenario**

In the Prosperous Port scenario a real symbiosis between city and port is created. This means that the exposure of the area is better, since many people are working and living in the port area. Figure 16.4 shows the image of the area is the Prosperous Port scenario. The PRT system proposed for local transportation is shown on figure 16.5.

**Figure 16.3.** Image of the Waalhaven area in the Steady Growth scenario, the relation between the city and the port is poor. (picture by Paul Houtman)

**Figure 16.4.** Image of the Waalhaven area in the Prosperous Port scenario, a symbiosis between city and port. The water is used for floating urban development.

**Figure 16.5.** Image of the PRT system in the Cityports area (image by C. Kobus and J. Breeuwer)
Transit oriented development in Botlek

The transit oriented development potential of Botlek is very high (figure 14.1), because it functions as a transfer station for two public transport lines. Truck parking and basic amenities can be created for truck drivers and port employees. Housing can be created for new port employees and office space to accommodate innovative companies. The image of the area can be improved by exposing the port area: Figure 16.6 shows the image I want to create when standing at the transit station. The sustainable character of the area should be shown at the station.

Difference between the scenarios

In the Steady Growth scenario, the existing industry will not be moved. Therefore, safety contours may block the development around the station (figure 16.7). This means that spatial development can only take place next to Rozenburg. In the Prosperous port scenario, this industry may be moved in such a way that the development can take place around the station area.

In the Prosperous Port scenario, the port activity with highest employee density (distribution and fruit) is situated close to the transit station. This means that more people will use the transit station and therefore, body for the amenities is higher in this scenario.

Spatial development proposal for the station in Botlek

For the Prosperous port scenario, a spatial design is made for the development around the transit station, to show how the development could look like and what it could mean for the port area.

Figure 16.6. Image from the transit station in Botlek

Figure 16.7. Safety contours may block development at the transit station.
Internal logistics

In order to understand what is happening in the area, the internal logistics are explained. Fruit from greenports is processed and shipped in Botlek. Waste is used for energy processing in the area. Liquid bulk comes in and is processed into energy and chemicals and distributed through the distribution centre to the south of Rozenburg.

The Botlek-loop is a concept that enables companies to make use of each other’s residual waste warmth (RCI, 2009) (figure 16.9). This way, less energy is needed for the production of chemicals and energy and therefore adds to the sustainability objective of the Port of Rotterdam.
Infrastructure

Figure 16.10 shows the current infrastructure in the area. A new tunnel is proposed next to the village of Rozenburg. This tunnel contains a new highway and a new railway that are both connected to the existing infrastructure at the South side of Botlek (figure 16.11). Because both sides of the train station have to be reached by foot, the infrastructure is bundled around the transit station. A bridge is created over this bundled infrastructure (figure 16.12). For the highway, a maximum radius of 400 meters is used, so that car drivers can maintain speeds of 80km/h. A minimum of 300 meters is used for car drivers to ascent and descent 10 meters.

The transit station blocks the road South of Botlek. Therefore, a new road is created where inhabitants of Rozenburg can drive directly to the ramp of the new highway.

Transit oriented development

Figure 16.12 shows the spatial development around the station. It consists of all the elements as described at the right side of this spread. The new dwellings create a boundary between the village and the port. Yet, at the train station a bridge is built to bring the port and the village together.

Figure 16.13 displays the image of the transit stop, where industry, offices and dwellings meet. It shows the beacon building, that can be seen from different all different angles, when visiting the area or just driving trough (figure 16.14). This way, the Botlek area will stay in peoples minds and the port area becomes part of daily life.

Figure 16.15 shows the view from the transit station. The industry and offices are combined in one image, together with the Botlek Sustainability Centre where visitors and students can learn all about the (sustainable) processes that go on in the Botlek area.
Dwellings
New dwellings are proposed, to create a boundary between the new highway and the village of Rozenburg. The green area in between Rozenburg and these new dwellings is kept open. The location of this area close to the transit stop enables the development of a park for visitors and inhabitants of Rozenburg.

Innovative companies
Innovative companies can rent office space next to the transit station. These companies can stimulate innovation in the area, like showing companies what residual product they can use from other companies and by stimulating space innovation.

Beacon building
A building is proposed, that functions as a beacon for Botlek. People traveling trough the area will recognise Botlek by this building. It is visible from various angles. A big energy concern could use this building as their main office.

Botlek Energy Centre
Students and visitors that want to know more about the energy process in Botlek can visit the Botlek Energy Centre. Companies can present themselves and their sustainable innovations here. Furthermore, the Botlek Loop is used as a showcase for the area and is explained in the centre.

Basic amenities
Basic amenities like a supermarket, a sandwich shop and a juicebar can be used by port employees, visitors, truck drivers and Rozenburg inhabitants.

Truck parking
Truck drivers can park their truck at the guarded truck parking.
Figure 16.13. Image of the transit station, where industry, offices and dwellings meet. The building in the middle can be seen from various angles and functions as a beacon for the Botlek area. (view towards the North)
Figure 16.14. When driving on the highway the new dwellings, the industry and the beacon building can be seen. (view towards the South)

Figure 16.15. Image from the train station. (View towards the East)
17. Final network proposal

The impact of the transit oriented development opportunities on the preferred network from chapter 14 is evaluated in this chapter. Based on this evaluation and the evaluation from chapter 14, adaptations are made to design the final proposed network for this research.

Impact of the transit oriented development on the regional network

Since the development has most impact in the Prosperous Port, the effect of this development is taken into account in this sub-chapter.

Transit oriented development in Cityports

For Cityports, two development concepts are presented (figure 15.9). One where the port and city are separated and one where they are integrated. This integration has several benefits over the separation: More space is kept available for port development and the exposure and therefore the image of the port will improve with an integrated design. The linear metro system proposed is likely to produce a separation in functions, while a branched system like PRT may provide dispersed development in the area. Furthermore, the metro system is not very cost-efficient (figure 11.4 and 17.1) and therefore, it is replaced by a PRT system. The additional loads generated by the development in this area are not taken into account, and should be part of future research on public transport in the Cityports area.

Transit oriented development in Botlek

The development potential in Botlek is considerable in the Prosperous Port scenario and many public transport travelers are generated:

Moving existing industry

Industry with high employee densities is moved towards the transit stop. This may increase the public transport share in Botlek. The current share is 22.6 (figure 14.4). I assume this share may increase to 28%, which is the share of Rozenburg. Average, the share of Botlek will become about 25%. This means that an additional 2.4%*14332 travelers= 350 people will use public transport because the industry is redistributed.

Densification of existing industry

The existing industry is densified because of a shortage of space. Density may increase with about 1/3rd. This means that an additional 25%*14332/3=1200 public transport travelers may use public transport to travel to Botlek.

New functions around the node.

The amount of people dwelling, visiting the area per day and working is estimated at 2000. The beacon building (figure 16.3) is about the same size as the port company building, we here 700 people work. The other buildings may triple this amount. These 2000 travelers will have a high public transport share. Since they are situated next to a regional transit node. I estimate the public transport share at 35%, which means that an additional 700 people will use public transport in Botlek.

Distribution of additional trips on the regional network

The total amount of public transport travelers in Botlek may increase with 2250 because of the development in the area. This means an additional 4500 public transport trips from and to Botlek. Current port employees dwell mostly in Voorne-Putten, while most new employees will come from The Hague. Rotterdam also has an important share in Botlek travelers. Therefore, the 4500 public transport trips are distributed equally among the three legs; The Hague-Botlek, Rotterdam Central-Botlek and Hellevoetsluis-Botlek. The cost-efficiency of the fast train between Dordrecht and Hellevoetsluis changes from 1.15 to 1.22. The costs efficiency of the lightrail between The Hague and Botlek changes from 0.88 to 0.95. The benefit/cost ratio of the system changes from 0.52 to 0.55.
**Transit oriented development in Maasvlakte**

The development potential on Maasvlakte generated by the public transport system is small (figure 14.1). Therefore, no additional travelers will be generated by the transit oriented development.

**Additional public transport travel demand added to the network**

Figure 17.2 shows the additional travel demand, generated by changing solving the shortage of port employees (chapter 14) and the additional travelers generated by the transit oriented development. Especially the line between The Hague and Botlek benefits from this change in demand, since many new port employees may be attracted from The Hague. This analysis may be inaccurate, since many assumptions are made for this analysis. The demand estimations have to be elaborated on in further research.

**Adaptations to the network**

In order to make the system even more cost-efficient, some adaptations are made to the network. Figure 17.5 shows the adapted network that is the final network proposal of this research. Figure 11.4 shows the benefit/cost ratio of the different public transport lines. It shows that the lightrail in the port area and the metro between Schiedam and Dordrecht has the lowest benefit/cost ratio. The loads on these lines are not increased by transit oriented development and should be altered in order to make them feasible.

**Adaptations to the metro between Schiedam and Drechtsteden**

The metro system in Cityports is replaced with a PRT system, because:

- The designed metro line is cost inefficient.
- The designed metro could bring about undesired separation of city and port in the Cityports area, while the PRT system could bring about a symbiosis between port and city.

Furthermore, the metro part between Barendrecht and Dordrecht is cost-inefficient (figure 17.1). This metro line contains a minimal amount of travelers bound for Botlek and
Maasvlakte (figure 14.5) and is therefore removed from the design. Since the metro between Rotterdam Alexander and Zuidplein can be made feasible (figure 11.3), it is added in this design.

**Adaptations to the light rail between Maasvlakte and Botlek**

Since transit oriented development on Maasvlakte doesn’t add public transport travelers, the transit line is not made feasible. The transit line between Botlek and Maasvlakte has a benefit/cost ratio of 0.37 (including new demand because of a shortage of employees on Maasvlakte, chapter 14). The light rail on the port railway can be made feasible by letting the system run on the existing port railway. This means that cargo capacity on the port railway is reduced. Yet, since the light rail only runs on the last part of the railway, this capacity will be available (figure 17.3). If development on Maasvlakte is higher than expected, no capacity is available on the port railway. Yet, development on Maasvlakte means that more travelers will use the public transport system, and the development of a separate passenger railway is legitimate.

**Solving the robustness problem**

In case the tunnel between Maassluis and Botlek is blocked, a solution has to be found for the port employees traveling with public transport. Therefore, in case of a blockade, the ferry between Maassluis and Rozenburg will be used to transport people over the water. Busses from Vipre will transport people from the ferry stop to the port railway, where travelers can continue their trip. The train coming from Rotterdam will run to Maassluis, to ensure a good transfer to the light rail towards The Hague and to bring people to the ferry landing. Even though travel times will increase with about half an hour, the accessibility of the port is warranted. Port employees working in shift schedules will have to prolong their working day with half an hour to take over from their colleagues who arrive late at work.

**Cost-efficiency of the new system**

The cost-efficiency of the new network is calculated. These calculations can be found in appendix IV.3. The final network design has investment costs of 1.7 billion euro and a benefit/cost ratio of 77%. The PRT system in the Cityports area is kept out of this design.

![Figure 17.3. Capacity use on the port railway in case of passenger transport on the port railway.](image_url)

![Figure 17.4. Cost estimations of the final network design, excluding the metro and the PRT network.](image_url)
Figure 17.5 Final development proposal

*The part between Maasvlakte and Botlek runs only between 6.00-9.00 h, 14.00-19.00 h and 22.00-24.00 h, to match the shift times of port labour.
calculation, since the cost effectiveness is unknown. More research is needed to estimate the performance of such a system. The metro between Rotterdam Alexander and Zuidplein is also left out of this calculation, since it is not very beneficial for the Port of Rotterdam.

**Cost effectiveness with changes in travel demand**

The travel demand in the area may change because of the new network as described in this chapter. This change in transit demand could add 16 percentage points to the benefit/cost ratio of the network.

**Cost estimation validation**

The travel demand in the area may change because of the new network as described in this chapter. This change in transit demand could add 16 percentage points to the benefit/cost ratio of the network.
Part 7
Conclusions and recommendations

Contents

In chapter 18, the hypothesis created at the beginning of this research is tested, based on the results from the simulation and the evaluation. In chapter 19, the implications of this research on network design within the fields of Urbanism and Transport & Planning is explained. Furthermore, the implications of the proposed network design for the Port of Rotterdam are given. Chapter 20 contains recommendations for further research, based on an evaluation of the strong and weak points of this research.

Results of this part

It can be concluded that cost-effective public transport can be created that restores physical and mental connections between the port and its surroundings, thereby enhancing the competitive position of the Port of Rotterdam. Therefore, I advice the port company to think about public transport in their long term infrastructure vision. Furthermore, I give an advice to the fields of Urbanism and Transport & Planning about network planning, which gives stronger results when elements from both fields are combined in one research project.

Some additional research should be done on the final network design, like performing more elaborate cost estimations and changes in travel demand, caused by spatial development and changing socioeconomic patterns.
18. Conclusions

The Port of Rotterdam used to be embedded in the city. Yet, when the port grew and started to automatize, and public reluctance to the port emerged, the port grew apart from its surroundings. The goal of this project is to re-establish this connection, solving the different problems that have risen because of this poor connection, thereby enhancing the competitive position of the Port of Rotterdam within the European port industry. The network shown on figure 17.5 is proposed to reconnect the port area.

Hypothesis

The following hypothesis was determined at the beginning of this research:
Cost-effective public transport can be created that restores physical and mental connections between the port and its surroundings, thereby enhancing the competitive position of the Port of Rotterdam.

Cost-efficiency of the proposed system

Figure 17.4 shows the cost and benefit estimations of the final network design. The system as proposed has a benefit/cost ratio of 77% and needs an investment in infrastructure of 1.7 billion euro. In this estimation, changes in travel demand are not taken into account. When the travel demand does change, because of a need of more port employees and because of transit oriented development around the station areas, the benefit/cost ratio could rise to 93%. Even when the costs are underestimated by a factor 2, and revenues are overestimated by a factor 2 the benefit/cost ratio is still 47%, which is an acceptable percentage for public transport, especially in an area where public transport is hard to generate.

I conclude that a cost-effective system can be created in this area, so the first part of the hypothesis can be answered positively.

Enhancing the competitive position of the Port of Rotterdam

The competitiveness of the port is dependent on port related companies. By accommodating those companies, a strong competitive position can be maintained or preserved. The five factors most important for port related companies, that may be altered with spatial interventions are: Accessibility, a strong and educated labour pool, the innovative character of the port area, sufficient space for development and sustainable character of the area.

Physical connections established by the new system

Figure 14.1 summarizes the socioeconomic relevance of different public transport designs. The Rivercrossing alternative performs best and the physical benefits of the system are evaluated in this sub-chapter:

- The system can reduce daily car traffic on the A15 and the Beneluxtunnel with 5%, which will give trucks a better passage when passing through the port area.
- The number of port employees within 60 minute public transport travel time from their work in the port increases with approximately 66%, which will reduce car traffic.
- The new transit system dramatically increases the amount of potential new employees that dwell within 60 minute travel time from the port area (an additional 173.000). The expected shortage of port employees in 2025 is 7.000 employees (table 7.1). If only 4% of these potential new employees start working in the area, the expected employee problem can be solved.
- The number of youngsters within 60 minute public transport travel time from port related knowledge institutes increases with about 20%, increasing the chance of attracting qualified personnel.
- More leader firms are connected to port related knowledge institutes (about 30% extra), which enables students to take internships and visit companies which may enhance the innovative nature of the companies.
- CO2 emission reduction will be caused by the public transport system. This amount is estimated at 36.000 tons/year, which fits in with the sustainability objective of the Port Company of Rotterdam.
Mental connections provided by the new system

One of the problems of the Port of Rotterdam is that the area is unknown to people, causing problems with the attraction of educated employees and making its societal relevance known that the port offers to Dutch society.

Mental connections between the port and its surroundings are provided with the design, meaning that the port becomes part of everyday life. In Botlek, a regional transit station is created, meaning that many people will pass trough the port area. The transit oriented development in Botlek (figure 16.12 and 16.13) contributes to peoples awareness of the existence of the port. The beacon building and the sustainability centre will provide a positive image that will stay in the minds of people passing trough the area.

Conclusions, answering the hypothesis

Cost-effective public transport can be used in the port area. Furthermore, physical connections between the port and surroundings can be created, to make the port area more attractive for companies to settle in the area. Mental connections between the port and surroundings are also improved, that can improve the available labour pool for the port area. Therefore I conclude that cost-effective public transport can be created to restore physical and mental connections between the port and its surroundings, thereby enhancing the competitive position of the Port of Rotterdam.

19. Implications

This chapter describes the implications of this research for the fields of Transport & Planning and Urbanism. How did the combined approach benefit the outcomes of this research? Furthermore, the implications for the Port of Rotterdam are described, for they provided the case for this research.

Implications for network design within the field of Transport & Planning

Including socioeconomic relevance and transit oriented development in the network design and evaluation

The general network design approach used in the field of Transport & Planning focuses mainly on travel behaviour and cost-efficiency (figure 4.1). Elements from the field of Urbanism are added in this research: Socioeconomic relevance and transit oriented development potential are added when simulating and evaluating the different network alternatives. If the investment costs and the benefit/cost ratio would have been the only evaluation criteria, the Waterbound network may have been chosen, since investment costs are considerably lower and the benefit/cost ratio is acceptable in this alternative (figure 14.1). Yet, when socioeconomic relevance and development potential are included as criteria, the choice for the Rivercrossing network alternative becomes obvious. Since politicians will include the socioeconomic relevance of the network in their policy choices, transport planners should include these criteria in their network design.

Transit oriented development may enhance the cost-effectiveness of the public transport network

The transit oriented development opportunities provided by the transit system may enhance the benefit/cost ratio of the system (figure 17.4). Therefore, the transit system can benefit when both elements are combined in one design.
Implications for network design within the field of Urbanism

Creating cost-efficient public transportation

In the field of Urbanism, establishing socioeconomic relations and accommodating transit oriented development is the reason for creating new infrastructure. Unfortunately, since travel behaviour and cost-efficiency are not included in the evaluation, unfeasible networks are often created. When these networks are adapted by transportation planners, the socioeconomic relevance of the new infrastructure may be lost. Therefore spatial planners should work together closely with transportation planners, since the estimation of benefits and costs is difficult without a transportation model.

Combining socioeconomic data with transportation model output

The transportation network used in this research enables me to combine socioeconomic data with data on public transport travel time. This way, the socioeconomic relations established can be made explicit, as shown in figure 14.1.

Implications for the Port of Rotterdam

Position of the port area in the regional infrastructure discussion

Since public transport has the potential to enhance the competitive position of the port area, the port company should seriously consider public transport in their long term vision. Yet, the port company will not develop any public transport system by itself, since this is the task of the Ministry of Transport, Public Works and Water management. The new transit system benefits several parties, like different port companies, the cities of Rotterdam, The Hague and Hellevoetsluis and several other municipalities. The port company should discuss with these parties on long term infrastructure development. This report can help the port company to position themselves in this discussion.

20. Recommendations

In this chapter, recommendations for further research are described. Since the methodology used in this research was developed by myself, I will start by evaluating the strong and weaker points of this methodology.

Strong elements of this research

A lot of time was spend on setting the context of this research. A network design that is relevant to society and has a good benefit/cost ratio resulted from this research. The different elements that are strong and well executed are explained in this sub-chapter.

Competitive position of the port area as starting point of the design

The Port of Rotterdam relies on port related companies for their market share. Therefore, regarding these companies as most important party enables the design of a network that really benefits the port.

Accommodating different flows with one design

Creating high quality, cost-effective public transport for the port area proves to be difficult, because flows to and from the port are very unbalanced throughout the day and employee density in the port area is generally low throughout the area. Combining external flows and port related flows generates several benefits:

- More body is created for the regional public transport system, thus the quality of the proposed system can be higher.
- Port flows combined with external flows show a more evenly distribution throughout the day, enhancing the possibilities of creating a cost-effective system.
- Apart from the port companies, different municipalities will benefit from the system, thus the creation of a regional public transport system will be supported by different parties.
Network design based on socioeconomic data

The integration between the field of Urbanism and Transport & Planning delivers excellent results in the regional network design. By using the relevant socioeconomic data as basis for network design, societal relevance of the system is expected during the simulation. Different network alternative(s) are generated, attempting to establish the socioeconomic relations as strong as possible. By testing the different networks on travel behavior & cost-efficiency and socioeconomic relevance, a strong network alternative emerges, that shows good results from the point of view of both fields.

Combining socioeconomic data with transportation model output

Not only are the different networks designed based on socioeconomic data, they are also tested according to it. The transportation network used in this research enables me to combine socioeconomic data with data on public transport travel time. This way, the socioeconomic relations established can be made explicit, enhancing the credibility of the benefits of the network design.

Elements with room for improvement

The pioneer character of this research implicates that some elements of it can be improved or could be approached differently. Recommendations to improve these elements are given.

The effect of spatial development on the regional network

The calculation of the transit oriented development potential of the network alternatives is based on the working population, dwelling within 60 minute public transport travel time. Many other factors influence the development potential, like local conditions, regional policies, the kind of development etc. Making spatial designs for all network alternatives would be very time consuming, and is therefore not desirable. The development potential of the different public transport alternatives is very difficult to make explicit and more research is needed on this topic.

Changing travel demand

The method I use includes the assumption that the total origin/destination data between zones does not change when a new network is introduced, only the modal split changes. In reality, social-economic patterns will change eventually. Furthermore, the transit oriented development brought about by the new public transport system changes the travel demand in the area. I included these effects roughly, in order to give some insight in the effects of changing travel demand, but these results may be inaccurate. In order to include changes in travel demand, a simulation on simultaneous trip distribution and mode-choice should be executed.

Including network alternatives and variations in different scenarios makes the study too complex

Three different network alternatives are created, with slight variations, in different growth scenarios. The parameters that change are different for each chapter. Therefore, results are sometimes hard to compare. I should have made my choices explicit in the beginning of this research. This way the relation between the alternatives, the slight variations and scenarios would be stronger or even better, would originate from each other. That way the relation between the network alternative, the variations and the scenarios would have been stronger and results could be compared more easily.

Case as starting point of the research vs fundamental research on the possibilities of combining the two research fields, explained with a case study

This study started with the case of the Port of Rotterdam. A methodology for network design is created for this case, which includes elements from the fields of Urbanism and Transport & Planning. Some problems emerge from this approach, for instance the spatial design inside the port. It took a long time to understand the area and examples of spatial development inside port areas are barely present. Therefore, the methodology I created could not be tested fully, which may have been different if an different case was chosen.
Starting with a case may add to the societal relevance of the design and the applicability of the method for the case, since it is development specially for the case. I could have taken the research to a higher abstraction level, enhancing the scientific relevance of this study even more.

**Cost estimations**

The costs estimations are based on a research used by DS+V. Yet, costs are often underestimated while benefits are overestimated. Therefore, costs and benefits should receive more attention in further research. Yet, for this research where the best network alternative is identified for the region, the cost estimations are sufficient.

**Benefits of the spatial development**

The only benefits generated by the spatial development around the port is in terms of additional public transport travelers. The benefits in terms of real-estate value and decreasing internal passenger flows are not made explicit. The relocation of companies to solve safety problems and optimize internal transportation costs money. Even though durations of contracts and new densification principles are taken into account, the total benefit/cost balance may be negative.

**Recommendations for the research on regional public transport for the Port of Rotterdam**

**Considerations when designing public transport in the port area**

When designing public transport for the port area, the context should be very clear. I described different problems for the port area, as well as the benefits that public transport may offer to the port. Establishing socioeconomic relations can be a succesvol basis for network design, yet the designs should be tested on travel behavior & cost-efficiency and socioeconomic relevance. Combining port flows and external flows in one design can really enhance the cost-effectiveness of the system.

**More elaborate simulation of the chosen network alternative**

This study gives good indications that the network as designed (figure 17.5) could enhance the competitiveness of the port area. Yet, costs may be underestimated while benefits are overestimated. A independent study on the cost-efficiency of the system should be executed. For this study, changes in travel demand should be included, by executing a simulation on simultaneous trip distribution and mode-choice.

**Cost-efficiency of transit oriented development in the port area**

Whether transit oriented development potential should be included when designing regional public transport for the port area is not proven in this research. The benefits of the spatial development may be lower than the costs necessary to make them happen. Therefore, the costs and benefits of the spatial development proposals in Botlek and Cityports should be researched.

**Port influence on travel behavior**

The simulation of travel behavior is based on the travel choices people make elsewhere in the province of South Holland. This travel behavior can be influenced by choices made by the port companies. If free transit tickets are provided for port employees, or parking on the industrial plots is made more expensive, more employees may choose public transport to travel to the port area. Such policy choices can be made collectively, since the entire port benefits when less passenger cars are driving in the area. Less CO2 emissions and a better passage for trucks are the result, as well as a more feasible public transport system. Since 75% of the vehicles on the A15 are passenger cars, the effects may be considerable.

**Other benefits of the system**

The system as designed provides a rail connection between greenports and the port area. This line may be used by goods as well as people. Further research should point out how this connection benefits the port and greenports.
Recommendations for regional public transport design in general

**Considerations when designing regional public transport**

A lot of time is spend on setting the context of this research, which resulted in societal relevant and cost-efficient network design. Therefore, the context should always be considered when designing regional transportation.

This study provides a case in which travel behavior & cost-efficiency, socioeconomic relevance and development potential are integrated in the simulation of different network alternatives. Especially the integration of travel behavior & cost-efficiency and socioeconomic relevance contributed to the generation of a strong, integral design for the region and the port area.

**Further research on the integration of travel behavior & cost-efficiency, socioeconomic relevance and development potential when designing regional public transport**

Since this methodology is created for the case of the Port of Rotterdam, further research should point out whether this methodology is applicable for other cases as well. The positive effect of development potential on the regional transportation network is not made explicit in this study, and should be elaborated on in further research.
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