Evaluating the usefulness of including flexibility in public transport network design and planning

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By

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Preface

Dear reader,

With this thesis that is before you is the product of nine months work and is a conclusion of my life as a master student in Transport, Infrastructure & Logistics.

I would like to express my gratitude to my thesis committee. First of all, my thanks go to my daily supervisors, Niels van Oort and Jan Anne Annema. You were always very willing to help and I was often surprised by how quickly you responded to my emails. Moreover, Niels, thank you for extending my professional network and for bringing me in contact with RET. Jan Anne, thank you for inspiring me to this research and, very important, giving me positive energy when I needed it to hold on. Furthermore I would like to express my gratitude to Professor Bart van Arem for his input during the formal meetings. Last but not least, of course, I am very grateful to my supervisors from RET, Jeroen Henstra and Theo Konijnendijk. You were the supervisors I saw the most since you gave me the opportunity to conduct my research at your department. Jeroen, thanks to you I was able to get familiar with all the interesting transport models you use. I am very thankful for all the time and effort you put in helping me doing that. Theo, thank you for encouraging me during this research. I enjoyed receiving your enthusiastic emails concerning sustainable and innovative transport planning documents.

Furthermore, I would like to thank my colleagues at RET for the pleasant days at the office, the support during my research and all the interesting public transport knowledge. You really made me feel part of the team, the company and even of Rotterdam.

Lastly, I want to thank all my family, friends and the people from the ‘afstudeerhok’, who supported me during these months.

Anne Reinders
Delft, May 2019

Summary

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Abstract

Investing in urban transit is necessary to fuel urban growth and sustainable mobility. Decision making for public transport projects usually involves long term forecasts of travel demand. Future development of factors that influence those forecasts and hence the expected net societal benefits of the investments are uncertain. Decision makers may want to account for uncertainty by incorporating flexibility in project designs, which makes it possible to adapt the project to developments of uncertain factors. Real options theory offers a method to assess the flexibility. While real options analysis is proven to be useful in many sectors involving irreversible, high investments, it has not been applied to the development of urban public transport networks. In this study, the usefulness of real options analysis in the design and evaluation of tram and BRT systems in combination with bike sharing systems is investigated. One of the options to include flexibility is decision tree analysis. This approach, in combination with societal cost benefit analysis, is used in a case study. It was found that flexible investment strategies perform better compared to inflexible ones in every tested scenario, resulting in improved net present values of up to 70 million euros. Nevertheless, both flexible and inflexible investment strategies were economically inefficient in the case studies. The clear difference in outcomes for flexible and non-flexible options that the case showed still indicate that the real options approach results in useful information for decision-making. Recommendations for further research to include flexibility even better are to test the method for cases in which the quality of the current public transport system is lower, include other real options such as delay, include cheaper direct investment options, include more welfare effects, and include other uncertain factors, such as shared mobility and technological development.

Keywords: real options analysis; urban public transport; public transport investment; decision tree analysis

I. Introduction

All over the world, urban populations are expected to grow in the next years (United Nations, 2018). The increase in urban population that started in the 1970’s, combined with the conventional transport planning approach, which encouraged the use of private vehicles and the construction of additional road infrastructure, lead to urban development in the suburban regions, referred to as urban sprawl. This phenomenon entailed some negative external effects including air pollution from motor vehicles, longer commuting times because of traffic congestion, overuse of land resources caused by low-density, and driver safety (Tafidis, Sdoukopoulos, & Pitsiava-Latinopoulou, 2017). Improving the quality of public transport services can solve these problems, while at the same time fueling economic growth, accessibility and public health (Van Oort, Van Der Bijl, & Verhoof, 2017).

Policy making in the field of (urban) public transport is about making choices regarding the allocation of public money. Because of all the choices to be made, there is a strong need for ex-ante evaluations of choice options (van Wee, 2012). Those evaluations and the resulting policies are usually based on long term forecasts of travel demand and system performance, while those forecasts are based on many assumptions (Chatterjee & Gordon, 2006). In fact, future development of factors that influence the profitability of transport investment, such as demographics, economics, mobility and spatial development, are uncertain. This results in uncertainty in the estimations of cost and benefits for projects which makes decision-making about project investments difficult.

Uncertainty and risk can be included in the evaluation of projects by defining alternatives that account for the uncertain future developments and enable future adaptations. Including flexibility in projects enables decision-makers to respond better and earlier to future developments in technology and demand. Step-by-step investing can save in retrospect unnecessary investments costs, but it also precludes taking advantage of economies of scale in both investment costs and political effort

Although there has been attention for (managerial) flexibility in project designs and the possible usefulness of methods to evaluate flexibility such as the real option approach, the available amount of scientific literature is limited to large infrastructures. These methods have been applied amongst others to wet infrastructure and road widenings. In those applications they were proven useful to save money, but up until now there have been no applications to urban public transport networks. This raises two problems: Firstly, because multiple techniques exist for the evaluation of flexibility and real options, it is not clear which of these methods is (most) suitable for urban public transport planning. Secondly is it unknown what the added value of including flexibility would be for decision-making for this type of projects. However, decision makers are currently missing a tool to evaluate investment strategies with multiple decision moments in which the project can be adjusted to future developments. For large infrastructure projects, flexible strategies have been shown to help decision makers to save money, but it is not clear if this is also the case for smaller urban public transport projects.

This study aims to fill this gap by applying real options analysis to an urban public transport network by means of a case study. The following main research question is proposed:

To what extent is real options analysis useful to develop and evaluate public transport networks?

This paper is structured into four parts. The first part consists of a literature review that is used to specify the methodology that was used to evaluate flexibility in urban public transport network design and planning. The methodology is followed by a description of the investment strategies that were designed. After that, the application of the methodology to the case study is described followed by the results of this application. Finally, this paper ends with the conclusions based on answers to the proposed research questions followed by a discussion and the limitations of this research.

II. Literature review

Flexibility in urban public transport network design

Three stakeholders are involved in public transport network design: the traveler, the operator and the authority. Each stakeholder has their own interests. Travelers want to minimize their perceived travel time which can be conflicting with operators that want to minimize the cost associated with a network. Authorities tend to take the perspective of the traveler and the operator by seeking cost-efficiency (R. van Nes & Bovy, 2007). Moreover, authorities are interested in the wider benefits for society. Light Rail Transit (LRT) and Bus Rapid Transit (BRT) are considered being high quality transport systems which can improve public transport systems (Van der Meijs, Genot, & Van Oort, 2015);(van der Bijl & van Oort, 2014). BRT systems are said to offer a lot of flexibility in design. This flexibility can and should be used to design and adapt BRT systems following the development of the travel demand

Evaluation of urban public transport projects

Evaluating transport projects can be done using several appraisal tools, ranging from multi criteria analysis, to societal cost benefit analysis. The (societal) Cost-Benefit Analysis ((S)CBA) is a widely used ex-ante evaluation tool used to support the decision-making process in transport in most western countries (Annema, Mouter, & Razaei, 2015). Within SCBA all future direct and indirect effects are monetized and discounted using the NPV (Net Present Value) method. The result of CBA analysis is the Net Present Value, benefit-to-cost ratio and internal rate of return.

The framework for SCBA proposed by (Bakker, Zwanevel, Berveling, Korteweg, & Visser, 2009) with indicators for wealth effects of public transport projects is used for the calculation of the cost, benefits and the NPV. Since the future is uncertain, the estimation of cost and benefits is uncertain too. As the costs and benefits of a transport project depend on future conditions they are calculated for every scenario separately.

Evaluation of flexibility

Whereas societal cost benefit analysis enables decision makers to evaluate transport projects, real options theory enables decision makers to incorporate flexibility in the design and evaluation of projects. Flexibility can be included in project design by means of real options. A real option provides: "*The flexibility arising when a decision maker has the opportunity to adapt or tailor a future decision to information and developments that will be revealed in the future. A real option conveys the right, but not the obligation, to take an action (e.g., defer, expand, contract, or abandon a project) at a specified cost (the exercise price) for a certain period of time, contingent on the resolution of some exogenous (e.g., demand) uncertainty.*" (Chevalier-Roignant & Trigeorgis, 2011). These defined real options are kept in mind during the design of investment strategies for the case.

Real option valuation techniques

Several techniques have been applied in previous studies to evaluate flexibility in projects. Literature describes five main techniques for the valuation of real options: the Black-Scholes Option Pricing Model (BSOPM), the Binomial Option Pricing Model (BOPM), the Risk-Adjusted Decision Trees (RADT), and the Monte Carlo Simulation (MCS). (Martins, Marques, & Cruz, 2015). All these models have their advantages and disadvantages. Contingent claims methods require a clear and present value of the underlying product, which does not always exist for public infrastructures. Decision tree analysis is easy to implement in a standard SCBA, is transparent and accessible (Van der Pol, Bos, & Zwaneveld, 2016).

III. Methodology

As a first step in the methodology, a case study is chosen, as an application to a real case is expected to provide important insights into the usability of the method. The municipality of Rotterdam has plans for urban development in the area of Rotterdam Feijenoord. As RET is operating public transport in the area, they want to adapt their services to the future development to maintain a suitable public transport system. Since the developments plans create uncertainty which results in risk, this area is chosen as the case study.

The second step in the methodology is application of an existing real options method. For this study it is chosen to apply decision tree analysis. A key argument for this choice is that decision tree analysis can be used in addition to societal cost benefit analysis. This makes it relatively easy to incorporate real options analysis in the current practice for transport project evaluation. Moreover, compared to the other option valuation techniques, decision tree analysis can deal with multiple uncertainties and enables decision makers to develop insight about real options.

Besides, uncertainty in future travel demand does not meet the assumptions required for other option pricing models such as the binomial option pricing model.
A decision event tree is a decision model in the form a network with a tree structure that can be used for analysis of sequential decisions under uncertainty. Every branch of the tree shows a potential future. In this study the decision tree is constructed based on urban development scenarios and investment strategies consisting of interventions to improve the urban transit network. The set of investment strategies consist of one inflexible strategy with high investment cost and a flexible, phased investment strategy with lower investment cost. The method used to construct the strategies is a brainstorm workshop with experts from the transport operator RET. The scenarios are designed based on urban and transport development plans for Rotterdam. To determine the economically preferred strategy, the criterion value for each branch of the tree is calculated.

The third step in the methodology is the quantification of the decision tree. Societal cost benefit analysis is performed to estimate the cost, the benefits and the resulting NPV per strategy for the designed scenarios using the discounted cash flow method (Equation 0-1). Indicators for the SCBA are obtained from literature and interviews. This resulted in the following list:

- Travel time savings
- Reliability benefits
- Passenger revenues
- Investment cost
- Maintenance cost
- Operational cost (DRU)
- Capital cost bike share system
- Operational cost bike share system
- Avoided external cost

The benefits of the projects for the traveler follow the savings in travel cost, which are calculated using equation 0-1.

$$C = VOT * \left(\theta_1\, \tilde{T}_{l,j}^{waiting_{origin}} + \theta_2 * \tilde{T}_{l,j}^{access} + \theta_3 * \tilde{T}_{l,j}^{waiting} \theta_4 * \tilde{T}_{l,j-k}^{in-vehicle} + \theta_5 * \tilde{T}_{l,k}^{egress}\right) + TP + \Phi \qquad (0\text{-}1)$$

Where:
C = generalized passenger cost for public transport
VOT = average value of time for public transport passengers
$\tilde{T}_{l,j}^{x}$ = stochastic duration of travel time element X (on line l departing at stop j)
θ_x = relative weights of travel time component x
TP = ticket price
Φ = public transport mode preference constant

For a project j, the net present value (NPV) is calculated as the benefits B minus the cost C for year t, discounted back to year t=0 by discount factor r, over the project lifetime T (equation 0-2).

$$NPV(j) = \sum_{t=0}^{T_j} \frac{B_{jt} - C_{jt}}{(1+r)^t} \qquad (0\text{-}2)$$

The values of the indicators for the NPVs are partially calculated in spreadsheets and partially using a transport model, specifically OV Lite, being a short term ridership model ((van Oort, Ebben, & Kant, 2015)). For the estimation of savings in travel times, timetables from the RET and Google maps are used.

Finally, in order to determine what the optimal investment strategy when there is no no-regret strategy, the expected net present value for the flexible investment strategy as well as the inflexible investment strategy are calculated. By assigning probabilities to the future scenarios, the expected value of every decision, and with that the expected value of the flexible options can be determined. By assigning different sets of scenario probabilities, insights in the scenario sensitivity of the decision model is obtained.

The expected net present value (NPV) of the investment strategies (j) are equal to the sum of scenario probabilities (P_i) multiplied by result ($V_j(s_i)$) given the scenario i for external factor s_i as shown by equation 0-3 and equation 0-4.

$$E\left(NPV_{flex}\right) = \sum_{i=1}^{N} P_i * V_{flex}(s_i) \tag{0-3}$$
$$E\left(NPV_{Inflex}\right) = \sum_{i=1}^{N} P_i * V_{Inflex}(s_i) \tag{0-4}$$

The optimal decision for the flexible or inflexible planning strategy follows from equation 0-5:

$$\max_{\{flex,inflex\}} \{E(NPV_{flex}), (NPV_{inflex})\} \tag{0-5}$$

As a final step, the usefulness of the methodology and its outcomes for the field of urban transit are validated using a workshop with experts from RET.

IV. Application

Case study

Just as for other urban areas all over the world, population and employment in the city of Rotterdam are expected to grow. To facilitate this growth, 50.000 extra houses have to be constructed before 2040 within the existing urban area. The municipality of Rotterdam wants to facilitate urban growth and economic facilities but does not want to have the negative effects of the resulting increase of transport movements. Therefore the municipality desires a transition towards sustainable forms of mobility. This desire is translated into concrete plans, of which examples are a railtangent and the transformation of the Oude Lijn (current heavy rail connecting from Leiden via The Hague to Rotterdam and Dordrecht) to a system with a higher quality which means a higher capacity, higher frequency and higher reliability. To facilitate growth of the population several locations are marked by the municipality of Rotterdam and MRDH as searching locations for urban development. Among those locations are Kop van Feijenoord, Kop van Zuid-Entrepot and the area around the Feyenoord Stadion. However, if and when these plans are going to be executed is uncertain. Figure 1-1 shows the area with the urban development plans.

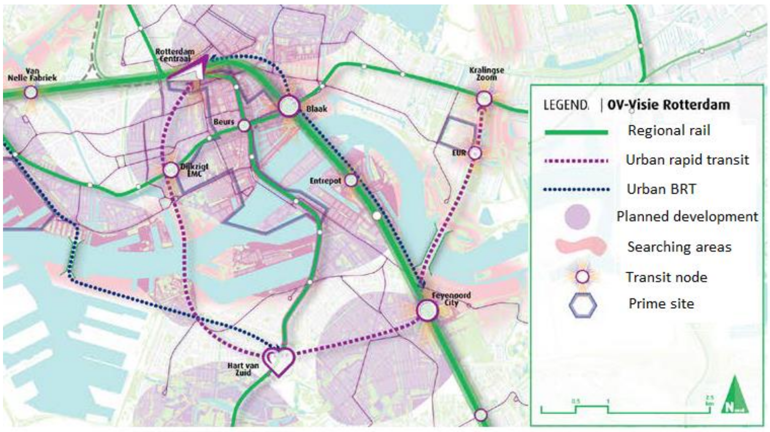


Figure 1-1 Public transport and urban development 2040. Revised and adopted from (Gemeente Rotterdam & MRDH, 2018)

Investment strategies

In this study investment strategies to improve the transit network are constructed based on an analysis of uncertain factors that might (heavily influence) projects benefits combined with the outcomes of a workshop with experts. Based on planning documents published by the municipality of Rotterdam, the following uncertain factors are included in the scenarios: housing, the establishment of a tangent rail and whether or not the Oude Lijn is being transformed into metro. Currently Feijenoord is served by two busses, being bus 32 and bus 66. Stadionpark is accessible by tram 23, which stops close to the Stadionpark/Feyenoord city stop that may be served by the rail tangent in the future. The following investment strategies to develop the network are designed to cope with uncertain factors (scenarios)(see Figure 1-2):

1. Inflexible direct investment in tram for the complete section Blaak- Zuid- Stadionpark

Flexible development:
At the first decision moment decide to construct BRT at a part of the section, being Blaak -Zuid
At the second decision moment

2. Decide to construct an extension of the BRT system, being the part Zuid -Stadionpark (phasing option) or do nothing
3. Decide to transformation the current BRT section into tramway and extend it by constructing the part Zuid-Stadionpark (Growth and phasing option) or do nothing

Figure 1-2 Left: Phase 1: Part of the section, being Blaak-Zuid. Right: After phase 2: complete section Blaak – Stadionpark.

Figure 1-3 shows the decision tree for the case study.

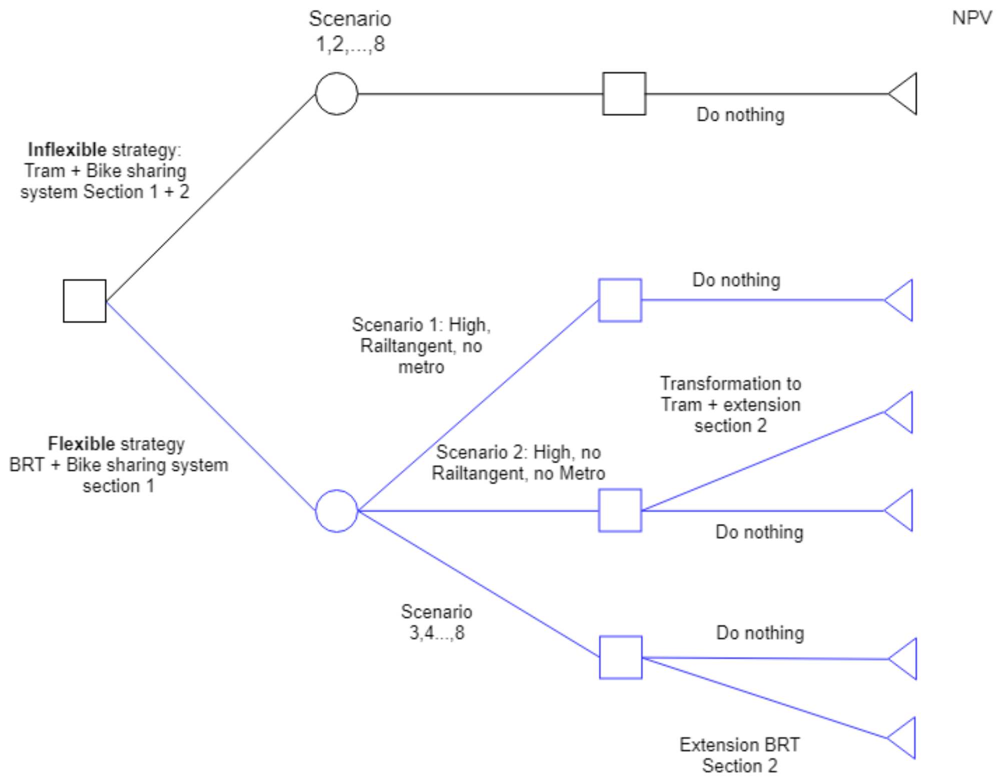


Figure 1-3 Decision tree specified for the case study

Operationalization

Within Feijenoord, the expected weighted travel time savings between BRT and tram do not differ (much), while for the Stadionpark area, tram provides more Generalized Journey Time (GJT) savings than BRT (14 minutes compared to 6 minutes) as can be seen in table 0-1. The savings in Generalized Journey Time (GJT) per trip for the inhabitants in Feijenoord and for the inbitants in Stadionpark are shown in Table 1-1.

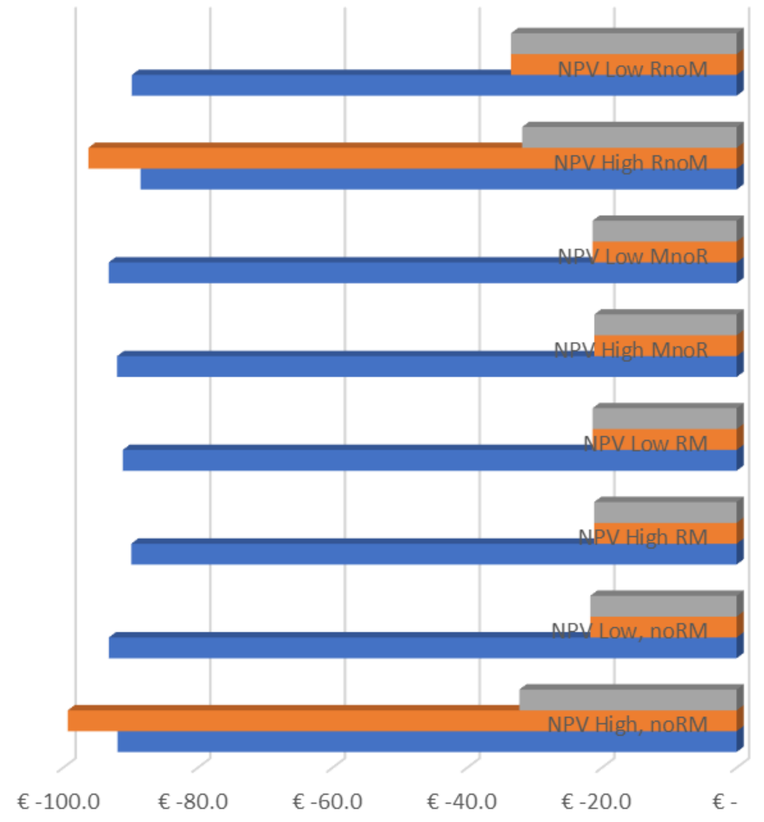
Table 1-1 Generalized Journey times

	Reference bus 32	**Reference: tram 23 + metro**	**BRT + BSS (F=12)**		**Tram + BSS (F=8)**	
Stop	GJT [min]	GJT [min]	GJT with BSS [min]	GJT time savings [min]	GJT with BSS [min] (including rail bonus)	GJT savings [min]
Average Feijenoord - Blaak	22		16	5.9	16	5.7
Stadionpark - Meent		41	35	6	27	14

V. Results

Estimated costs, benefits and NPV per strategy

For the original model setup, the flexible investment strategy (BRT + extension BRT or nothing) results in the highest Net Present Value (NPV) in every scenario (Figure 1-4). This result indicates that this strategy is a no-regret strategy and the optimal investment strategy. However, although this strategy results in the highest NPV, this is a negative NPV and hence an economically inefficient investment strategy in the analysis. An explanation can be found in the high cost of the investment strategies compared to relatively low benefits based on included indicators (Table 1-2).



	NPV High, noRM	NPV Low, noRM	NPV High RM	NPV Low RM	NPV High MnoR	NPV Low MnoR	NPV High RnoM	NPV Low RnoM
■ 3. Flexible BRT	€ -32.3	€ -21.7	€ -21.2	€ -21.4	€ -21.1	€ -21.4	€ -31.9	€ -33.5
■ 2. Flexible tram	€ -99.3	€ -21.7	€ -21.2	€ -21.4	€ -21.1	€ -21.4	€ -96.3	€ -33.5
■ 1. Inflexible	€ -91.9	€ -93.2	€ -89.9	€ -91.2	€ -92.0	€ -93.3	€ -88.5	€ -89.8

Figure 1-4 Net present value of each investments strategy per scenario

The investment decision is found to be almost insensitive to the scenario probabilities. From the sensitivity analysis concerning scenario probabilities, there is no indication that another strategy becomes more interesting for different scenario probabilities. This finding follows from the result that the flexible strategy, which only includes BRT, has the highest NPV for every scenario.

Table 1-2 Estimated costs and benefits of the strategies

(in million €)	1.Inflexible: Tram	2. Flexible: BRT + extension tram or nothing	3..Flexible: BRT + extension BRT or nothing
Investment cost	€ -49.4	€ -57.7	€ -26.7
Maintenance cost	€ -22.1	€ -17.2	€ -0.9
Cost of operaton	€ -27.2	€ -31.0	€ -10.4
Total cost	€ -107.0	€ -114.9	€ -46.9
Benefits			
High, noRM	€ 15.0	€ 15.6	€ 14.6
Low, noRM	€ 13.7	€ 9.8	€ 9.8
High RM	€ 17.7	€ 10.4	€ 10.4
Low RM	€ 16.4	€ 10.1	€ 10.1
High MnoR	€ 15.0	€ 10.4	€ 10.4
Low MnoR	€ 13.7	€ 10.1	€ 10.1
High RnoM	€ 18.4	€ 18.9	€ 15.0
Low RnoM	€ 17.2	€ 13.4	€ 13.4

Looking at the benefits of the strategies, the inflexible strategy results in higher benefits for almost every scenario. This suggests that there might be scenarios, out of the scope of this study, for which the inflexible strategy is preferred over the flexible strategies. However, because the cost of the inflexible strategy are 2.3 times the size of the cost of the cheapest flexible strategy, while the benefits are only around 1.04 times the benefits of the flexible strategy, the inflexible strategy does never perform best for the scenarios that were argued to be realistic for this study.

Tilting points

In order to get insight in the impact of the scenarios on the outcome of the decision model, the model-based layout of the scenarios was changed. To be more specific, it was investigated what the impact of the magnitude of urban development, different scenarios after the second decision moment, and the mode share parameter for the investment when the metro and/or rail tangent are build.

With respect to the layout of the scenarios, one tilting point in optimal investment strategy was found. It is found that the inflexible strategy has the highest expected NPV for a high probability that a scenario including metro becomes reality, in which the opening of the metro is delayed by five years, and in which the housing construction is multiplied by a factor 50. Apparently delayed scenarios result in a higher NPV for direct investment. This result can be explained by the fact that within the flexible investment strategies, the flexible option to extend the BRT from Zuid to Stadionpark is only executed in two scenarios. While the benefits from serving the demand in the Stadionpark area are substantial, especially if the magnitude of housing construction increases. This result also suggests that the benefits of the tram together with the lower cost of direct investment compared to phased investment outweigh the negative impact of metro on passenger revenues.

On top of that, the additional analyses revealed how many new inhabitants are needed to obtain a positive NPV for the flexible strategy. It was found that an increase of inhabitants by a factor 10, gives the flexible strategy an almost positive NPV in the scenarios “High housing, no rail tangent, no metro” and “High housing, rail tangent, but no metro”.

Moreover, it is interesting that the impact of metro on the benefits, NPV and decision tree analysis is low. An explanation for this observation is that the only impact of metro in the analysis is that demand drops and hence the passenger revenues for the operator decrease.

VI. Conclusions

Based on the results of this study, the first conclusion is that incorporating flexibility in the design and evaluation of urban public transport networks gives insight in the expected (net) benefits of a set of network development strategies including real options and hence can prevent decision makers from doing in hindsight unnecessary investment. Application of the specified methodology to a case study showed that a flexible, and cheaper, investment strategy is economically optimal and preferred, regardless of the scenario (figure 0-3). Searching for real options and then implement the flexible strategy can save up to 70 million euros. Although the flexible strategy results in higher Net Present Values (NPVs), it is the inflexible strategy that results in higher benefits for almost every scenario. Not only the benefits but also the cost of the inflexible strategy are higher than those of the flexible strategy. Since the difference in cost is larger than the difference in benefits, the inflexible strategy is never optimal in the experimental setup studied in this research.

Thirdly, real options analysis falls short as an evaluation method because it is biased towards phased strategies in the field op urban public transport. The reason for this is that it opts for the cheapest (hence flexible, staged) strategy if each strategy is economically inefficient, while urban public transport projects are very often not economically efficient but executed because of other reasons such as fairness. If investing is found to be economically inefficient, the result of real options analyses is that investing the least is the optimal strategy. The flexible strategy provides the possibility to only construct a part of the project (for instance 4 km tram of a project that involves a total of 8 km in the inflexible strategy) and gives the option to defer the construction of the other part. In other words, if the cost are higher than the benefits for every strategy (e.g. negative NPV), it is economically optimal to choose the cheapest strategy, which is the flexible strategy including the defer option. In such a case, an analysis comparing a flexible, phased investment strategy with an inflexible investment strategy will give the result that the flexible strategy is optimal.

Further, the method is proven to be able to find tilting points for which a shift in optimal investment strategy occurs. On top of that, tilting points can be identified from which layout of scenarios strategies become economically efficient with respect to the model and its assumptions.

To summarize, this study contributed to both research and society. With respect to research this study contributed in insights about the usefulness of real options analysis in urban public transport systems. Besides, the research gives insights in how to apply these type of analysis in this field of operation. For society this research has proven that real options analysis can help in saving public money by preventing decision from makers from doing in hindsight unnecessary investments in urban public transport. Moreover it helps transport authorities and operators to think about potential flexible, phased development options for urban transport and provides a method to asses these options.

Discussion

When comparing the results to results from previous studies, it is remarkable that within this study the cheapest flexible strategy is the optimal strategy in every scenario and hence is the no regret investment strategy. Within this study, every investment strategy was found to be economically inefficient. This implies that the optimal strategy is investing the least money, and not to start with a flexible strategy because the future is uncertain. In other words, the flexible strategy is the optimal strategy because it is the cheapest strategy. The uncertainties in this study did not influence the outcome of the decision model. In other studies the optimal investment strategy was more dependent on the scenario probabilities than in our study.

Moreover, the analysis does not reflect the advantages of direct investment over phased investment. In reality, constructing a tramway or exclusive bus lane at once is cheaper and politically easier to achieve than constructing in phases. In the analysis in our study it is assumed that the investment costs only depend on the number of km tramway or bus lane

In our research, metro is included as an external event causing knowledge uncertainty, while one can argue that it is not external and more a policy uncertainty. Policy uncertainties are better to tackle by means of agreements and covenants (Bos et al., 2016). Also, the impact of the metro on the benefits of our strategies is rather small, while RET thinks that the investment options considered in this study are unnecessary in the presence of the metro.

Limitations

This study has a few limitations. First of all, not all the effects of public transport are included in the analysis. For instance capacity is not included, though seat probability is a welfare effect on which tram performs better than BRT due to a higher vehicle capacity.

What is currently not reflected in the model properly is the potential demand between Feijenoord and the new area of Stadionpark. The new demand between those areas is not incorporated in the model. The model only reflects the demand within Stadionpark for the faster route to the city center via the new connection through Feijenoord. The potential attraction Stadionpark will have from Feijenoord (and other zones) is not included in the model. If this is assumed being very high, the benefits in the model and the preferred strategy might change.

Furthermore, not all the type of real options were applied in this analysis. Also not every relevant type of uncertainty was included, like technological development.

Recommendations for further research

Based on the presented results, discussion and limitations, the following recommendations for further research can be given. In this study a simplified societal cost benefit analysis is executed. The result of this analysis was that every investment strategy was found economically inefficient and hence the cheapest strategy was the optimal choice in every scenario. It is recommended to include more and/or other welfare effects in further research. As not all the effects of public transport are measured well by cost benefit analysis, this is a limitation for real options analysis within this field. Based on this limitation, it is recommended to explore if there are ways to monetize the wider benefits of urban public transport.

Furthermore, future research may want to include other type of real options, such as delay and other uncertain variables, such as technological development.

Recommendations for practice

Based on the results and conclusions it is recommended to include flexibility in the design and planning of urban public transport development.

Based on the finding that the cheapest alternative performs better in the analyses regardless of the scenario, it may be interesting to compare a phases BRT strategy with an inflexible strategy in which BRT is directly invested for a whole section.

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List of abbreviations

PT	Public transport
CBA	Cost Benefit analysis
SCBA	Societal cost benefit analysis
NPV	Net Present Value
NCW	Netto contante waarde
VoT	Value of Time
GJT	Generalized Journey time
noRM	No Railtangent no Metro
RnoM	Railtangent no Metro
MnoR	Metro no Railtangent
RM	Railtangent and metro
OD pair	Origin Destination pair

1. Introduction

This chapter provides more background information on the problem and objectives of this study. To achieve these objectives, a number of research questions are formulated which are answered in this study.

1.1 Background

All over the world urban population is expected to grow in the next years (United Nations, 2018). The increase in urban population that started in the 1970's together with the conventional transport planning approach, which encouraged the use of private vehicles and the construction of additional road infrastructure, lead to urban development in the suburban regions, referred to as urban sprawl. This phenomenon entailed some negative external effects including air pollution from motor vehicles, longer commuting times because of traffic congestion, overuse of land resources caused by low-density, and driver safety (Tafidis et al., 2017). Improving the quality of public transport services can solve these problems, while meanwhile fueling economic growth, accessibility and public health (Van Oort et al., 2017).

Policy making in the field of (urban) public transport is about making choices regarding the allocation of public money. Because of all the choices to be made, there is a huge need for ex-ante evaluations of choice options (van Wee, 2012). Those evaluations and the resulting policies are usually based on long term forecasts of travel demand and system performance, while those forecasts are based on many assumptions (Chatterjee & Gordon, 2006). In fact, future development of factors that influence the profitability of transport investment, such as demographics, economics, mobility and spatial development, are uncertain. This results in uncertainty in the estimations of cost and benefits for projects which makes decision-making about project investments difficult.

1.2 Problem definition

A transition towards a sustainable mobility system requires long-term orientation (Spickermann, Grienitz, & Gracht, 2014), while investing in new (innovative) mobility services for the future is risky. Future development of factors that influence the profitability of investments, such as demographics, economics, mobility and spatial development, are uncertain (CPB, 2017). This results in uncertainty in the estimations of cost and benefits for projects which makes decision-making about project investments difficult while resources for financing are scarce. Those long-term transition projects might benefit from phased investment strategies.

Uncertainty and risk can be included in the valuation of projects by defining alternatives that account for the uncertain future developments and enable future adaptations. To every form of uncertainty belongs a flexible measurement that mitigates this uncertainty or reduces the negative effects (CPB, 2017). Including flexibility in policy enables decision-makers to respond better and earlier to future developments in technology and demand. However, besides the potential benefits of phased and flexible investment, there are also some disadvantages. Step-by-step investing can save in retrospect unnecessary investments costs, but it also precludes taking advantage of economies of scale in both investment costs and political effort (CPB, 2017).

1.3 Related studies

The future is uncertain and because of that also the cost and benefits of investments in the mobility system (CPB, 2017). Cost Benefit Analysis is widely used to assess the profitability of infrastructure investments. Problematic is that the CBA estimation of the variables construction cost and demand are most inaccurate of all variables (Flyvbjerg, Skamris, & Buhl, 2003);((Asplund & Eliasson, 2016), while those variables make up for most of the cost and the travel time savings. These authors therefore conclude that most gains can be achieved by improving the forecasts for these variables. Many papers can be found about transport appraisal methods that enhance CBA with risk analysis, pointing out that investment risks due to uncertainty should be minimized (see chapter 4).

However, another way of coping with risk due to uncertainty in variables is by taking into account (managerial) flexibility in the risk management process (Saleh, Mark, & Jordan, 2009). Three different forms of flexibility can be distinguished (CPB, 2017). The first form is flexibility in timing, the investment can be delayed or executed step-by-step in small mitigating measures or combinations of measures. Secondly the design and layout can be adapted, for example by means of an extra firm version and right-of-way reservation. Thirdly can be invested in knowledge expansion by experimenting, monitoring and research. Many academics and practicing managers now recognize that the net present value (NPV) rule and other Discounted Cash Flow (DCF) methods are not able to properly capture management’s flexibility to adapt and overhaul future decisions in response to unexpected market developments (Trigeorgis, 1999).

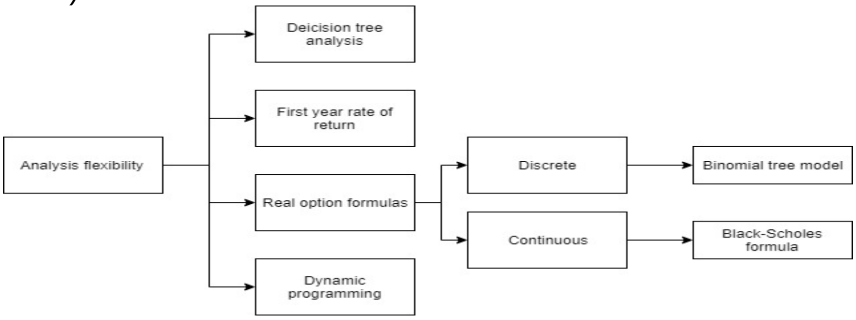


Figure 1-1 Methods to determine cost and benefits of flexible measures (CPB, 2017)

Fortunately, there are several methods (Figure 1-1).available that are able to capture the value of flexibility in infrastructural projects. When the effects of projects strongly depend on future (economic) developments the Real option Analysis (ROA) can be suitable for assessment of project effects (CPB, 2017). This is a modern methodology for economic evaluation of projects and investments under uncertainty. It complements (not substitutes) the currently used tools by accounting for flexibility (Acheampong, 2010). This type of analysis does explicitly value flexible options in infrastructural projects under uncertainty. When there is no uncertainty, flexibility has no value Figure 1-2 shows the different value approaches of discounted cash flow analysis and real option analysis. However, unlike in CBA, a standardized approach for calculating real options does not yet exist. There is a lack of clarity
on the approach of ROA. Three different classes of how ROA is used by firms exist: ROA as a way of thinking, ROA as an analytical tool, and ROA as an organizational process (Alex Triantis & Borison, 2001).

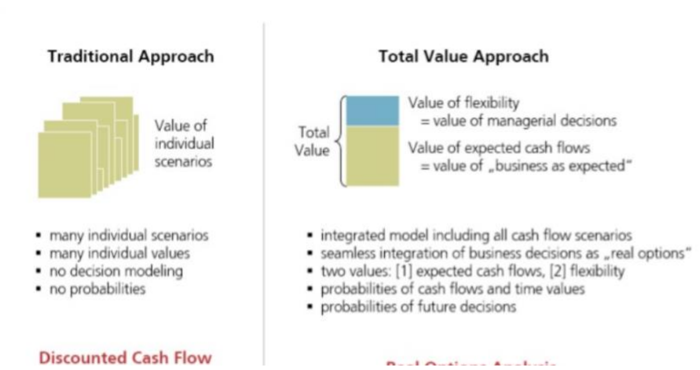


Figure 1-2 Difference in approach. Adopted from The total value approach. Adopted from (Acheampong, 2010)

1.4 Knowledge gap

Although there are several studies regarding the assessment of transport projects under uncertainty, there are still knowledge gaps for which more insight is needed.

Although there has been attention for managerial flexibility in project designs and the possible usefulness of real option approach and similar decision-making instruments (in ‘t Veld & Schenk, 2008), the available amount of scientific literature is limited. These methods have been applied to amongst others wet infrastructure and road widenings, but up until now it has not been applied to urban public transport system transitions (see literature review, chapter 4). This raises two problems: Firstly it is not clear how to apply such a method in urban public transport planning. It is not known how flexibility can be included in the planning of the development of urban public transport networks. Secondly is it not clear what the added value of including flexibility would be for decision-making for this type of projects. For large infrastructure projects flexible strategies help decision makers to save money, it is not clear if this is also the case for smaller urban public transport projects.

1.5 Research contribution

This study has both research and societal relevance. With respect to research this study contributes in insights about the usefulness of real options analysis in urban public transport systems. Besides, the research gives insights in how to apply these type of analysis in these field of operation. For society this research can help in saving public money by preventing afterwards unnecessary investments in urban public transport. Moreover it helps transport authorities and operators to think about potential flexible, phased development options for urban transport and provides a method to asses these options.

1.6 Research Objectives

Section 1.2 showed that there is a gap in literature concerning the usefulness of real options analysis in urban public transport systems. This study aims to contribute to filling this knowledge gap by developing a methodology for real options analysis in urban public transport planning and testing the usefulness in practice.. The objective of this study is twofold. The first objective is to find out if and how real options analysis can be applied in urban public transport planning at a strategic level. The second objective is to identify the usefulness of real options analysis in public transport planning.

1.7 Research questions

Based on the research objectives, the main research question is:

To what extent is real options analysis useful to develop and evaluate public transport networks?

To help answer the main research question, the following two subquestions are formulated:

1. What kind of real options do public transport operators and other stakeholders have for the improvement of an urban public transport network?
2. How do future scenarios affect the performance of investment strategies in urban public transport network design and planning?

1.8 Method

In order to answer the research questions, a three step approach was used within this study. First a literature research is conducted to provide insight in public transport network design and methods to analyze flexibility in project investment. This is followed by the second step, which is the specification of a method to analyze flexibility based on the reviewed literature. The third step was to apply the found method to a case study. Application to a case study should reveal if application is possible and which development strategies are economically efficient for the case study. A reflection on the process and outcomes of the process for the case study provides handles to answer the main research question. More details about the method and application of the method to the case can be found in chapter 4.

Step 1: Literature review

The first part of this study consists of a literature review. The literature research was initially used to identify research gaps. After the gap in research was found, the aim of the literature was to choose and/or specify a methodology for the design and assessment of flexibility in planning strategies for the improvement of public transport networks. To do this, the literature review focused on two topic.

Firstly, the literature review focused on literature regarding the design and evaluation of public transport networks. With respect to the design part, the review started with an overview of the design principles of urban public transport network design. Literature within this part focused on the objectives of the involved stakeholders regarding the public transport network and the existing means to meet those objectives. Insights from this review can be used to design public transport projects for the improvement of the network within the case study. With respect to the evaluation of public transport projects, literature regarding transport appraisal tools was reviewed. Within this part the concept of societal cost benefit analysis is introduced. Societal cost benefit analysis enables monetization of all the effects of public transport projects, which is an important feature for an analysis with the purpose of minimizing financial risk.

Secondly, the focus of the literature review was on literature regarding real options analysis. Thus literature helped to understand how flexibility can be incorporated in the design and evaluation of transport projects. Within this part the concept of real options theory was introduced and an overview of real option categories was provided. These categories can be included in the design of planning strategies in the case study to cope with uncertain future development. Finally, the literature review provided an overview of the techniques that can be used to value real options. Those option valuation techniques can be combined with transport project evaluation techniques and hence provide a methodology to assess real options in urban public transport development.
The literature is found using Scholar and the snowballing technique. Keywords used are amongst others real options analysis, real options theory, public transport appraisal and public transport network design.

Step 2: Specification methodology

The second step in the research approach was to specify a research method based on the literature review. This method should be suitable for the design and valuation of real options (i.e. flexibility) in the development of urban public transport networks. More details about the selected method can be found in chapter 4.

Step 3: Case study

After a method is chosen, it is applied to a case study. The case study is used to test the usefulness and applicability of real options analysis in urban public transport development. The case study is an urban area in the city of Rotterdam which was nominated by the RET at the start of this research. This is an area for which large urban development is planned. This case is used in two parts of this research.

Firstly the case is used as inspiration to design planning strategies, varying in their degree of flexibility, in order to improve the public transport network (see chapter 5). Flexibility is included in such a way that it enables the decision maker to adapt the strategy in the future to information that will be revealed in the future.

Secondly the case is used to validate the real options analysis methodology for the urban public transport sector. For this purpose the designed planning strategies are used as input for the real options analysis method that was specified in step 2. Application of the real options analysis to a case enables the valuation of real options and hence reveals the usefulness of including flexibility in urban public transport design and planning. The results of this analysis are presented and discussed in chapter 6.

1.9 Scope

This section gives a first indication of the scope. The definitive scope is defined by the first subquestions based on literature review

- This study focusses on improving an urban public transport system. The current system in the case study consists of two bus services and a regional train. To improve the current system high-quality public transport services are considered and shared systems to complement those services.
- This study focusses on economical assessment of network development strategies. The objective of the analyses is to prevent decision makers from doing in retrospect unnecessary investments. Besides economic effects, public transport projects have other effects which can be a reason to invest in public transport. However, those effects are not included in this study. This study uses an existing assessment framework for public transport projects, hence only assesses the effects included in that framework.

Besides, this study has a geographical scope due to the case study. The case study area is scoped as the neighborhood Feijenoord and Kop van Zuid-Entrepot and the new to be build neighborhood Stadionpark. Key figures used to assess the impact of interventions are if possible based on Dutch research.

1.10 Thesis outline

This thesis report is structured as follows. Chapter 2 and 3 provide a review of literature required as input for chapter 4 in which the research methodology is specified. Chapter 2 starts with an introduction of the sector that is topic of this study. This chapter provides the main objectives and means to improve public transport networks and discusses appraisal tools for the evaluation of projects. In chapter 3 the concept of real options analysis is explained and techniques to calculate option values are discussed. Based on the outcomes of chapter 2 and 3, chapter 4 follows with a specification of the chosen methodology for the application of real options analysis to a case study. Figure 1-3 shows the structure of the study and the corresponding chapters.

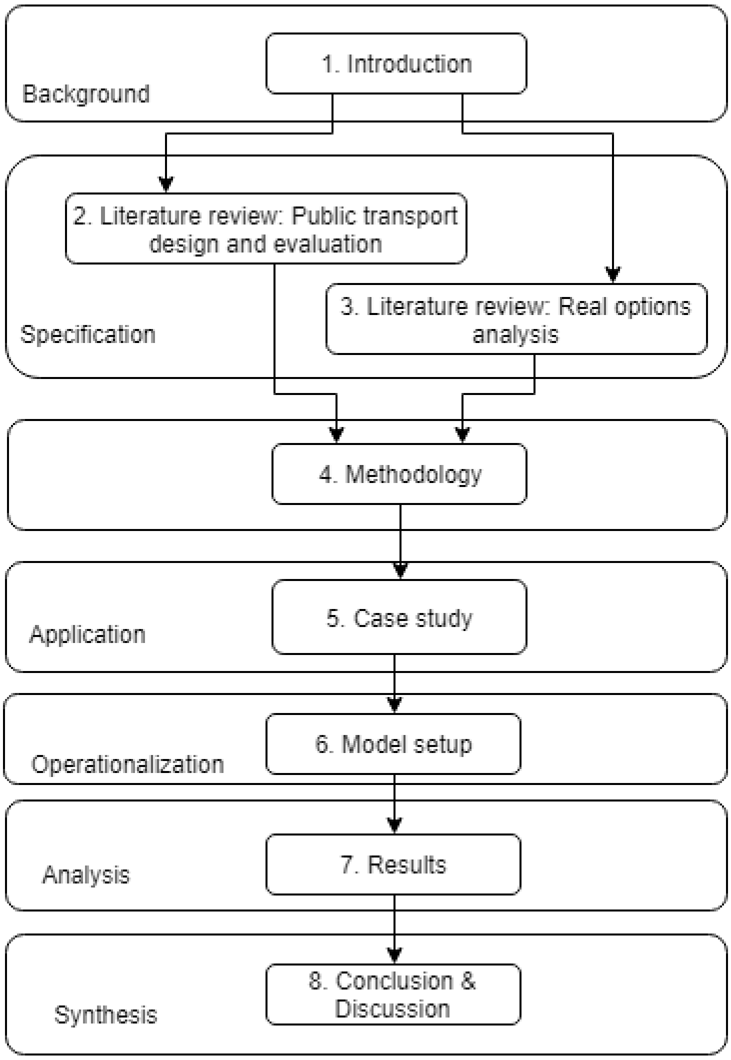


Figure 1-3 Study structure

2. Literature review: public transport network design and evaluation

In order to incorporate flexibility in the planning for urban public transport development, more insight in the planning and design of urban public transport system is required. This chapter aims to provide a theoretical framework for urban public transport design. This information will be used to assist in the design of network development strategies for the case study. This chapter serves as a starting point to answer the following subquestion:

1. What kind of real options do public transport operators and other stakeholders have for the improvement of an urban public transport network?

Section 2.1 describes the demand side of public transport starting with an introduction of the stakeholders involved in urban public transport. These stakeholders have different interests resulting in different objectives regarding public transport systems. To meet those objectives, means to improve public transport systems are described in section 2.2. In order to assess public transport projects, appraisal tools are required. Section 2.3 discusses the appraisal tools multi-criteria-multi-decision analysis and societal cost benefit analysis based on literature. Moreover, assessment criteria are discussed.

2.1. Public transport Design

The main process in public transport is the operation that is driving vehicles enabling passengers to travel from origin stop to destination stop within a specified time frame. Prior to the operation is the design process which specifies the timetable and schedules (van Oort, 2011). The input of the process is a network, consisting of infrastructure and service lines, a schedule, crew and vehicles. The output of the process are actual vehicle trips from stop to stop, including actual departure and arrival times. The schedule shows the intended output, namely trips planned in time and space. The planning process consists of three stages as can be seen in Figure 2-1. At the strategic level the focus is on the design of the transit network, which consists of lines, types of vehicles, stop spacing and frequency. Input for this network design are expected ridership, budget, and geographical characteristics (van Oort, 2011).

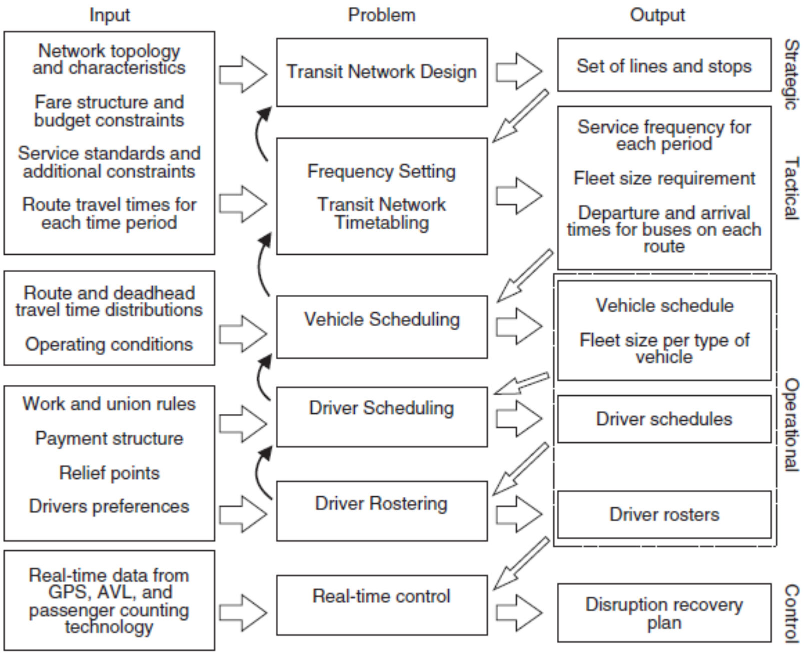


Figure 2-1 Interaction between stages of the planning process and real-time control strategies. Adopted from (Ibarra-Rojas, Delgado, Giesen, & Muñoz, 2015)

2.1.2 Stakeholders in urban public transport

In urban public transport, three groups of stakeholders are involved: the users of public transport, the operators, and the authority (**Fout! Verwijzingsbron niet gevonden.**). Every stakeholders has their own perspective on the objective that has to be used in public transport network design.

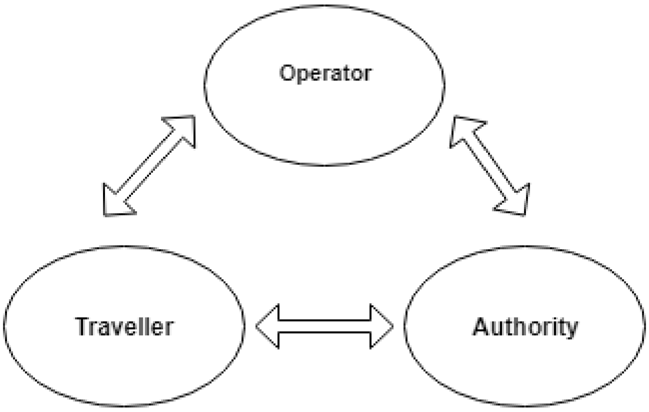


Figure 2-2 Stakeholders in public transport

1. Traveler's perspective

The traveler is the user of the transit network. The main interest of travelers is that they want to reach their destinations quickly. For travelers the most important elements of transport services are: travel time, costs, and comfort (van Nes, 2015) The traveler also expects the trip to be reliable and hopefully comfortable.
From the user's perspective, a transit network should cover a large service area, be highly accessible, offer numerous direct-through trips, not deviate much from the shortest paths, and should globally be able to meet the demand

Travel time components
The main objective of the traveler is minimizing his or her perceived travel time (R. van Nes & Bovy, 2007). The total travel time can be decomposed into access time to a stop, waiting time, in-vehicle traveling, transfer time, and egress time. Travelers do not value every element of their trip equally. The valuation per element relative to the in vehicle time found in Dutch studies is shown in Table 2-1.

Table 2-1 Time valuation per element relative to the in-vehicle time

Trip element	Valuation	Source
Factor out-of-vehicle-time (waiting time)	2	(De Bok & Wesseling, 2017)
Factor first- and last mile	1,75	(De Bok & Wesseling, 2017)
Transfer penalty [min]	7,5	(De Bok & Wesseling, 2017)

2. The operator's perspective

From the operator's perspective, transit network must stay within the current budget, be efficient in obtaining revenues, and be able to satisfy the demand. Hence, transit network design considers elements such as the service area, line coverage, spacing of stop, directness of the lines, line lengths, policy headway (separation time between consecutive trips), loading standards, and road speeds (Ibarra-Rojas, Delgado, Giesen, & Muñoz, 2015). Objectives that meet the interest of operators are maximizing the cost-effectiveness and maximizing profit (R. van Nes & Bovy, 2007).

3. The authority's perspective

The local authorities are the third party involved in transit network design. They might take the perspective of the traveler by subsidizing transit, or they might try to find a balance between the traveler's and the operator's objectives (R. van Nes & Bovy, 2007). Typical objectives for the authority are minimizing total cost and maximizing patronage. As patronage (travel demand) depends on travel time, maximizing patronage may equal the minimizing travel time objective that meets the interests of travelers.

Besides the interests of the traveler or the operator, the authority also takes into account the interests of society as a whole within the design of public transport networks. Public transport services have a wide array of benefits for society (Van Oort et al., 2017). It can for instance reduce the negative impact of transport in cities, while meanwhile facilitating business growth, accessibility and improving public health. The wider effects that should be taken into account are grouped within the 5E framework consisting of the following 5 E's (Van Oort et al., 2017):

- Effective mobility. Public transport is able to transfer a large number of people from A to B in a fast and reliable way and reduce congestion during the process. The aim of public transport projects is often to enhance service quality such as speed, frequency, reliability, comfort and safety;
- Efficient city. Public transport uses land and space efficiently and is able to (re)structure and (re)shape cities;
- Economy. Public transport improves competitiveness of an area by attracting companies and inhabitants to its direct surroundings. Public transport has showed to represent an important condition for creating urban situations with positive economic effects, but always in combination with other interventions.;
- Environment. Public transport is friendly for the environment and is essential for keeping cities and urban areas green and liveable;
- Equity. Public transport helps in establishing a safe and healthy society with equal opportunities for all inhabitants. Due to public transport, people that cannot use private transport can access education, employment centers or healthcare. This raises the employment level, aides social inclusion and improves the level of public health.

2.1.3 Design dilemma's

The objectives of the three stakeholders can be conflicting, even within a group of stakeholders, resulting in dilemma's in the design of public transport networks. The key design variables for urban public transport networks are stop and line spacing. Within literature several design dilemmas have been formulated showing the difficulty of finding optimal relationships for stop and line spacing.

For public transport networks the design dilemma can be formulated as looking for short travel times versus low operational costs, and since travel time determines patronage, the dilemma can also be formulated as high patronage versus low operational costs. These dilemmas show that the main problem in network design is to find a balance between opposing influences (Rob van Nes, 2015). The primary trade-off faced in the planning and operating processes is between the level of service experienced by users and the operating costs for transport operators. This trade-off is illustrated in Figure 2-3.

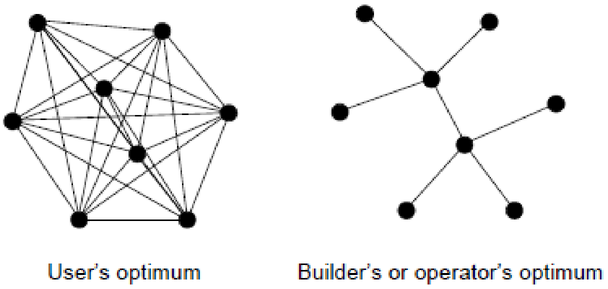


Figure 2-3 Illustration of the user's and the builder's, or operator's, optimum. Adopted from (Van Nes, 2015).

According to (Rob van Nes, 2015), two design dilemmas are important for urban public transport design. One is the 'short access times versus short in-vehicle times'. Many stops per square kilometre result in short access distances, but the buses have to stop at every stop leading to very low speeds and thus large in-vehicle times. Another important dilemma is the one of short waiting times versus minimization of transfers. High line density, that is, total line length per square kilometre, results in a minimum number of transfers, but at the same time to low frequencies per line and thus to large waiting times. If a specific network structure is assumed, the theoretical concepts of space density and line density can be translated into design variables such as stop spacing and line spacing. In the case of an urban corridor having parallel lines to and from the city center these relationships can be illustrated as in Figure 2-4.

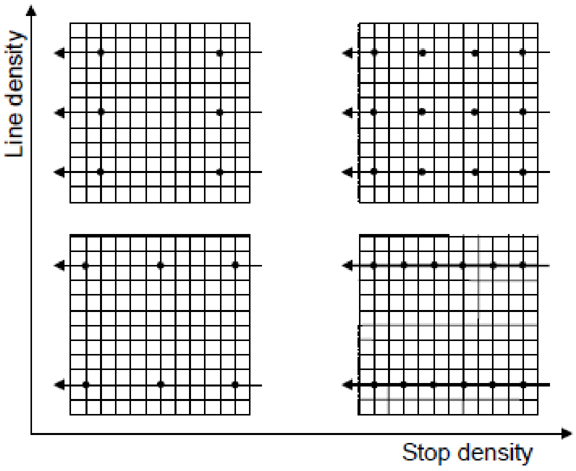


Figure 2-4 Stop and line spacing for different values of stop and line density. Adopted from (Rob van Nes, 2015)

2.2 Means to improve public transport: modes

The previous section described objectives of stakeholders in public transport network design and the key design variables to meet the objectives. Authorities can improve public transport networks and increase usage of public transport systems by means of projects that influence the perceived travel time (Warffemius, 2015). A key strategic decision in urban transport policy is the choice of technology for a transit system. This sections provides an overview of available technologies together with their characteristics and associated cost.

2.2.1 Characteristics modes

A particular important strategic decision is the choice amongst rail (light and heavy) and/or bus based systems, to provide service in a particular corridor and across a network. Train and busses differ in many ways, such as capital and operating cost, speed, frequency, distance between stops, infrastructure requirements, reliability and comfort. Table 2-2 gives an overview of the characteristics of each technology (van Oort, 2018);(Vuchic, 2002). The chosen technology affects the social benefit per dollar; hence careful consideration of specific modes is needed to meet the objectives cost-effectiveness and total cost minimization (Tirachini, Hensher, & Jara-Díaz, 2010).

Table 2-2 Characteristics technologies (Revised and adopted from: (van Oort, 2018))

	Railway	**Metro**	**Light rail**	**Guided bus**	**Express bus**	**Urban tram**	**Urban bus**	**People mover**
Maximum speed [km/h]	120-200	80	50-80	50-80	50-80	50	50	
Operational speed [km/h]	70	30-40	25-35	20-30	15-20	15-20	25	
Guidance	rail	rail	rail	Rail, beam, electronical	-	rail	-	Rail, beam, electronical
Own infrastructure	Completely	completely	mostly	partially	partially	partially	locally	completely
Capacity [seats and standees]	600	800	200-400	120	120	65/165	35/75	4-100
Line capacity [pax/h/dir]	10,000	50,000	10,000	2,500	2,500	5,000	1,000	250-2,000

Technologies can be selected for a network level based on how suitable the characteristics of technology are for that network level. Table 2-3 shows a proposal for hierarchical levels in public transport networks based on trip distance, stop spacing, speed and line spacing. An urban bus is for instance too slow [50 km/h] to meet speed requirements of an international transport network [150 km/h].

Table 2-3 Proposal for hierarchical levels in public transport network adopted from (Van Nes, 2018)

Name	Trip distance [km]	Stop spacing [km]	Speed [km/h]	Line spacing [km]
Local	1 - 3	0.3	20	1
Agglomeration	3 - 10	0.8 – 1.0	30	3
Regional	10 - 30	2	60	6
Interregional	30 - 100	15	90	45
National	100 - 300	50	120	150
Interntional	300 - 1000	150	150	450

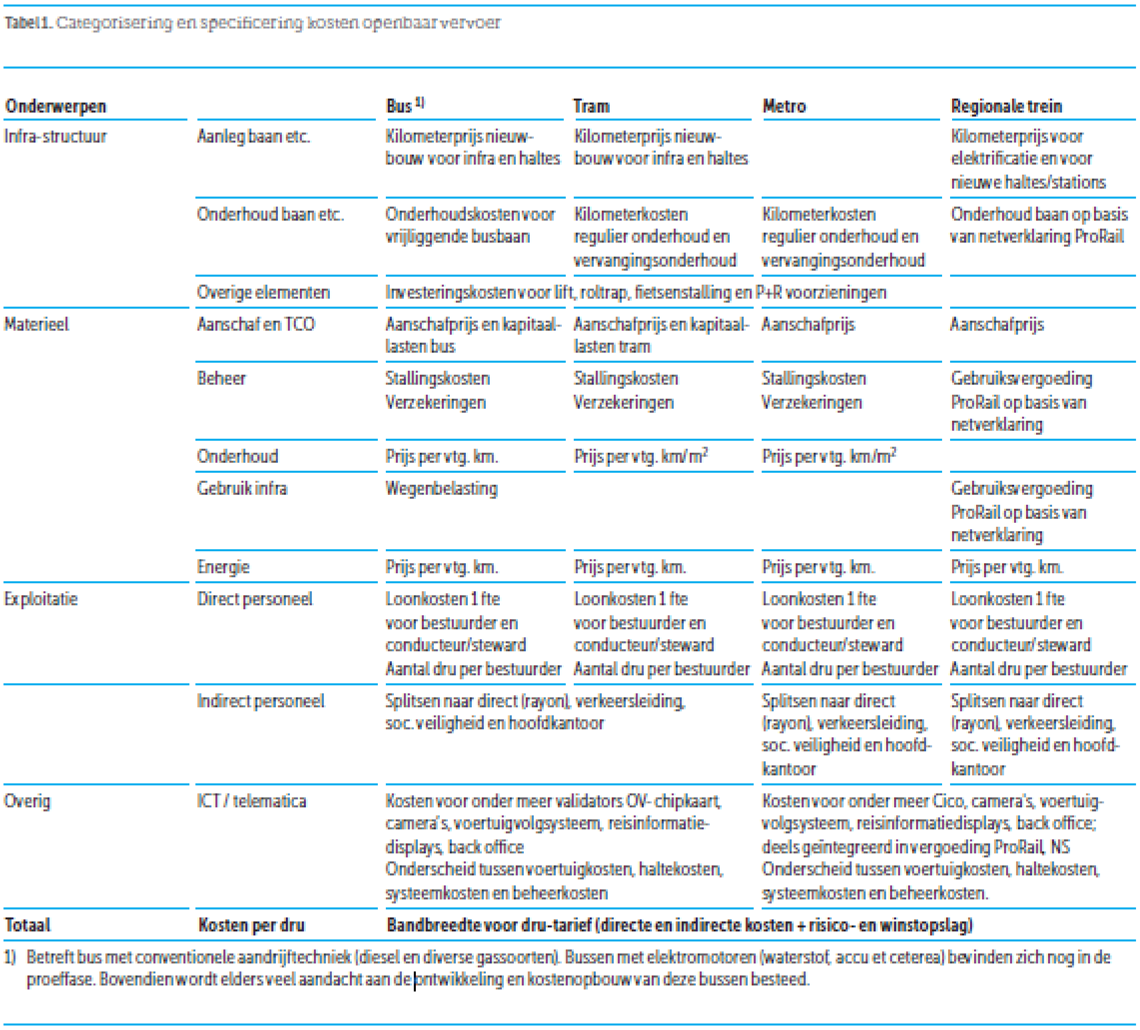
Rail bonus
Replacing a bus system by a tram system might result in additional travelers based on the so called ‘rail bonus’. A study performed by (Bunschoten, Molin, & van Nes, 2013) showed that replacing a bus by a tram was equivalent to reducing the in-vehicle time by 22% and the total travel time by 12%. Multiplying these travel time reductions with corresponding elasticities resulted in an increase of patronage of 13%.

2.1.2 Cost structure

Besides system characteristics, modalities also differ in the cost involved in constructing and operating a transport service. It is important for authorities and operators to have a realistic image of the cost elements and the magnitude of cost associated with public transport services. Table 2-4 presents a categorization and specification per mode of cost in public transport. To support decision making, (CROW, 2015) determined key figures for those elements which are shown in

Table 2-5.

Table 2-4 Categorization and specification of cost in public transport. Adopted from (CROW, 2015).



Tabel 1. Categorisering en specificering kosten openbaar vervoer

Onderwerpen		Bus [1]	Tram	Metro	Regionale trein
Infra-structuur	Aanleg baan etc.	Kilometerprijs nieuwbouw voor infra en haltes	Kilometerprijs nieuwbouw voor infra en haltes		Kilometerprijs voor elektrificatie en voor nieuwe haltes/stations
	Onderhoud baan etc.	Onderhoudskosten voor vrijliggende busbaan	Kilometerkosten regulier onderhoud en vervangingsonderhoud	Kilometerkosten regulier onderhoud en vervangingsonderhoud	Onderhoud baan op basis van netverklaring ProRail
	Overige elementen	Investeringskosten voor lift, roltrap, fietsenstalling en P+R voorzieningen			
Materieel	Aanschaf en TCO	Aanschafprijs en kapitaallasten bus	Aanschafprijs en kapitaallasten tram	Aanschafprijs	Aanschafprijs
	Beheer	Stallingskosten Verzekeringen	Stallingskosten Verzekeringen	Stallingskosten Verzekeringen	Gebruiksvergoeding ProRail op basis van netverklaring
	Onderhoud	Prijs per vtg. km.	Prijs per vtg. km/m^2	Prijs per vtg. km/m^2	
	Gebruik infra	Wegenbelasting			Gebruiksvergoeding ProRail op basis van netverklaring
	Energie	Prijs per vtg. km.	Prijs per vtg. km.	Prijs per vtg. km.	Prijs per vtg. km.
Exploitatie	Direct personeel	Loonkosten 1 fte voor bestuurder en conducteur/steward Aantal dru per bestuurder	Loonkosten 1 fte voor bestuurder en conducteur/steward Aantal dru per bestuurder	Loonkosten 1 fte voor bestuurder en conducteur/steward Aantal dru per bestuurder	Loonkosten 1 fte voor bestuurder en conducteur/steward Aantal dru per bestuurder
	Indirect personeel	Splitsen naar direct (rayon), verkeersleiding, soc. veiligheid en hoofdkantoor		Splitsen naar direct (rayon), verkeersleiding, soc. veiligheid en hoofdkantoor	Splitsen naar direct (rayon), verkeersleiding, soc. veiligheid en hoofdkantoor
Overig	ICT / telematica	Kosten voor onder meer validators OV-chipkaart, camera's, voertuigvolgsysteem, reisinformatiedisplays, back office Onderscheid tussen voertuigkosten, haltekosten, systeemkosten en beheerkosten		Kosten voor onder meer Cico, camera's, voertuigvolgsysteem, reisinformatiedisplays, back office; deels geïntegreerd in vergoeding ProRail, NS Onderscheid tussen voertuigkosten, haltekosten, systeemkosten en beheerkosten.	
Totaal	**Kosten per dru**	**Bandbreedte voor dru-tarief (directe en indirecte kosten + risico- en winstopslag)**			

1) Betreft bus met conventionele aandrijftechniek (diesel en diverse gassoorten). Bussen met elektromotoren (waterstof, accu et ceterea) bevinden zich nog in de proeffase. Bovendien wordt elders veel aandacht aan de ontwikkeling en kostenopbouw van deze bussen besteed.

Table 2-5 Key figures cost categories, adopted from CROW (2015).

Topics		Bus	Tram	Metro	Regional train
Infrastructure	Construction track Simple [mln € /km]	0,3 – 4 (simple) 4,7 – 12 (complex)	12 - 35		
	Stops [x1000 €]		400.000 – 600.000		
	Maintenance	1-2 % of construction cost (annual)	50.000 – 60.000	130.000 – 200.000	
Material					
Operation	Direct personnel				
Other					
Total	Cost per DRU	108	207	450	400 - 800

In tenders and concession management the concept of cost per schedule hour (DRU) is often used. This concept comprises the cost associated with one hour of public transport. A key figure for this variable can be determined based on direct and indirect cost. The direct cost cover the cost of personnel, vehicle cost, kilometer cost (maintenance and energy). The indirect cost cover the overhead (housing, ICT, marketing and administration) (CROW, 2015).

2.2.3 BRT and LRT

It was determined by Howes & Rye (2005) what type of services are needed in medium sized cities and urban regions to meet the citizens' requirements for the public transport system. Based on case studies they developed understanding in the importance of different qualities of public transport in attracting previous non-users and in getting existing users to use public transport more. The conclusion were that medium sized cities should take the following actions to increase usage amongst both existing users and current non-users of their public transport systems (Howes & Rye, 2005):

- Speed up their core services, preferably by converting them to some form of segregated rail-based mode, or otherwise by simplifying the routes and introducing bus priority.
- Simplify routes more generally: focus on high frequency on core corridors.
- Start with corridors: because these are easier to grow than networks as a whole.

These actions can be taken by implementing Bus Rapid Transit (BRT) and Light Rail Transit (LRT) systems, which are described in literature as high quality public transport solutions (Van der Meijs et al., 2015);(van der Bijl & van Oort, 2014).

Light rail can be defined as: "Light rail is a rail-bound mode of public transport for cities and urban regions. Contrary to train (heavy rail) and metro (subway, underground) light rail principally is able to be integrated within public realm, sharing public space with other traffic to some extent" (van der Bijl & van Oort, 2014).

Light rail is a hybrid mode that has characteristics of train, tram and metro. It has the ability to serve different transport objectives and network levels making it an adaptive system that can easily be integrated with different types of existing infrastructure. In contrast to other urban rails systems like metro and tram, light rail is able (to some extent) to share traffic with other means of transport at some parts of the line.

Lightrail (LRT) is said to have positive effects for society and the city that can be captured by the five dimensions within the earlier described 5E framework. Firstly it is an efficient mode of public transport allowing cost effective operations, specifically regarding service reliability. Secondly it

Bus Rapid Transit (BRT) may be defined as follows: “BRT offers the opportunity to create a fast and reliable public transport system for relative low cost, but with a high degree of flexibility that can be realized quickly.” (Van der Meijs et al., 2015)
BRT systems are found to offer a lot of flexibility which makes it possible to create a suitable solution for specific situations (Van der Meijs et al., 2015). It was found that BRT only succeeds if the line or system is designed for the travel demand. The flexibility of BRT should be used to follow travel demand. There are examples from the Netherlands where a BRT line has grown towards a BRT system and a BRT line that generated so much demand that it is going to be transformed into a tram.
Main differences between BRT and LRT can be found in the associated cost and the generated travel demand. Light rail systems are generally more costly than bus rapid transit systems, which is illustrated in Figure 2-5 (van Oort, 2018). However, LRT is also found to attract more travelers due to a so called rail bonus (Van Oort et al., 2017). Main advantages of BRT are that it is cheaper and also more flexible (Van der Meijs et al., 2015).

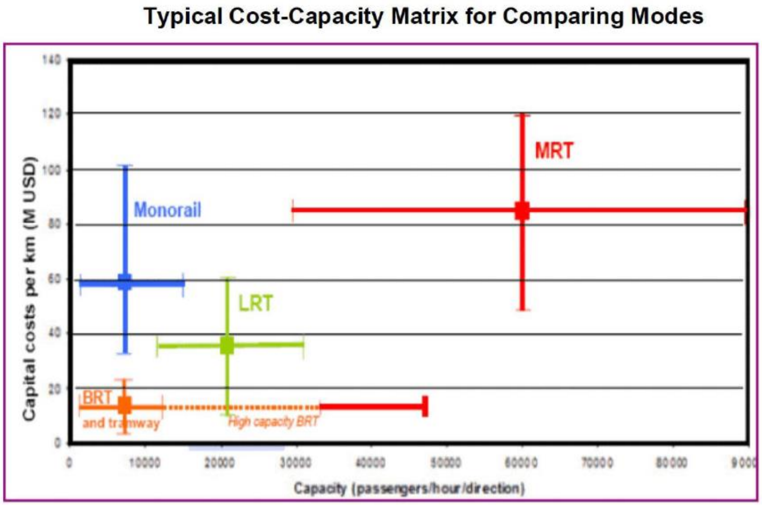


Figure 2-5 Typical Cost-Capacity Matrix for comparing modes. BRT vs. LRT. Adopted from: (van Oort, 2018)

2.2.4 Bike share systems

Stop and line spacing influences the access and egress distance of public transport. The general issue of access and egress travel is often referred to as transit’s ‘first and last mile problem’. Cycling is often suggested as a means to increase the catchment areas of existing transit stations (Figure 2-6). Reasons for this are a) its higher speed, b) the quadratic relationship between distance and area, and c) the high scalability and flexibility without requiring high marginal public or private resources. (Kager & Harms, 2017) The bicycle-transit combination benefits from the flexible aspect of the bicycle, and the larger spatial range of public transport. Together they compete with private motorized vehicles, in a more sustainable and space-efficient way

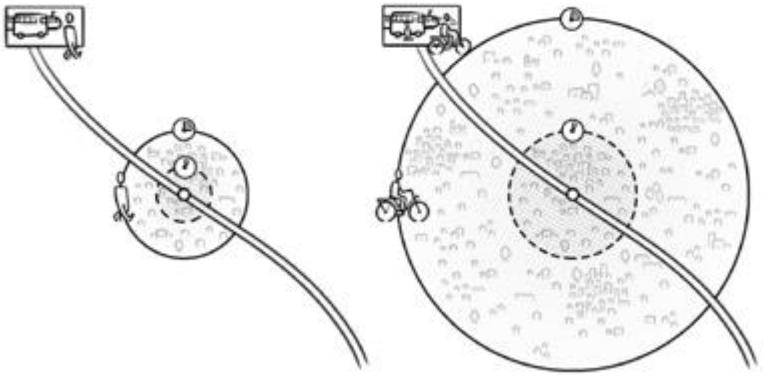


Figure 2-6 The bicycle increases catchment areas of public transport stops. Adopted from (Kager & Harms, 2017)

Martin and Shaheen (2014) found that in high density areas, where public transport networks are more concentrated, bike sharing can substitute public transport trips, while in areas with lower densities and less available transit bike sharing mostly functions as the first or last mile to public transport. Another study revealed that the median overall feeder distance found 400m and when modes are considered separately, it is 380m for walking and 1025m for cycling (Rijsman, 2018). The following factors were found to be significantly related with the observed feeder distance: feeder mode, amount of transfers, frequency at the stop, directness and transit stop density.

2.3 Public transport project evaluation

Projects meant to improve the public transport system can be evaluated using appraisal tools. Section 2.3.1 describes the most important appraisal tools: CBA and MCA. Section 2.3.2 elaborates on indicators for an assessment framework to measure the effects of public transport projects.

2.3.1 appraisal tools for transport policy

Appraisal tools are supposed to help transport policy decision makers. Previous studies have discussed if cost-benefit analysis (CBA), multi-criteria decision-making (MCDM) or a combination of both is the appropriate appraisal tool in transport policy-making (Annema et al., 2015). Next to CBA and MCDM other supportive information tools exist, such as Environmental Impact Assessment reports and a broad set of specialized impact report. However, special about both CBA and MCDM is that they aim to comprise all the effects that result from a transport project and aggregate them in one final indicator. This section starts with a description of CBA and MCDM methods followed by their advantages and disadvantages.
CBA is a technique which is used to appraise the efficiency of a policy (Annema et al., 2015).

The (social) Cost-Benefit Analysis (CBA) is a widely used ex-ante evaluation tool used to support the decision-making process in transport in most western countries. For large-scale projects CBA is often mandated by some national funding regulations. Within SCBA all future direct and indirect effects are monetized and discounted using the NPV (Net Present Value) method. The result of CBA analysis is the Net Present Value, benefit-to-cost ratio and internal rate of return.
Literature describes many arguments pro and against CBA as a tool for supporting transport policy-making. The main argument against CBA is that it is found to be inadequate to incorporate and assess multiple, often conflicting objectives and criteria like environmental and social issues (Barfod & Salling, 2015). Some impacts, such as equity, can hardly be monetized while the monetization of impacts such as nature and landscape deterioration is highly

questionable (Barfod & Salling, 2015). Other disadvantage of CBA are the extensive data requirements and the complexity (Bristow & Nellthorp, 2000). The strong point of CBA is that it is theoretically unambiguous making it a common language which is widely used (Beria, Maltese, & Mariotti, 2012) and firmly embedded in project appraisal (Browne & Ryan, 2011). Moreover, it is a way to overcome cognitive, structural and process-related limitations and biases in decision making (Mackie, Worsley, & Eliasson, 2014). Also, the main outcome of CBA (NPV) is seen as valuable input for decision-making on governmental money. However, research among Dutch transport politicians showed that the results of CBA are perceived to be pretentious. The Dutch politicians were more interested in appraisal tools which show them the political important trade-offs of a transport policy (Annema et al., 2015).

Multi-criteria decision-making refers to a class of decision-making methods based on which a number of alternatives is evaluated with respect to a number of criteria Where CBA is mainly used for infrastructure and large transformation projects, MCA is an acknowledged technique for the assessment of sustainability at neighbourhood level (Beria et al., 2012). In contrast to CBA, MCDM allows appraisal of non-monetary impacts: the criteria can be quantitative or qualitative. The result of MCDM is an aggregated score based on all the decision criteria. MCDM may be used in combination with CBA (Annema et al., 2015).

2.3.2 The assessment framework: Indicators

The main purpose of public transport projects is to make journeys faster, more comfortable, more reliable or cheaper. These direct effects provide prosperity for existing and new public transport users (Zwaneveld & Bakker, 2009). The most important benefits of transport system projects are usually travel time savings and travel cost savings, but also reliability and comfort are important. Network improvements often result in welfare effects for both current as new users (Zwaneveld & Bakker, 2009). The travel demand depends not only on the project (improvement on one specific PT line for instance) but also on the developments in competing mobility services (C. J. J. Eijgenraam, Koopmans, Tang, & Verster, 2000).

Table 2-6 provides an overview of wealth effects for the cost benefit analysis of public transport projects.

Table 2-6 Welfare effects: overview for a public transport project, adopted from (Zwaneveld & Bakker, 2009)

Direct effects for the traveler	
Accessibility beenfits (waiting time, travel time and reliability)	- commuting - business - leisure and other - school
Comfort during travel time	- per mode/service (for example railbonus) - crowding in train/station - material - train station
Change of tariff tickets	relation with operations
Nuisance during construction	
Option value and 'non-use value'	
Congestion/travel time effects	- Congestion road traffic (due to less car traffic and overpasses) - Congestion/ travel time freight traffic
Direct effects for the infrastructure manager and the operator	
Operations saldo	Passenger yield minus cost of operations
Investment cost	- Including estimation uncertainties - Including decision uncertainty - Including 'optimism bias'
Maintenance/management cost	
Indirect effects	
Agglomeration effects	Increase/decrease of productivity
Mutation imperfect competition	
Budget effect higher/lower bbp	- Due to higher/lower participation - Due to longer/shorter working hours - Due to more/less productive jobs
Other budget effects	Excise duties/charges
Avoided grants/operating profits parking	
cross-border effects	
External effects	
Emissions, local	From PT, walking, (moped)bicycles, motor and car
Emissions, global	Idem
Noise	Idem
Traffic safety	idem
Use of space	
Local barrier operations and quality of life	Relation/overlap with noise, emissions and use of space
Nature value	
Recreational value	
Distributional effects (non-additional indirect effects)	
Availability and use of PT by social groups (social functions)	Relation to non-use value
Increase of GDP	- Due to agglomeration benefits - Due to increased labor participation - Due to longer working hours - By accepting more productive jobs
Income and spending effects	

General: pros and cons per population group, region and users versus non-users	

2.4 Conclusion

The literature review aimed to provide an overview of the aspects related to the design of public transport networks. This overview can help to design investment strategies to improve the public transport system in the case study.

Three stakeholders are involved in public transport network design: the traveler, the operator and the authority. Each stakeholder has its own interests. Travelers want to minimize their perceived travel time which can be conflicting with operators that want to minimize the cost associated with a network. Authorities tend to take the perspective of the traveler and the operator by seeking for cost-efficiency. Moreover, authorities are interested in the wider benefits for society. From literature it is found that stop and line spacing are the key variables in urban public transport network design. Building a network with small stop spacing and line spacing meets the objectives of travelers, but knows high costs.

Light Rail Transit (LRT) and Bus Rapid Transit (BRT) are considered to be high quality transport systems which can improve public transport systems. LRT has many benefits for society and the city. It is an efficient mode of public transport that allows cost effective operations, specifically regarding service reliability. Rail-based public transport represents a strong and effective tool for urban planning and design. BRT systems are said to offer a lot of flexibility in design. This flexibility should be used to design and adapt BRT systems following the development of the travel demand. When comparing LRT and BRT, LRT is said to attract more travelers than BRT due to the rail bonus, but BRT is much cheaper and more flexible.

Public transport projects can be assessed using societal cost benefit analysis. This appraisal tool allows monetization of all the effects associated with public transport and is therefore very suitable for economic project evaluation.

The described findings are input for the next chapter which elaborates on methods such as real options analysis to include flexibility in project design and planning.

3. Literature review: Real options valuation & public transport policy appraisal

This chapter aims to find literature that helps to design and assess flexibility, in the form of real options, for public transport network design and planning. In order to assess the usefulness of incorporating flexibility in the design of public transport systems, more insight into how to incorporate and assess flexibility in projects is required. To find out which methods might be suitable for (public) transport projects, it is important to review previous studies regarding the application and evaluation of real options. This chapter helps to answer the following research question:

1. What kind of real options do public transport operators and other stakeholders have for the improvement of an urban public transport network?

The previous chapter described the stakeholders in public transport network design together with their objectives regarding this design. Moreover, the evaluation of public transport projects was discussed. Operators and authorities want to maximize cost-efficiency whereas the travelers want to minimize their travel time. To meet those objectives a balance has to be find. The cost-efficiency depends on the patronage and hence demand forecast is very important. If precise demand forecast is difficult, other methods have to be found to support operators in the planning of the urban public transport network.

This chapter focusses on methods to cope with the described uncertainty regarding future demand in urban public transport planning. First, the concept of real options theory is introduced. Real options theory offers a methodology to decrease financial risk related to investments by including flexibility in project design. A real option is defined as the opportunity to adapt a future decision to information and developments that are revealed in the future. This chapter continues by presenting a selection of previous studies that assessed real options in various sectors. Finally, the methods that exist to map and value real options are discussed.

The overview of the methods to map and value real options help to decide which methodology is suitable for application of real options analysis to urban public transport planning. Subsequently, this method can be used in our study for analyses in the case study.

3.1 Real options analysis

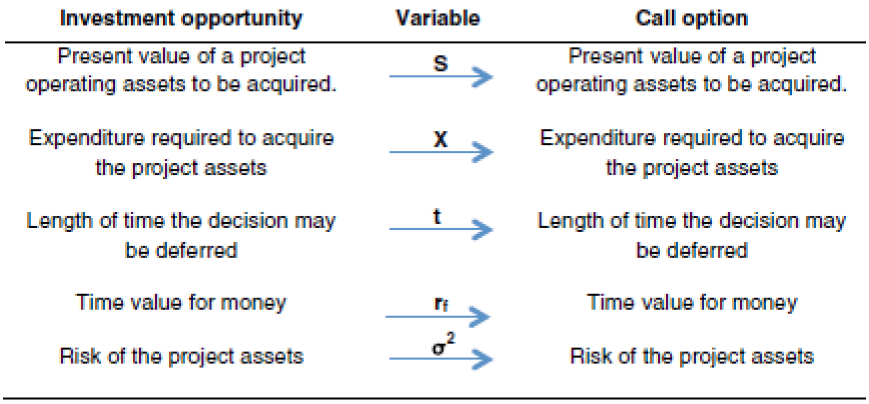
Decision-making about investments often has to deal with uncertain future market conditions, while the Net Present Value (NPV) rule and other discounted cash flow (DCF) approaches to compare investment alternatives require the assumption of perfect certainty of project cash flows. These methods cannot properly capture management's flexibility to adapt and revise future decisions in response to unexpected market developments (Trigeorgis, 1999). The Real Option Analysis approach explicitly recognizes that future decisions designed to maximize value will depend on new information (like changes in financial prices or market conditions) that is acquired over the course of time or through some exploratory investment (Alex Triantis & Borison, 2001). Instead of forecasting, real options analysis helps decision makers to create opportunities that can be used in the future when uncertainty is resolved. The main questions that real options theory attempts to answer are (Johnson, Taylor, & Ford, 2006):

- What are the future alternative actions?
- When should one choose between these actions to maximize value, based on the evolution of the key variables?
- How much is the right to choose an alternative worth at any given time?

i. Real options in relation to investment opportunities

The real option analysis and valuation emerged from the financial option analogy (Andrea, 2016). This approach has been used in the business environment since the 1970’s to assist in decision-making about investments (CPB, 2017). Real options and investment opportunities have several similarities (Luehrman, 1998). In his research (Luehrman, 1998) argued that a corporate investment opportunity is like a call option because the corporation has the right, but not the obligation to acquire something. This means that if a call option can be found sufficiently similar to the investment opportunity, the value of the option will tell something about the value of the opportunity. The only reliable way to find a similar option is to construct one. In order to construct an option it is required to find a correspondence between project’s characteristics and the five variables that determine the value of a simple call option on a share of stock. Luehrman (1998) linked the variables of a call option to the variables of an investment opportunity and gives the following explanation for the similarities.

“First, the investment is a certain fixed amount of money: the exercise price X of the option. Second, the present value of the asset to acquire corresponds to the stock price S. Third, the time for which each investment can be deferred without losing the opportunity resembles the option’s time to expiration t. The uncertainty concerning the future value of project cash flows corresponds to the standard deviation. Finally, the value of money is represented by the risk-free rate of return in both cases.” (Luehrman, 1998) This information is illustrated in Figure 3-1.



Investment opportunity	Variable	Call option
Present value of a project operating assets to be acquired.	S →	Present value of a project operating assets to be acquired.
Expenditure required to acquire the project assets	X →	Expenditure required to acquire the project assets
Length of time the decision may be deferred	t →	Length of time the decision may be deferred
Time value for money	r_f →	Time value for money
Risk of the project assets	σ^2 →	Risk of the project assets

Figure 3-1 Mapping an investment opportunity onto a call option. Adopted from (Luehrman, 1998)

3.1.2 Type of real options

Seven categories of real options can be identified. The type of options grants a specific type of flexibility, being upward potential or downside protection. A real option provides: “*The flexibility arising when a decision maker has the opportunity to adapt or tailor a future decision to information and developments that will be revealed in the future. A real option conveys the right, but not the obligation, to take an action (e.g., defer, expand, contract, or abandon a project) at a specified cost (the exercise price) for a certain period of time, contingent on the resolution of some exogenous (e.g., demand) uncertainty*.” (Chevalier-Roignant, B., & Trigeorgis, 2011).

Table 3-1 provides an overview of the categories of options, an explanation of those options, the fields of application, the type of flexibility the option grants, and the publications about the application of those options.

Table 3-1 Type of real options. Revised and adopted from (Andrea, 2016); (Triantis, 2003).

Option category	*Description*	*Fields of application*	*Type of flexibility*	*Publications*
Option to defer	Possible future conditions may be preferable comparing with the present situation. This option exists when management is able to leave an open door to investment opportunities, deferring the investment waiting for a better opportunity to capitalize.	Natural resource extraction industries, real estate developments, agricultural industries, paper products	Upside potential	Tourinho (1979); Titman (1985); McDonald and Siegel (1986); Paddock et al. (1988); Ingersoll and Ross (1992); Anderson (2000)
Option to abandon	When market conditions take an unfavourable turn, the company can terminate its operations, sell the project, and realize the residual value.	Capital intensive industries, financial services, new product introductions in uncertain markets	Upside potential	Myers and Majd (1990); Berger et al. (1996); McGrath (1999); McGrath and Nerkar (2004)
Time-to-build option, staged investment sequential option	There is an option to abandon the project while it is in progress in case the new information is deemed as unfavourable. The commencement of the individual phases is conditioned on the success of the previous phase. It can be interpreted as a serious of successive options.	All the R&D intensive sectors, especially the pharmaceutical industry; capital-intensive projects calling for long-term development (e.g. large-volume construction works, power plants); startup of risky enterprises	Upside potential and downside protection	Majd and Pindyck (1987); Carr (1988); Trigeorgis (1993); Kemna (1993); Perlitz et al. (1999); Loch and Bode-Greuel (2001); Lint and Pennings (2001); MacDougall and Pike (2003)
Growth options	An earlier investment is regarded as the precondition of another project. The success of the initial investment can open up new, future investment options for the company.	Infrastructure-based or strategic industries: especially high-tech, R&D, where there are complex product generations; strategic acquisitions; multinational activities; organizational capabilities	Upside potential and downside protection	Myers (1977); Kester (1984); Trigeorgis (1988); Pindyck (1988); Brealey and Myers (1991); Kester (1993); Borissiouk and Peli (2001); Tong and Reuer (2006); Brouthers and Dikova (2010)
Option to alter	Under favourable market conditions, the company can extend the lifecycle of the project, increase the size of series production or accelerate resource utilization. On the other hand, in unfavourable situations, the company may cut back production, or even suspend production temporarily in justified cases.	Natural resource extraction industries (e.g. mining); design of equipment and construction in cyclic industries; fashion products; consumer goods; commercial properties	Upside potential and downside protection	McDonald and Siegel (1985); Brennan and Schwartz (1985); Trigeorgis and Mason (1987); Pindyck (1988); De Neufville (2003); Chung et al (2010)
Flexibility option, option to switch, , input and output	Under conditions of production flexibility, in case there are changes in the prices or demand, the management of the company can change the output structure, product structure (production flexibility) or make the same products with the use of different types of inputs (process flexibility).	*Output changes*: In the case of products that are sold in small volumes, or attract fluctuating demand (electronics; toys; automobile parts) *Input changes*: electric power; agricultural crops; chemicals; raw materials requiring mechanical processing, pending opportunities	Downside protection	Margrabe (1978); Kensinger (1987); Kulatilaka (1988); Kulatilaka and Trigeorgis (1994); Lieblein and Miller (2003); Mol et al (2005)
Compound option	Options or option chains associated with other options. Because of the	Most of the real projects in the above-mentioned industries.	Upside potential and downside protection	Brennan and Schwartz (1985); Trigeorgis (1993);

	mutual dependencies, the values of	Kulatilaka (1994); Schwartz

b. Valuation of real options

At the start of a project it might be unclear how high the demand will be and where it will focus on. Keep options open until more information is available has an economic value. An important feature of real option theory is that it explicitly values flexibility (in project design). The option value is the reward for waiting for new information.

Literature describes five main techniques for the valuation of options: the Black-Scholes Option Pricing Model (BSOPM), the Binomial Option Pricing Model (BOPM), the Risk-Adjusted Decision Trees (RADT), the Monte Carlo Simulation (MSC), and finally, Hybrid Real Options (HRO) (Martins et al., 2015). All these models have their advantages and disadvantages.

3.2.1 Continuous contingent claims methods: Black-Scholes Option pricing model

The continuous contingent claims methods determine the value of a financial or real option using an equation consisting of a few variables. The Black-Scholes option pricing model is the most famous example of such a method. The Black Scholes equation refers to a financial call option of the European kind, which means the option provides the right but not the obligation to buy a certain share on a predetermined date for a predetermined price. The option price follows from (i) the price of the share, (ii) the exercise price (i.e. price it can be sold for), (iii) the discount factor, (iv) the volatility of the price of the price of the share and (v) the time until expiration of the share.

The main limitation of the model and hence often a disadvantage, is that it requires several assumptions to become applicable (Martins et al., 2015). This model can only be implemented if the options are European (call and put) since it requires a fixed decision date. Moreover, the variables need to follow a normal distribution, while most variables don't. Furthermore, the price process needs to be continuous. In fact, this model is a limiting case of the binomial option pricing model, that will discussed next.

3.2.2 Discrete contingent claims methods: Binomial option pricing model

The most famous discrete contingent claims models (or lattice model) is the binomial model from Cox et al. (1979) for American call options in discrete time. In contrast to the Black-Scholes model, the option can be exercised before the expiration date of the call option.

It works as follows: "The asset has an initial value X. In the next time period, its value either moves upward, being multiplied by u with a probability of Þ, or downward, being multiplied by d with a probability of 1 − Þ; the underlying asset can take only one of two possible values (binomial). In the following period, the value may have one of the following values: Xu2, Xud, or Xd2. By allowing a sequence of periods with such binomial movements, a large set of paths (a binomial tree—see Figure 3-2) can be generated and will closely approximate all the possible value changes that would occur to the underlying asset during the life of the option" (Arnold, Crack, & Schwartz, 2007).

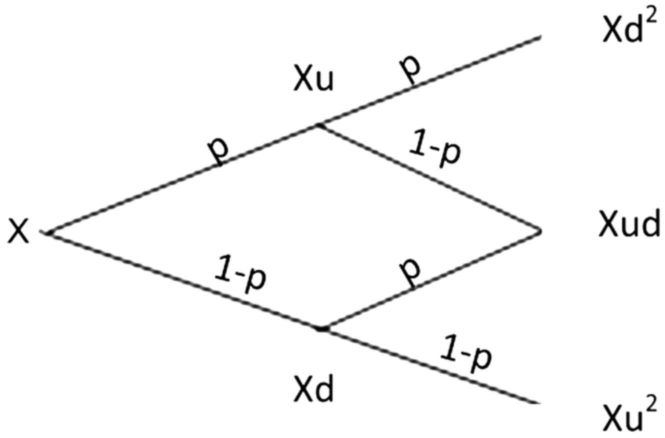


Figure 3-2 Binomial tree example. Adopted from (Martins et al., 2015)

The following advantages and disadvantages of the Binomial option pricing model are described by Martins et al., (2015). The most important advantage of the binomial model is the effectiveness in case of only one uncertainty. However, it is difficult to apply in case of several uncertainties at the same time. On the other hand, it does allow for estimating the value of several option futures, including the early exercise of an American option. Another disadvantage is that, just as for the BSOPM, the model is not easy to use, because it requires advanced financial knowledge. Comparing these two models, the Binomial Model can be defined as a simplified discrete-time approach to the valuation of options compared to the BSOPM (Cox & Ross, 1979). Looking at the use in practice of these models, Triantis (2003) stated that "the Black-Scholes and binomial option valuation models are widely used in practice for valuing growth options."

3.2.3 Risk-adjusted decision tree

A relatively easy method to evaluate real options is decision tree analysis. This method involves an analysis of investment decisions based on a simple decision tree that contains probabilities for the possible future scenarios. The decision tree can be constructed with either one or multiple decision moments. In order to analyze flexibility, such as delay or phasing options, a decision tree with at least two decision moments is required (Van der Pol et al., 2016).

The decision event tree is a computational decision model shaped like a network with a tree structure. The decision event tree contains three types of nodes (Bots, 2014):

- Decision nodes: represented by squares. Branches departing from this node provide alternative choice options.
- Probability nodes: represented by circles. Branches departing from a decision node show alternative events. To each of these branches belongs a probability (a number between 0 and 1). The probabilities are inserted into the model as input variables.
- End nodes: represented by triangles. At every end node a numerical value for the decision criterion has to be given.

The decision tree model has an implicit time dimension: the branches of the tree indicate sequentiality from left to right. The root of the tree, the first square from the left, shows the now to be made decision. Every path from this root until an end node described a potential future. The criterion value at the end node indicates how the decision maker values the end situation. To determine the optimal choices for every branch the expected criterion value has to be calculated (from left to right) (Bots, 2014).
When the NPV is used as criterion value, the expected NPV per alternative are calculated as follows. The expected NPV (net present value of the cost and benefits) of the cheap alternative

(here called X) follow from the sum of the scenario probability times the scenario outcome (NPV) . Formalized this means:

$$E(N\mathrm{PV}(X, S)) = PA + (1 - P)B, \quad (3\text{-}1)$$

in which S is the set of high and low scenario

The expected NPV of alternative Y is:

$$E(\mathrm{NPV}(Y, S)) = PC + (1 - P)D \quad (3\text{-}2)$$

The investment with the highest expected NPV is given by:

$$\max_{x,y}\{E\big(NPV(X,S)\big), E\big(NPV(Y,S)\big)\} \quad (3\text{-}3)$$

Decision tree analysis has many advantages. First, decision tree analysis can deal with multiple uncertainties, but it also enables decision makers to develop insights about real options (De Neufville, 1990). Moreover, it can estimate the approximate value of flexibility in projects with sequential decision opportunities and variable outcomes over time. However, a disadvantage is that it can become too complicated to interpret the results if more and more branches of the decision tree are developed (De Neufville, 1999). In contrast to the previously discussed contingent claims methods, decision tree analysis can be used for decisions in which a drastic change in the system occurs, and it is not necessary to possess as much financial knowledge (Martins et al., 2015).

Moreover, decision tree analysis can deal with risk and uncertainty in multiple ways. The analysis can be executed without allocating probabilities to the scenarios hence looking at the result of the branches, The decision tree analysis can be used as break-even analysis tool and thirdly it can be used by explicitly allocating different sets of scenario probabilities.

This method also has some disadvantages as argued by (Martins et al., 2015). First of all, when many branches of the tree are developed, it becomes too difficult to interpret the results. Moreover, decision tree analysis provides an approximation of the value of flexibility, but not the true value.

3.2.4 Monte Carlo Simulation

In contrast to the previous methods, Monte Carlo Simulation is a simulation model. A number of different values for the underlying uncertainties are generated based on distributions that are adjusted for systematic risk. The expected value of the option is then calculated, and a risk-free rate is used to discount this expected value back to the initial date (Triantis, 2003).The optimal strategy investment is determined at the end of each path, where the payoff is calculated.

Just like decision tree analysis, the Monte Carlo Simulaton methodology is able to deal with several uncertainties. Besides, it can deal with path-dependency future outcomes or decision depend on decisions made at earlier points in time (Baldwin & Clark, 2000). Furthermore, the possibility large construct large computer simulations easily and the ability to use spreadsheets, such as Microsoft Excel, to conduct the method make the model user-friendly (Clemen, 1996). Although the results are simple to explain graphically, the model may lack some transparency compared to binomial option pricing models and decision tree analysis.

In addition, it is a hard methodology to implement since simulation models use a subjective discount rate (as referred to previously) and do not incorporate financial market information (Clemen, 1996).

3.2.5 Dynamic programming

Dynamic programming (Bellman, 1954) is a solution method for a mathematic problem. This method can be used to determine the optimal investment per period and per scenario/possible future given ex-ante estimated future uncertainty and flexibility in the various investment strategies (Van der Pol et al., 2016). Dynamic programming can also be used to determine the value of flexibility given a certain problem statement. In contrast to contingent claims method, dynamic programming does not require replicating portfolio techniques or risk-neutral valuation. This means the method uses an exogeneous discount factor without the assumption of a complete market to determine risk margins.

Dynamic programming can be used to identify the optimal investment strategy if:

- There is no analytical solution for the cost-benefit problem.
- The problem is not suitable for contingent claims methods.
- A detailed economic analysis of flexible investment strategies is desired.

3.2.6 comparison valuation techniques

The practical implementation of decision tree analysis compared to other real options methods is discussed in (Van der Pol et al., 2016). This section describes the conclusions from this report.

Relation with MKBA, transparency and accessibility

Simple decision tree analysis is easy to implement in a standard SCBA using a few alternatives and a limited sensitivity analysis for a few uncertainties. Moreover, this method is transparent and accessible. The method and the assumptions are understandable for users with limited mathematical knowledge. The results are relatively easy to recalculate and to use in public discussions. The other methods have very technical assumptions and the function is complex.

Ease of implementation

Simple decision tree can often be constructed on main lines using societal cost benefit analysis. Contingent claims methods use standard models and the required input can be estimated relatively easy using historical data. Also Monte-Carlo simulation is relatively easy if suitable software is used. In contrast to the other methods, no standard implementation is available for dynamic programming.

Realism

A simple decision tree is only capable of including a limited number of decisions and scenarios. De indicative option value that can be obtained based on simple decision tree analysis is very rough.

Contingent claims methods are characterized risk-neutral price valuation. This requires the availability of a clear and present value of the underlying product. Clear and present values of underlying variable do not always exist for public infrastructure like roads, overpasses, tunnels, bridges, locks and dikes.

Historical volatility of road traffic can be estimated properly using historic traffic data. An important point of discussion is whether the assumption justifies uncertainties in scenarios such as the growth of cities. The size of a city has a major impact on the crowdedness on the road and hence the potential travel time savings.

For wet infrastructure volatility of variables is hard to determine since climate change is one of the most important uncertainties in wet infrastructures and the impact on floods are uncertain. Therefor the assumptions of contingent claims methods are unrealistic for water infrastructures.

3.3 Conclusion

This chapter aimed to scope the research by discussing possible option valuation techniques and their suitability for integration with appraisal methods for public transport projects. It was found that decision tree analysis is a real option valuation technique that can be used in combination with societal cost benefit analysis. This is a key finding which is very relevant for the practical application of real options analysis to urban public transport development. Contingent claims methods are found to be suitable for road infrastructure projects, except if growth of cities plays an important role. Since growth of cities is an important factor for the development of urban public transport networks, contingent claims method may not be suitable for our study. For wet infrastructures the contingent claims methods are found to be not suitable due to the nature of uncertainty that is affecting the benefits of projects, namely climate change. If the relevant uncertainties within an investment decision do not follow normal distributions, the contingent claims methods are not applicable.

Among the existing real options the option to defer, the staged investment option and the growth option seem to reflect the real options in public transport network design best. Staged development of public transport can be explained as the construction of a BRT or LRT system on a section in two (or more) steps. The construction of BRT or LRT can be executed in phases by starting with the construction of the first part of a section and later on extend the system with the construction of the final part of the section. There is also an option to defer the construction of the second part of the section. BRT is also seen as a stage of construction of LRT. Besides expanding the system by constructing the second part of the section, it can also be chosen to increase the capacity of the system by transforming BRT into LRT, which can be interpreted as a growth option. These outcomes are input for the next chapter: methodology.

4. Methodology

This chapter aims to specify the research methodology based on the findings from the literature review in chapter 2 and 3. The introduction chapter already proposed and described the methods ‘literature review’ and ‘case study. The previous chapters provided a theoretical framework for the design and analysis of flexibility in urban pubic transport projects. This chapter presents the methodology, based on the theoretical framework from chapter 2 and 3. The following methods are used to answer the research questions and will be discussed afterwards:

1.	Societal cost benefit analysis	Evaluation of planning strategies for urban public transport development
2.	Decision event tree analysis	Evaluation of flexibility and valuation of real options
3.	Interviews/workshop/ brainstorm	Design of planning strategies including real options for the case

The research approach for the case study is based on the 8-step plan for incorporating flexibility in societal CBA’s by CPB (2017) shown in Figure 4-1. This section starts with a description of the 8-step plan, followed by a description of how the literature review helped to complete the 8-step plan by specifying the methods used for step 3,4,5, and 6.

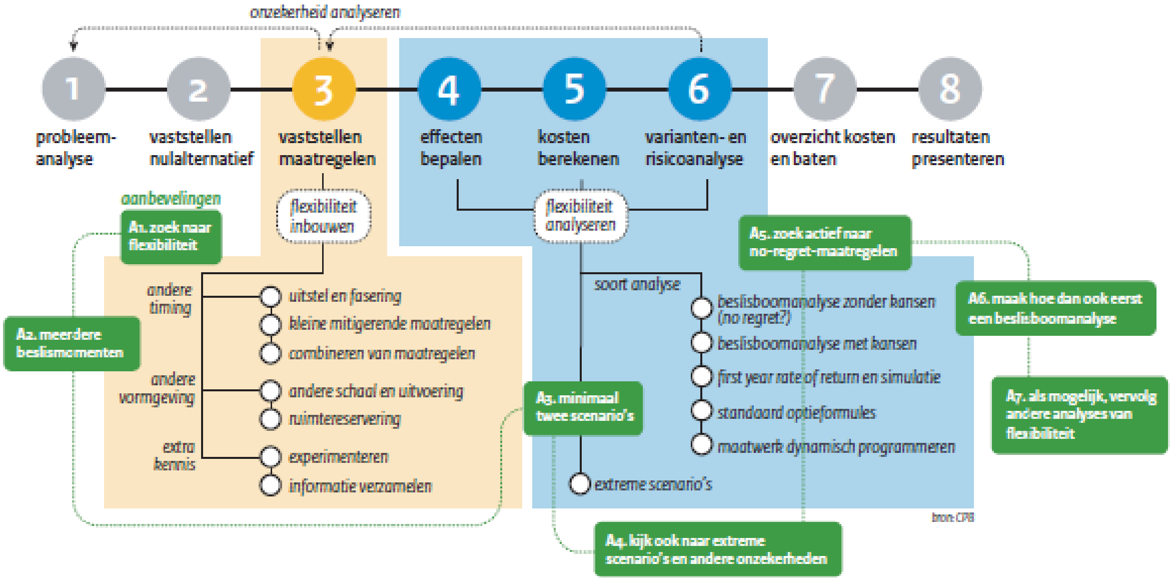


Figure 4-1 Flexibility in the 8-steps plan for societal CBA’s (adopted from (CPB, 2017))

The following steps can be distinguished within the 8-step plan in Figure 4-1. The analysis starts with a problem analysis (step 1), followed by a definition of the reference situation (step 2). Thirdly the flexible measures have to be defined (step 3) to incorporate flexibility in the investment strategies. Within this step it is necessary to account for uncertainty. In step 4 analysis of flexibility starts. This can be done in three steps: Determine effects of measures (step 4), then calculate the cost of the measures (step 5) and finally perform a risk analysis (step 6). After the analysis steps an overview of the cost and benefits is created (step 7) and the results of the analysis are presented (step 8).

The 8-step plan is not directly applicable to a case. Some steps have to be specified first. In order to perform step 3 (build in flexibility), the information from chapter 2 about measures to improve urban public transport networks was required. In order to analyze flexibility and hence perform step 4,5 and 6 the findings from chapter 2 and 3 were required.

4.1 Incorporating and Analyzing flexibility

In this study it is chosen to apply decision event tree analysis in combination with societal cost benefit analysis for the evaluation of planning strategies. Decision tree analysis is useful in two phases of the research. Firstly it is used to map strategies and visualize uncertainties. Secondly decision event tree is used to evaluate sequential decisions for a set of scenarios.
Among the reasons to choose decision event tree analysis instead of the other techniques for option valuation are that it can deal with multiple uncertainties and that it enables decision makers to develop insight about real options. Uncertainty in future travel demand does not meet the assumptions required for other option pricing models such as the binomial option pricing model.
From the literature review it was found that transport projects can be evaluated using societal cost benefit analysis. From this analysis one final indicator per project can be defined: the net present value. Multiple societal cost benefit analyses can be conducted in order to obtain one NPV for each planning strategy per scenario.
The next sections will describe how a decision tree is constructed and describes the steps involved in the process.

Construction of the decision event tree

This section describes how a decision tree is constructed. Figure 4-2 shows an example of a decision tree for a case with two decision moments, two project alternatives and two scenarios.

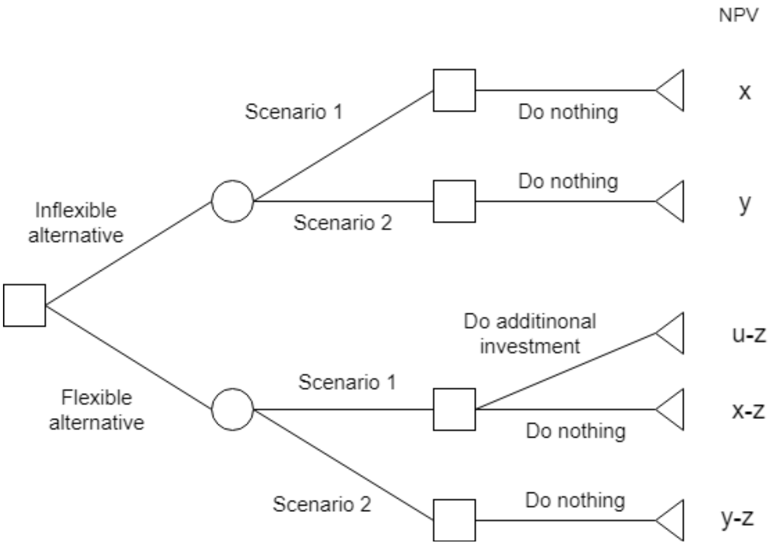


Figure 4-2 Decision tree analysis with two decision moments, two project alternatives and two future scenarios

A more detailed procedure for developing the decision event tree for infrastructure projects is provided by (Bos, van der Pol, & Zwaneveld, 2016). This is mapped in Figure 4-3 and described below.

1. Draw up simple decision tree:
    a. Inventory of investment alternatives and possibilities for flexibility, with the help of an extensive decision tree.
    b. Draw up simple decision tree including important decisions and at least two decision moments.
2. Draw up simple scenario tree:
    a. Inventory of uncertainties and scenarios and at which moment in time important information becomes available. Hereby not only a high and a low scenario should be considered but also more extreme scenarios and other uncertainties
    b. Draw up simple scenario tree with most important uncertainties and scenarios
3. Combine decision tree with scenario tree, possibly including new investment alternatives that better respond to uncertainties and scenarios
4. Calculate outcomes for every branch and scenario, possibly supplemented with a break-even analysis or a sensitivity analysis. This gives an indication of the value of flexibility and might lead to a more detailed analysis of uncertainties and other alternatives, for instance an earlier or later decision moment depending on the identified tilting points of costs and benefits.
5. Determine the preferred alternative. This is the strategy with the highest Net Present Value.

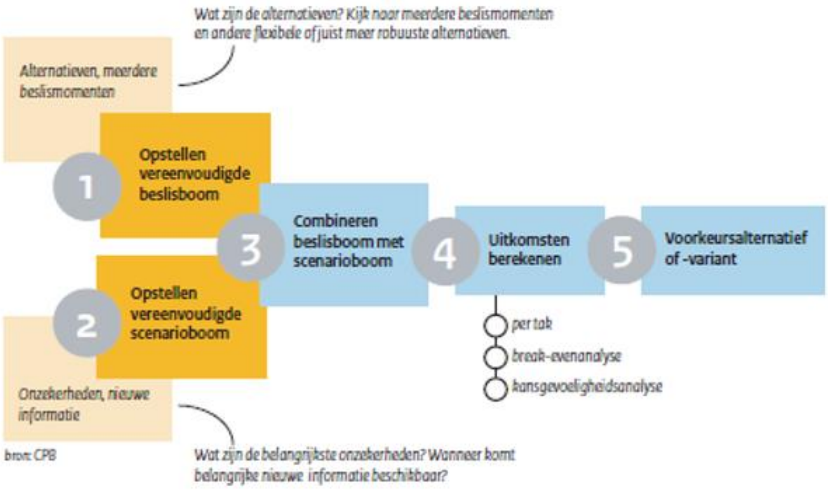


Figure 4-3 Stepwise procedure for building a decision tree, adopted from (Bos et al., 2016)

Step 1 and 2: Design of investment alternatives and scenarios

The first step in the construction of a decision tree is to make an inventory of investment alternatives and the possibilities to include flexibility. These investment alternatives are designed in cooperation with mobility advisors from RET and based on their insights and an analysis of the case study area.

The second step in the process of constructing a decision tree is to make an inventory of uncertainties and scenarios. The purpose of including flexibility in project design and planning is to tailor decisions to future developments of external factors that cause uncertainty in project evaluation. Therefor the external factors creating risk have to be identified and translated to scenarios that can be used to develop flexible strategies.

For the construction of scenarios documents published by the municipality are consulted of which mainly the OV-Visie 2040 for the city of Rotterdam. Those documents provide an overview of plans for the future regarding urban development. Those plans consist of factors creating uncertainty for the future. If, when and how the plans within the documents will be implemented eventually is uncertain. Therefor relevant events in the document are used to create scenarios which differ in the time of implementation or even in if they will be implemented or not.

Classification of uncertainties

To make a selection of external factors for this study two approaches are used:

1. Based on the expected impact on the benefits of interventions in the network development strategies
2. Based on the type of uncertainty the event/factor is related to. Three types of uncertainty are distinguished by (Bos et al., 2016):
   a. future uncertainty,
   b. knowledge uncertainty,
   c. and policy uncertainty.

Future uncertainty is the type of uncertainty of which the risk can be mitigated by flexibility using phased or delayed strategies. Hence the plans of the municipality containing future uncertainty are selected for the creation of scenarios.

The final outcome of this step are scenarios of which every scenario includes another future development of uncertain (external) factors. Every scenario actually consists of two in time succeeding set of events. Every set of events consists of the development of a selected set of external factors.

Step 3: Design of planning strategies including flexibility

After making an inventory of the investment alternatives and the uncertain factors, investment strategies can be defined to adapt investment towards future development of uncertain factors. In order to design the investment strategies for the development of the network a brainstorm workshops with experts from RET is performed. Theoretical real options (categories) such as phased investment are obtained from literature, but the translation of phased investment into public transport network design is made using the insights of experts. Brainstorm sessions are held to find out what experts would change in the transport services in different scenarios. The final selection of investment strategies varying in their degree of flexibility is designed using a decision event tree. This method helps to get insight in the available real options.

4.2 Quantification of the planning strategies: Societal cost benefit analysis

After the decision tree is constructed, the next step is to calculate the decision criterion per branch (investment alternative) and determine the optimal investment strategy.

Based on literature review the net present value (NPV) is chosen as the decision criterion within the decision tree analysis. The net present value per strategy is determined using societal cost benefit analysis. Societal cost benefit analysis evaluates the strategies by monetizing the most relevant direct and indirect wealth effects. The NPV of an investment alternative depends on the future scenario. The NPV is calculated per investment alternative for a set of scenarios. In practice this means the cost and the benefits are calculated per strategy for different scenarios. The final outcomes of the analysis are the cost, the benefits, the NPV and cost-benefit ratio per alternative per scenario. Each branch of the decision tree is quantified.

This section starts with a description of how cost and benefits realized by projects at different moments in time can be made comparable. Next follows a description of the indicators used for societal cost benefit analysis in this study. More details about the operationalization of indicators per alternative for each scenario can be found in chapter 5. After the description of indicators this section will continue with an explanation of the data collection method. Finally, this section ends with a description of the methods and tools that are used to calculate the option value per strategy.

4.2.1 Discounting cash flows and the discount factor

Transport project generate cost and benefits up until far in the future. However, one euro received in a future year t does not have the same value as one euro possessed at this moment. To make all the future project effects comparable and assess the total project value it is necessary to discount these effects using a specified discount factor (C. J. J. Eijgenraam et al., 2000). Every cost and benefit generated by a project are discounted and combined in to one indicator: the net present value (NPV). For a project j this is calculated as shown in equation 4-1.

$$NPV(j) = \sum_{t=0}^{T_j} \frac{B_{jt}-C_{jt}}{(1+r)^t} \qquad (4\text{-}1)$$

Where
t = year
T = project lifetime
r = discount factor
B = Benefits
C = Cost

The correct discount factor depends on the return of investment if the financial resources would be used for alternative purposes. The discount factor used in projects differs per country and varies between 3% and 8%. When determining the discount factor to be used for Dutch Government projects the Council of Ministers assumed the average real interest rate on 4% the international capital market applies to risk-free long-term loans (C. J. J. Eijgenraam et al., 2000). For this study it is chosen to use a discount factor of 4,5%.

For this study a project lifetime of 20 years is chosen. Due to long lifespans of projects, it necessary to decide upon a time horizon for the assessment of project effects when performing societal cost benefit analysis (C. Eijgenraam, Koopmans, Tang, & Verster, 2000).

4.2.2 indicators for the SCBA Assessment framework

This section provides a motivation and description of the effects/indicators included in this study. Chapter 2 presented a complete list of indicators described by literature to measure the total effect of transport projects in societal cost benefit analysis. Due to limitations in time and available data a selection of these indicators is made for case study. The most important benefits of public transport projects are the travel time savings and the travel costs savings (including reliability and comfort). These direct effect provide prosperity and can be monetized. The cost mostly comprise of investment cost and maintenance cost. The balance of operations can either a cost or a benefit depending on the situation. Table 4-2 shows which effects (or indicators for the NPV) are included within this study. This section follows with a description of how these effects are calculated and monetized.

Table 4-1 Indicators for cost and benefits included in case study

Direct effects for the traveler	
Accessibility beenfits (waiting time, travel time and reliability)	
Comfort during travel time	- per mode/service (for example railbonus)
Direct effects for the infrastructure manager and the operator	
Balance of operations	Passenger revenues minus cost of operations
Investment cost	- Including estimation uncertainties - Including decision uncertainty - Including ‘optimism bias’
Maintenance/management cost	
External effects	
Emissions, local	From PT, walking, (moped)bicycles, motor and car
Emissions, global	Idem

4.2.2.1 Direct effects for the traveler

This section elaborates on the calculation of the direct effects for the traveler. For this study it is chosen to include travel time savings and reliability benefits.

The total journey from origin to destination consists of several elements. The total travel time can be decomposed into access time to a stop, waiting time, in-vehicle traveling, transfer time, and egress time. Travelers do not value every element of their trip equally. The valuation per element relative to the in vehicle time found in Dutch studies is shown in Table 4-2. The costs of a trip are the generalized cost, containing the in-vehicle time, waiting time, number of transfers and the fare.

Equation 4-2 shows the generalized cost function of public transport users in case of no transfer. (In case of a transfer the transfer penalty multiplied by the number of transfers has to be added to the function as well as the time spent on each trip element). The generalized cost function consists of the generalized travel time costs, the ticket price and the mode specific constant. The total generalized cost consist of the generalized travel time, which is the travel time together with their perceived weights, multiplied with the Value of Time (VoT). All the time elements related to the total journey are stochastic in real-life due to variability of different trips in a single period and variability of a single trip over different days (van Oort, 2011). The stochastic variables are indicated with the ~ symbol.

Previous studies found a value of time of €6,75/hour for an average Dutch public transport user (KiM, 2013). (Within this thesis no distinction is made between the different type of travelers as it is unknown what the distribution of travelers is or will be.)

$$C = VOT * \left(\theta_1\, \tilde{T}_{l,j}^{waiting_{origin}} + \theta_2 * \tilde{T}_{l,j}^{access} + \theta_3 * \tilde{T}_{l,j}^{waiting} \theta_4 * \tilde{T}_{l,j-k}^{in-vehicle} + \theta_5 * \tilde{T}_{l,k}^{egress}\right) + TP + \Phi \qquad (4\text{-}2)$$

Where:

C = generalized passenger cost for public transport

VOT = average value of time for public transport passengers

$\tilde{T}_{l,j}^{x}$ = stochastic duration of travel time element X (on line l departing at stop j)

θ_x = relative weights of travel time component x

TP = ticket price

Φ = public transport mode preference constant

Table 4-2 Time valuation per element relative to in vehicle time

Trip element	*Valuation*	*Source*
Factor out-of-vehicle-time (waiting time)	2	(De Bok & Wesseling, 2017)
Factor first- and last mile	1,75	(De Bok & Wesseling, 2017)
Transfer penalty [min]	7,5	(De Bok & Wesseling, 2017)

Accessibility benefits are often the primary goal of transport projects (Bakker et al., 2009). Due to the accessibility benefits transport projects have the power to attract new users. New demand due to reduced travel cost can be calculated using elasticity models. The value of the elasticity variable depends on the situation. Equation 4.3 shows an elasticity model to predict ridership adopted from (van Oort, Brands, & de Romph, 2016)

$$D_{ij}^{1} = \left(E\left(\frac{C_{ij}^{1}}{C_{ij}^{0}} - 1\right) + 1\right) * \ D_{ij}^{0} \qquad (4.3)$$

With:

D_{ij}^{1} Demand on OD pair I,j in the scenario
E Elasticity
C_{ij}^{1} Generalized costs in the scenario
C_{ij}^{0} Generalized costs in the base scenario
D_{ij}^{0} Demand on OD pair I,j in the base situation

1. Travel time savings

The most important benefits of public transport projects are the travel time savings and travel cost savings. The travel time savings are calculated using equation 4.2. The generalized cost are calculated for the base scenario (reference alternative) and for the scenario in which the project is realized.

Rule of half

If a project leads to a change in generalized travel cost the change in consumer surplus is a good approximation of the benefits for the users (C. J. J. Eijgenraam et al., 2000). Improved transport systems do not only give benefits to the current users but also have the power to attract new users. The number of new users due to service improvements can be estimated using elasticities. Key figures are used for elasticity. The full travel times savings only hold for current travelers using PT. For new users (elastic demand in this study) the travel time savings are divided by two because of the rule of half (C. Eijgenraam et al., 2000). A general formulation for the total benefits (travel time savings) for both existing and new users is given by equation 4.4.

$$B = 0{,}5 * (Q^{0} + Q^{1}) * (P^{0} - P^{1}) \qquad (4.4)$$

Where:

B = Benefits (here travel time savings in minutes or hours)
Q^{0} = Travel demand base scenario, before the project
Q^{1} = Travel demand due to the project
P^{0} = Generalized cost in the base scenario (C instead of p in equation 4.4.1)
P^{1} = Generalized cost due to the transport project (C instead of p in equation 4.4.1)

The travel demand due to the project Q^1 may be calculated in two ways. The first way is using the elasticity model in equation 4.4.3. The elasticity value within this model is then specified for a Dutch urban public transport (BTM) case. PT travel time elasticity GJT on the number of PT trips is found to be -0,6 in the Netherlands for BTM to BTM (Warffemius, 2015). The second way to calculate future travel demand is using transport models in which elasticity models are incorporated.

2. Reliability benefits

The three most important effects of reliability of public transport are the average longer travel time, the deviation of the arrival time and the increase of crowding in the vehicle. In theory all these effects should be included in societal cost benefit analysis, but this study only focuses on the impact of unreliable PT on travel times. Van Oort developed an indicator, the average additional travel time per passenger, that indicates what the additional travel time that a passenger on average needs to travel from the origin to the destination stop due to service variability.

In order to calculate the additional waiting time component, two situations have to be distinguished: high frequency transit systems (with random arrivals of passengers at the stop) and low frequency transit systems (with planned arrivals of passengers at the stop) (van Oort, 2011). For high frequency services passengers do not use a schedule. In this situation, the additional travel time is calculated using the coefficient of variation (CoV) of the actual headways $\left(\tilde{H}_{l,j}^{act}\right)$. A mathematical formulation to estimate the expected waiting time per passenger is given by equation 4.5 adopted from (van Oort, 2011).

$$E\left(\tilde{T}_{l,j}^{waiting}\right) = \frac{E(\tilde{H}_{l,j}^{act})}{2} * (1 + CoV^2\left(\tilde{H}_{l,j}^{act}\right)) \qquad (4.5)$$

Where:

$\tilde{T}_{l,j}^{waiting}$ = passenger waiting time for line l at stop j
$\tilde{H}_{l,j}^{act}$ = actual headway of line l at stop j
$CoV^2\left(\tilde{H}_{l,j}^{act}\right)$ = coefficient of variation of actual headways of line l at stop j

The reliability benefits per trip are given by the product of the decrease of travel time variation per trip due to a project and the value of reliability (VoR). Multiplying this number by the annual number of trips made on the considered route gives the annual reliability benefits. Previous studies revealed that the average value of reliability among Dutch public transport users is €3,75 per per person per hour (KiM, 2013).

Besides the method described above using equation 4.5, also a more pragmatic method exists to calculate the reliability effect of replacing a bus by a tram. This method calculates the reliability effect per trip using average values for reliability of buses in the Hague found by (van Oort & van Nes, 2006). This study depicted that the average variability in travel time is 17,6 s/km for bus and 11,1 s/km for tram. The average savings of 6,5 seconds per km multiplied by the length of the route in km are used as reliability savings per trip. Multiplying the time savings by the Value of Relibaility (VoR) of €3,75 per hour gives the monetized benefits per trip.

3. Comfort benefits: Rail bonus

Replacing a bus system by a tram system might result in additional travelers due to the so called ‘rail bonus’. A study performed by (Bunschoten et al., 2013) showed that replacing a bus by a tram was equivalent to reducing the in-vehicle time by 22% and the total travel time by 12%. Multiplying these travel time reductions with corresponding elasticities resulted in an increase of patronage of 13%.

4.2.2.2 Direct effects for the infrastructure manager and the operator

This section elaborates on the calculation of the direct effects for the infrastructure manager and the operator. For this study it is chosen to include the balance of operations, the investment cost and the cost of maintenance. In order to determine the annual investment cost, maintenance cost and cost of operations key figures are used. An overview of these cost key figures can be found in

Table 2-6 in chapter 2.

1. Balance of operations

The balance of operations is the difference between the passenger revenues and the cost of operations. A distinction is made between public transport systems and bike sharing systems. Starting with public transport, this subsections first explains how to calculate the passenger revenues and subsequently describes the method to calculate the cost of operations. The next subsection describes the capital costs and the costs of operations related to bike sharing systems.

1.1 Public transport

Passenger revenues

The passenger revenues depend on the effect of a project on passenger demand for the service. The future demand can be calculated using the elasticity model in equation 4.4.3 or a transport model.

An average yield per trip is calculated for the RET using an average yield in € per km and an average trip length. The average yield per km is calculated by dividing the total passenger km's by the total passenger revenues for the year 2017 (RET, 2018). The average trip length is calculated by dividing the annual passenger km's by the annual number of people boarding over 2017. The outcomes are shown in Table 4-3.

Table 4-3 Parameter values for passenger revenues, based on (RET, 2018).

Parameter	Value
Average passenger revenue [€/trip]	0.22
Average trip length [km]	5.09

The passenger revenues from operating the interventions in this case study are calculated based on length of route for the different PT systems in the case study area, multiplied by the average revenue per trip, multiplied by the expected annual number of users of the route.

Operational cost

The operational cost consist of energy cost, cost of personnel and cost of the material as described in chapter 2. For the operational cost of bus and tram services DRU units are used and the cost per DRU. DRU stands for Dienst Regeling Uur (Schedule hour) and includes the cost for operating a bus or tram service for an hour given the frequency, the length and the travel time of the service. Key figures for the cost per DRU are used to multiply the number of DRU's and to obtain the cost of operating a certain service. The average DRU for bus and tram found in literature are respectively €108 and €207 per hour (CROW, 2015).

1.2 Bike sharing system

For shared bike systems slightly other aspects are considered to calculate the operational cost. The cost of a bike sharing system depend on the design. The operational cost of a bike sharing system depend on the following aspects: staffing, redistribution maintenance, control and customer service center, marketing and customer information, and insurance (anti-theft, accidents, vandalism). The capital cost occur annually and depend on the number of bikes, the number of stations, the software, and the control center, depot and maintenance and distribution units. The operational cost and capital cost are based on guidelines and key figures from existing systems in other countries.

For the societal cost benefit analysis the capital cost and the operational cost together with an expected revenue of €0,80 per trip. Based on the guidelines the BSS is assumed to have 200 bikes with yearly capital cost of €3000,- per bike. Furthermore it is assumed that 2 trips are made per day per bike.

2. Investment costs

The investment cost depend on the type of infrastructural adaptation. In this study investment cost are calculated by multiplying the cost in € per km for this infrastructural adaptation (see table 4.2.1) with the length of the route.

3. Maintenance costs

Key figures for the maintenance cost per km are used. These figures can be seen found in Table 4-4 (CROW, 2015).

Table 4-4 Cost structure

Topics		Bus	Tram
Infrastructure	Construction track Simple [mln € /km]	0,3 – 4 (simple) 4,7 – 12 (complex)	12 - 35
	Stops [x1000 €]		400.000 – 600.000
	Maintenance	1-2 % of construction cost (annual)	50.000 – 60.000

4.4.2.3 External effects

This section elaborates on the calculation of the external. For this study it is chosen to include the avoided emissions due to a modal shift from car to public transport.

1. Avoided emissions

Among the external effects are the avoided emissions of mode shift due to public transport service improvement. For this study These benefits are calculated using key figures (Table 4-5) for emissions obtained from (Schroten, van Essen, Aarnink, Verhoef, & Knockaert, 2014). The (average) marginal external cost for passenger cars is multiplied by the number of car users shifting to public transport due to the quality improvements. The number of car users shifting from car to public transport is calculated using cross elasticities. The cross elasticity that is used for the calculation is for PT to car 0,07 (Brogt, 2013).

Table 4-5 Parameters external costs (Schroten et al., 2014)

Parameter	Value
Marginal external cost passenger car gasoline [€/1000 rkm]	114 ((122+113+107)/3)
Marginal external cost passenger car diesel [€/1000 rkm]	113
Marginal external cost passenger car LPG [€/1000 rkm]	107

4.4.3 Data collection

- Travel times are based on timetables found online, Google Maps, and the transport model OV Lite.

- Current demand (current trips being made) is based on OV-chipcard data provided by RET. The current demand is used to calculate effects of projects for current users. The current demand also functioned as input for elasticity functions to determine the potential new trips due to projects.
- Concerning the calculation of costs, key figures from literature are used

4.4.4 Data analysis: Evaluation strategies and Option valuation

Finally, the value of the real options is approximated following the steps defined by (Van der Pol et al., 2016).

First, the NPV per branch is calculated using the indicators described in the previous section. In order to calculate the values for the indicators described in the previous subsection, a few methods were applied. Firstly, Microsoft Excel spreadsheets were used to combine all the information and to calculate the NPVs per indicator. In order to calculate travel time savings, Google Maps, time tables from the RET website, and OV-Lite was used.

$$NPV(j) = \sum_{t=0}^{T_j} \frac{B_{jt} - C_{jt}}{(1+r)^t}$$

Based on the NPV of each investment strategy per scenario, no-regret or low-regret investment decisions can be found (Van der Pol et al., 2016). The way to do this is by looking what the best strategy is per scenario. If the cheapest strategy has the highest NPV in every scenario, it is a no-regret strategy. If there is not such a no-regret alternative, further analysis into the probabilities for the scenarios is required to determine the best investment decision.

Decision tree analysis including a probability-sensitivity analysis

Finally, in order to determine what the optimal investment strategy when there is no no-regret strategy, the expected net present value for the flexible investment strategy as well as the inflexible investment strategy have to be calculated.

The decision tree uses nodes and branches to illustrate investment decisions that can be taken, the different possible future scenarios, and the outcomes dependent on those decisions and future scenarios. By assigning probabilities to the future scenarios, the expected value of every decision, and with that the expected value of the flexible options can be determined.

The expected net present value (NPV) of the investment strategies (j) are equal to the sum of scenario probabilities (P_i) multiplied by result ($V_j(s_i)$) given the scenario i for external factor s_i. For the inflexible strategy

$$E\left(NPV_{flex}\right) = \sum_{i=1}^{N} P_i * V_{flex}(s_i)$$

$$E\left(NPV_{Inflex}\right) = \sum_{i=1}^{N} P_i * V_{Inflex}(s_i)$$

The optimal decision for the flexible or inflexible planning strategy follows from:

$$\max_{\{flex,inflex\}} \{E(NPV_{flex}), (NPV_{inflex})\}$$

Scenario probabilities

To test the sensitivity of the outcome of the decision tree analysis for the scenarios, the outcome of the analyses is tested for different sets of probability distributions for the scenarios. Various sets of scenario probabilities are designed and used to calculate the expected NPV per strategy. This makes it possible to analyze the impact of the scenario probabilities on the preferred strategy. Within this study it is chosen to use equal probabilities and extreme probability distributions to test the sensitivity of the decision outcome for the scenarios.

Break-even point and option value

An illustration of how the option value can be calculated is given using Figure 4-4, which is based on an example from (Van der Pol et al., 2016), the expected NPV of the flexible strategy is P(x-z) + (1-P)(y-z). For the inflexible strategy the expected NPV is Pu + (1-P)y. Te expected value of flexibility is equal to P(x-u)-z

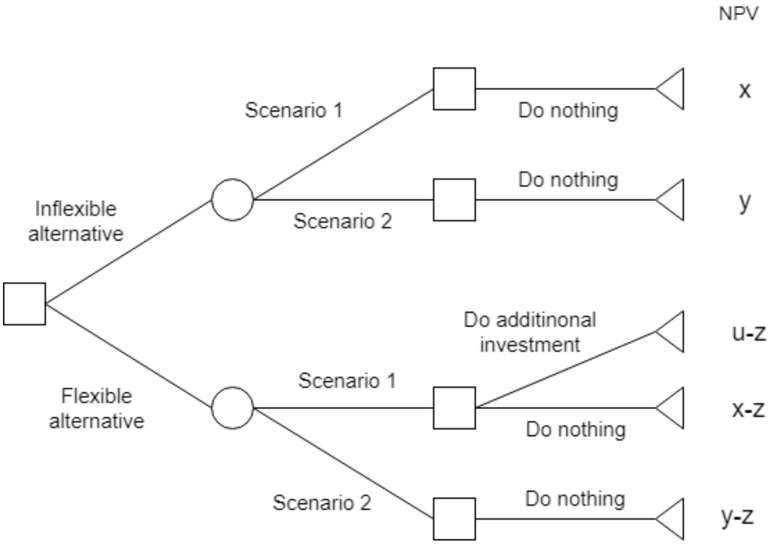


Figure 4-4 Decision tree analysis with two decision moments, two project alternatives and two future scenarios

To find out for which probability the additional cost and benefits of the flexible alternative are justified, the break-even point for this probability can be calculated.

P/(1-P) = z / (x-z-u)

4.3 Reflection on the usefulness of including flexibility

As a final step in research a workshop with experts is used to reflect on the qualitative and quantitative usefulness of the investigated method. During this workshop the tested method is compared to the current process.

4.4 Conclusion

This chapter aimed to specify the research methodology to incorporate and evaluate flexibility in urban public transport network development. Chapter 1 already proposed and described the methods ‘literature review’ and ‘case study. Chapter 2 provided a theoretical framework for the design and analysis of flexibility in urban pubic transport projects. This chapter presented the methodology, based on the theoretical framework from chapter 2 and 3.
The methodology consists of the following steps and corresponding methods:

Step 1: Construction decision tree
Step 1.1: Inventory of alternatives to improve the network
Step 1.2: Inventory of uncertainties
Step 1.3: Combine alternatives and scenarios and design planning strategies. Use real options categories and insight from experts.
Step 2: Evaluate the project alternatives and the planning strategies by calculating the decision tree using societal cost benefit analysis
Step 2.1 Determine which effects to include in the assessment framework
Step 2.2 Define methods to calculate the effects
Step 2.3 Data collection: how to gather date?
Step 2.4 Data analysis: calculate the NPV per alternative
Step 2.5 Data analysis: calculate the expected NPV per strategy (flexible versus inflexible strategy)

The next chapter focusses on step 1 (1.1., 1,2 and 1,3). In order to come up with flexible strategies in practice, a case study is used which will be introduced in the beginning of the next chapter.

5 Case study: design of Planning strategies

The previous chapter provided an overview of the research approach for the design and evaluation of flexible planning strategies in urban public transport. This section describes the design of planning strategies that make it possible to deal with uncertain future urban development. The planning strategies have to enable decision makers to improve the public transport system in Rotterdam in such a way that it meets the needs of the city and its travelers. This chapter focuses on step 1 and 2 in Figure 5-1 Stepwise procedure for building a decision tree, adopted from (Bos et al., 2016) and aims to answer subquestion 1:

1. What kind of real options do public transport operators and other stakeholders have for the improvement of an urban public transport network?

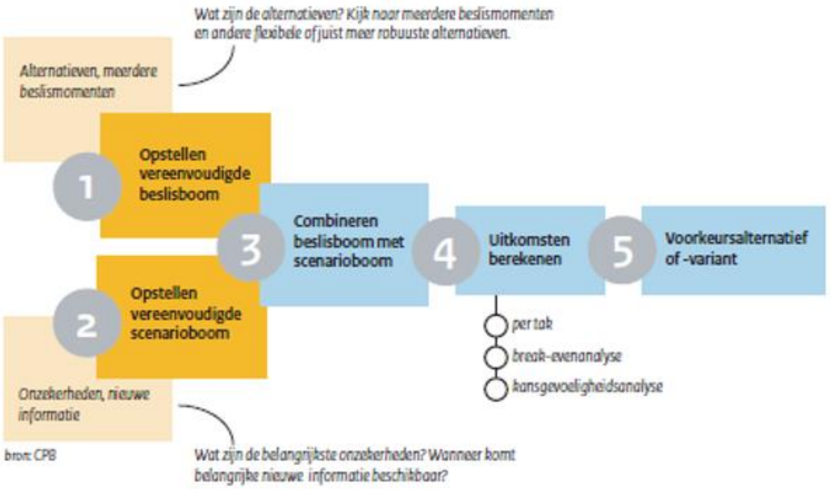
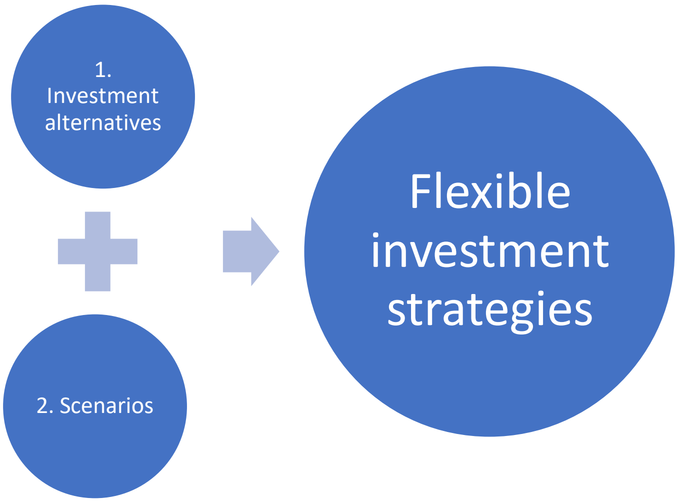


Figure 5-1 Stepwise procedure for building a decision tree, adopted from (Bos et al., 2016)

First, in section 5.1, this chapter provides some background information regarding the case and motivates the selection of this case. Then, in section 5.2, an inventory of investment alternatives is presented. Next, section 5.3 describes the selection of uncertain factors to which the real options should respond. The outcome of the literature review helps to define real options for development strategies for the public transport network. From the literature review it was found what the general type of real options are and how they are applied in previous studies. Moreover, the scientific literature pointed out the expected improvements for all stakeholders by developing a BRT or LRT system, especially in combination with shared bicycle systems. Based on those findings, section 5.4 presents the developed investment strategies by specifying the area and the corridor where a BRT or LRT system may be constructed within the selected case study..



The outcome of this chapter is used for the construction of the (unweighted) decision event tree.

5.1. Introduction case study

Just as for other urban areas all over the world, the population as well as the employment of the city of Rotterdam is expected to grow too. For the purpose of this growth 50.000 extra houses are required until 2040 within existing urban area. The mobility system of Rotterdam is currently almost reaching its capacity limits and with the foreseen growth this problem is getting bigger (Gemeente Rotterdam & MRDH, 2018). The municipality of Rotterdam desires a transition towards sustainable forms of mobility and the OV-visie Rotterdam 2018-2040 elaborates on this desire.
De kop van Feijenoord is an area in Rotterdam where many of the described urban development plans take place (**Fout! Verwijzingsbron niet gevonden.**). The area is marked as searching location for the construction of new houses and in response to those plans it is planned to upgrade the heavy rail connection going through the area (named the 'Oude Lijn'). All these plans create uncertainty for the profitability of the existing public transport services in the future (figure 2). Besides, the profitability of the public transport plans itself is also very uncertain and depending on the other developments.

Currently there are three (or four) public transport systems operating in the case study area (Figure 5-3),namely:

- Bus 32 (Blaak – Zuid)
- Bus 66 (Feijenoord – Zuid – Zuidplein)
- Heavy rail Sprinter (Blaak – Zuid – Lombardijen)
- (Bus 47 driving around Noordereiland)

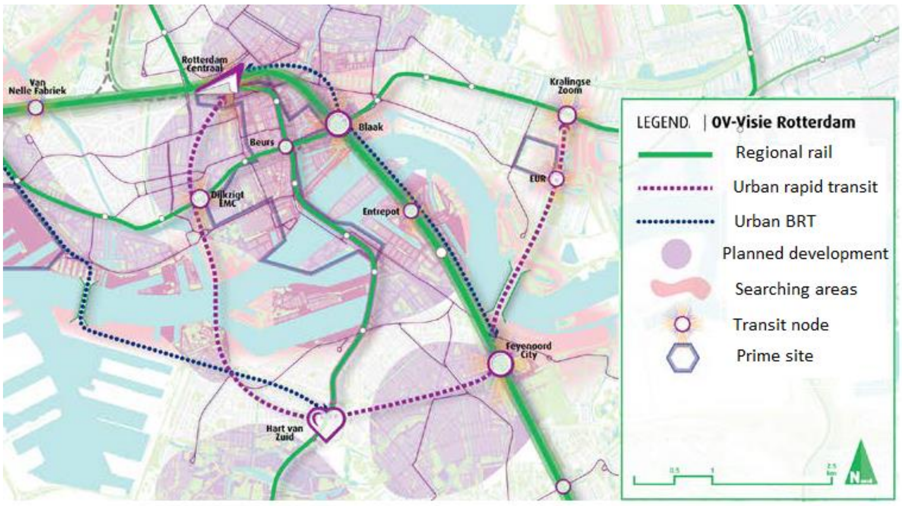


Figure 5-2 Public transport and urban development 2040. Revised and adopted from ***(Gemeente Rotterdam & MRDH, 2018)***

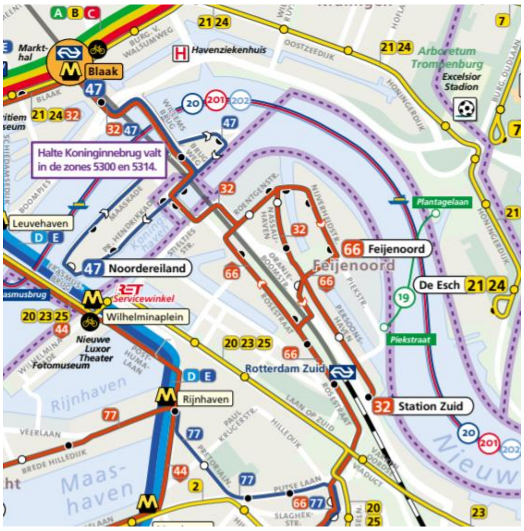


Figure 5-3 Public transport network: Part of network map of lines from RET. Adopted from (RET, 2019)

In order to provide some context, the main development plans are presented. The main source of these plans is the OV-Visie 2040 published by the municipality of Rotterdam and the transport authority MRDH. The OV-vise 2040 provides information concerning the development plans for the public transport system. The other sources that are used provide more detailed information concerning urban development plans such as locations for new houses. These sources comprise the Woonvisie 2030 and

5.1.1 Public transport plans

The OV-visie 2040 describes several public transport development plans for Rotterdam which should be implemented in phases until 2040 (Gemeente Rotterdam & MRDH, 2018). The plans concerned with the case study area are presented in Table 5-1. Besides the plans this table also provides and an indication of the time period it is supposed to be realized. As the time period is an indication it means it is uncertain when this plans will be realized if they will be. What now follows is a description of those plans.

Firstly there is the idea to transform the Oude Lijn, which is currently a heavy rail line, into a metro or an S-bahn type of system. At this moment NS is operating heavy rail on the Oude

Lijn. Secondly there are plans to build a railtangent to make a connection between metro station Dijkzigt, Zuidplein, the new to be build Feyenoord city station (Stadionpark) and Kralingse Zoom. This railtangent requires two new bank connection over water making it very costly and complicated. Thirdly there is an idea to replace station Zuid in northern direction to the kop van Zuid-Entrepot area.

Table 5-1 Planned measures in OV-visie 2040, Revised and adopted from (Gemeente Rotterdam & MRDH, 2018) .

Phase	Internvention	2018-2022	2023-2029	2030-2040	Na 2040
1	BRT Willemsbrug	X			
1	Versterken busstructuur op Zuid (bundelen en strekken)	X			
2	HOV-bus Maastunnel, Willemsbrug en Zuidplein-Feyenoord City	X	X		
3	Nieuwe Oostelijke oeververbinding + HOV-rail Hart van Zuid - Feyenoord City - Kralingse Zoom		X		
3	Uitvoering Programma Hoogfrequent Spoor: frequentie sprinters 6xpu + IC 8xpu (N.B. is referentie)		X		
3	Nieuw (lightrail) station Feyenoord City		X		
3	Nieuwe tramverbinding Hart van Zuid-Feyenoord City ('Coen Mou-lijn')		X		
3	HOV-rail nieuwe Oostelijke Oeververbinding (Hart van Zuid-Feyenoord City-Kralingse Zoom)		X		
4	Deels geautomatiseerde trams		X	X	
5	Verplaatsen bestaand station Zuid richting Entrepotgebied (nieuw lightrail station)			X	
5	4 sporigheid 12x/u, lightrail			X	

5.1.2 Other urban development plans

Besides public transport planning the OV-visie 2040 also reveals searching and planning locations for the provision of housing. The area of around the Oude Lijn within Feijenoord and Stadionpark are such locations. The urbanization plans within Rotterdam go along with the plans for the public transport networks and reinforce eachother according to the OV-visie 2040. Websites, such as the nieuwekaartnl.nl, provide more details concerning the exact locations where new houses might be build and also how many houses. An indication of the urban development with respect to houses to be built in Rotterdam can be found in Table 5-2. This table gives very detailed numbers obtained from (Nieuwe kaart van Nederland, 2019) regarding the neighborhoods in the case study area.

Table 5-2 Housing construction plans for urbanization Rotterdam

	Rotterdam Binnenstad	**Rotterdam Willemsas**	**Rotterdam Stadionpark**	***Rotterdam & Schiedam Stadhaven XL***	***Rotterdam & Schiedam Schieveste/ A20 zone***
2030+	*1900*	*290*	*800*	*1550*	*2830*
2025-2029	*550*	*320*	*590*	*1280*	*1140*
2018-2024	*8090*	*1030*	*1450*	*1600*	*1210*

5.2 Investment alternatives

This section provides an inventory of the public transport investment alternatives. As stated in the methodology chapter, the first step in constructing a decision tree is to make an inventory of investment alternatives (or in other words, the deicsions).

During the process of designing investment alternatives for the case study, the plans from the OV-visie are used as a guidance. Previous studies discussed in the literature review argued that BRT and LRT, especially in combination with bike sharing systems, have proven to improve public transport systems in other cases. These modalities are discussed during brainstorm sessions (see appendix 1), while keeping in mind the various plans for the future that were presented in the previous section. This resulted in the following list of investment alternatives to improve the public transport system:

1. BRT instead of bus 32 (in combination with a bike sharing system)
2. LRT instead of bus 32 (in combination with a bike sharing system)
3. Bike sharing systems in combination with new modes such as autonomous taxi's or other demand responsive transit as replacement of bus 66

This list is used as input for the next section. It can be used to select uncertain factors for the case study analysis.

5.3 Scenarios

This section aims to describe the scenarios that were constructed. Traditional cost benefit analysis assumes one decision moment. However, for decision making under uncertainty this is not an appropriate assumption. In order to adapt an investment decision towards new information, at least two decision moments are required. At the second decision moment, more information about the development of uncertain factors is known. What this information exactly is, is described by scenarios. Scenarios consist of future outcomes for uncertain factors. Which uncertain factors are relevant for scenarios that should be included in the analysis, depends partially on the impact it has on the investment alternatives.

This section is organized as follows. As explained in the methodology chapter, constructing scenarios starts with making an inventory of uncertainties. Next, the uncertainties are classified as: future uncertainty, knowledge uncertainty, or policy uncertainty. Future uncertainty is the type of uncertainty of which the risk can be mitigated by flexibility using phased or delayed strategies. Hence the plans of the municipality containing future uncertainty are selected for the creation of scenarios. Secondly, the impact of the uncertainties on the public transport demand is estimated. When the selection of uncertainties is made, the final step in constructing scenarios is the actual construction of scenarios for the selected uncertain factors.

5.3.1 Inventory and selection of uncertainties

This subsection provides an inventory of uncertainties after which a selection is made for decision tree analysis. At the end of this section a simple scenario tree consisting of the selected uncertain factors is presented.

Uncertainty about the future of Feijenoord exists with respect to urban development in the area and the demographic development. Authorities are still searching for locations for further urban development and plans exists for development along the Oude Lijn, but how many new houses are being built over there, near which station, and how fast is uncertain while this is of major importance for the mobility demand in the area. Besides, the changing composition of travelers with corresponding travel preferences might change along the development and functions in the area change. Within the transformation process itself are many stakeholders involved and the process has to deal with a lot of policy uncertainties which influence the requirements for the underlying network. First it is unclear what the layout will be, how big the support for this layout will be and who is going to finance the project, because NS and RET have different ambitions for the type of system on the line. Because the ambition for the line is not unanimously determined, also the locations and number of stations is currently uncertain. As a consequence of the opening of the new station 'Feijenoord City' nearby station Zuid the location and future existence of station Zuid becomes uncertain. Finally there is knowledge uncertainty in terms of behavioral responses towards changes in price for mobility services.

1. Metro on the Oude Lijn

One of the plans the municipality of Rotterdam and MRDH have is to give the Oude Lijn rail connection a regional functions. This objective can be reached by increasing the frequency and/or transforming the system. Currently heavy rail operates on the line, but there are plans to transform the system into metro or lightrail.
The impact of the metro might be that bus 32 loses passengers between station Zuid and station Blaak (and perhaps further).

2. Railtangent

Among the plans in the OV-visie is the development of a railtagent connecting Zuidplein (Hart van Zuid) via Feyenoord City (Stadionpark) to Kralingse Zoom. This intervention requires two new bank connections making it expensive, and far-reaching and hence uncertain.
The realization of a railtangent offers opportunities for the public transport network. If the railtangent serves the station Feyenoord City within the Stadionpark area, and if this station becomes an important transport node, it might be interesting to extend bus 32 to station Feyenoord City. The extended bus 32 may offer an alternative for metro D and E, that is, if the quality of bus 32 becomes high enough.
The impact of a railtangent in combination with the metro on the Oude lIjn might be that it competes with bus 66 and bus 32. The railtangent without a metro offers great potential for a service parallel to the metro. This services may consist of an upgraded and extended bus 32 ending at station Feyenoord City instead of station Zuid.

3. Location station Zuid

The authors of the OV visie have the idea to relocate station Zuid when the Oude Lijn is transformed into metro or light rail. Stadion Zuid is not performing well (in terms of users, safety and appearance) and is not well suited within the area, especially if station Feyenoord City opens. If latter happens, the distance between these stations might become too small. However, the location of the station is not expected to heavily affect the demand of a service connecting the neighborhood with the city. For example, if a BRT axis between Zuid and Entrepot is developed it doesn't really matter if the system feeds people from Zuid to Entrepot or the other way around. However, if people want to go from the whole area towards station Blaak demand is maybe lower for the Entrpot to Zuid than for Zuid to Entrepot. Besides, keeping station Zuid and feeding this station from Entrepot gives a detour for Entrepot inhabitants. However, this factor has no major influence on the network design

4. Housing construction

There are plans to build many new houses within the case study area. New houses lead to new inhabitant resulting in an increase of travel demand. If the economy stays high, the plans may be executed according to plan. However, low economic growth can result in a delayed construction of houses, less houses being built than expected and low number of new inhabitants and also a (relatively) low travel demand. This makes any service relatively less profitable compared to a high scenario.

Impact of housing is not very relevant for the current transport system, but it is very relevant for the potential demand of new services. Especially high quality services may only be legit if high demand can be realized due to many new inhabitants.

Conclusion

A final selection of uncertain factors for further analysis in this study is made based on the outcomes of the impact analysis. These uncertain factors for the decision tree analysis are metro, railtangent and housing.

5.3.2 Scenarios

This subsection describes the construction of scenarios for the decision tree analysis. At the second decision moment, more information about the development of uncertain factors is known. What this information exactly is, is described by scenarios.

Scenarios consist of future outcomes for the uncertain factors, which were selected in the previous section. Within this study three uncertain factors exist and hence packages of scenarios are constructed. Technically, for every uncertain factor exist at least two scenarios. In theory, 2^3 combinations are possible as shown in Table 5-3. These 8 scenario packages are illustrated in the scenario tree in Figure 5-4.

Table 5-3 Scenarios

	Housing construction	**Railtangent**	**Metro**
Single variable scenarios	[High, low]	[Yes, No]	[Yes, No]
Scenario package 1	High	Yes	Yes
Scenario package 2	High	No	No
Scenario package 3	High	Yes	No
Scenario package 4	High	No	Yes
Scenario package 5	Low	Yes	Yes
Scenario package 6	Low	No	No
Scenario package 7	Low	Yes	No
Scenario package 8	Low	No	Yes

These 8 scenario packages are illustrated in the scenario tree in Figure 5-4 Scenario tree. How the scenarios per uncertain factor exactly influence the benefits of the investment alternatives to improve the public transport system is described in chapter 6.

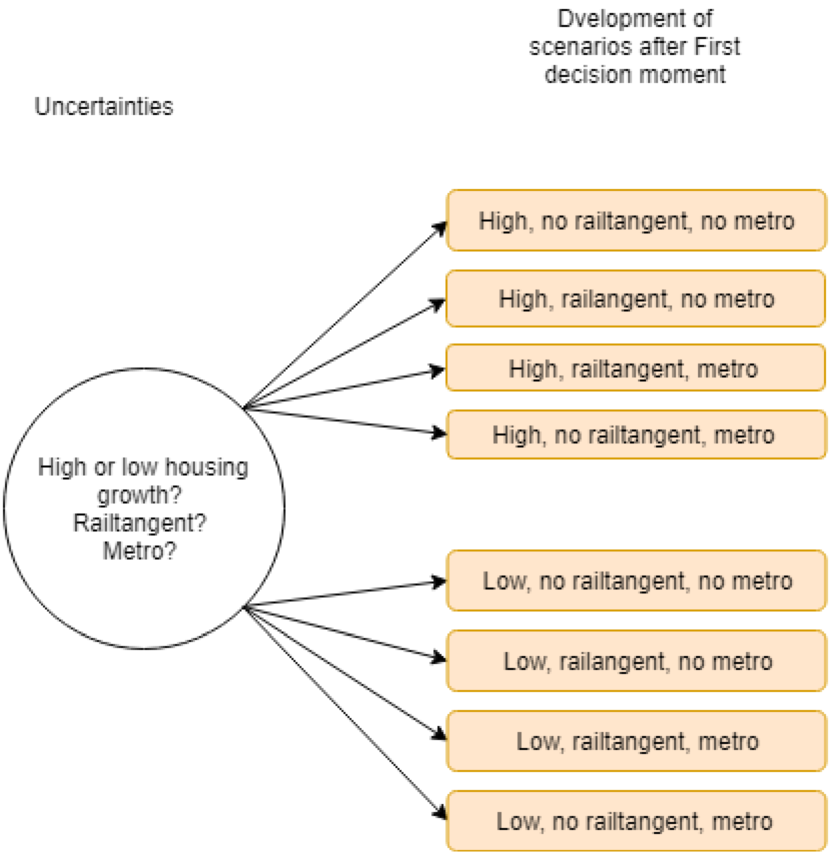


Figure 5-4 Scenario tree

5.3.3 Conclusion scenarios

This section described the construction of scenarios for uncertainties within the case study. An inventory of uncertainties is made. Then a selection of these factors is made for further analysis. The selection consists of: Economic growth and urban development, railtangent, and metro. At the end of the section scenarios were constructed consisting of future outcomes of the uncertain factors. The outcome of the section is that 8 scenario packages are constructed based on three uncertain factors. These scenario packages are input for the next section in which flexibility is incorporated in the investment alternatives. Moreover, the scenarios are input for the decision tree analysis of which the results are presented in the next chapter.

5.4 Planning strategies and experimental design

This section describes how flexibility is included in investment strategies in order to tailor future decisions to future scenarios. This section builds on the previous section in which scenarios were described.

Based on the scenarios from section 5.3 and in consultation with strategical advisors from RET network strategies are designed for the development of the network. The following section describes the investment strategies which differ in the degree of flexibility.

The purpose of every development strategy is to improve the transport system for society. The purpose of the flexible development strategies is to enhance future decisions towards future scenarios.

To enable comparison of network development strategies it is necessary to define a reference alternative. Section 5.4.1 describes this reference alternative, followed by a description of the inflexible strategy consisting of a direct investment alternative in section 5.4.2. As the benefits differ per scenario it can be valuable to adapt the network development strategy over time.

Flexible strategies enable decision makers to do this and avoid unnecessary investments. These flexible strategies analyzed in this study are described in section 5.4.3.
The outcome of this section, namely the investment strategies for network development, together with the scenarios described in the previous section provide the input for the construction of the unweighted decision even tree.

5.4.1 Reference alternative

Within the reference alternative no real investments are done, at least not the ones done in the not flexible and flexible strategies. Bus lines 32 and 66 keep on operating within the case study area. The following list is more specific about the reference situation:

- Bus 32 keeps operating exactly as it does right now, in every scenario.
- Bus 66 keeps operating exactly as it currently does in every scenario, also in case of a metro and a railtangent.

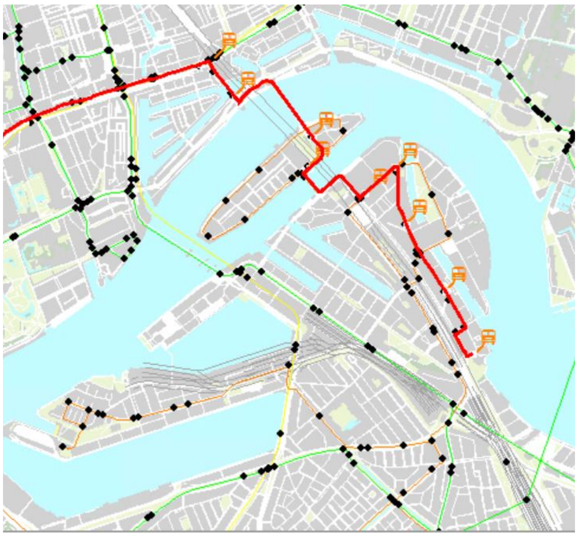


Figure 5-5 Reference situation

In the reference situation bus 32 is operating according to the current timetable (see appendix 3). The frequency of the service is 6 per hour during the day and in peak hours (7 between 7 am and 8 am). Figure 5-5 shows the route of the bus 32 zoomed in on Feijenoord on a map of Rotterdam.

5.4.2 Inflexible alternative

The inflexible development strategy involves high investment cost and does not allow the decision maker to adjust the strategy to new circumstances. Typical inflexible development strategies consist of direct investment in infrastructure for a complete section. For the case it is decided to include a direct investment strategy for the whole section in the case study too. This means that the decision maker decides at the first decision moment upon building tram infrastructure within Feijenoord to connect station Blaak to station Stadionpark via the Willemsbrug and through Feijenoord and station Zuid. After finishing the infrastructure a fast tram (light rail type of system) can start operating, replacing bus line 32. This means that the day tram “32” starts operating, bus 32 is not operating anymore.
The frequency of the new tram service is 8 per hour as the RET offers services according to demand.

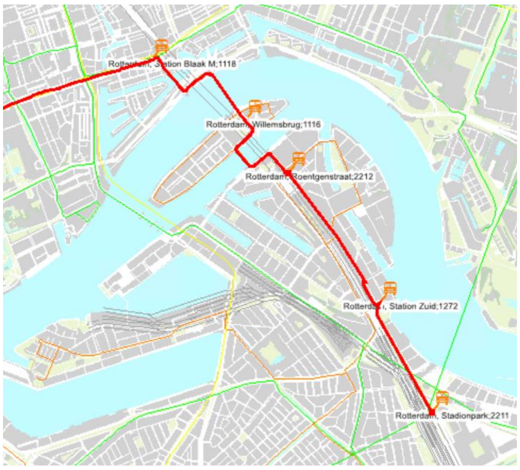


Figure 5-6 Tram to Stadionpark

5.4.3 Flexible network development strategies including real options

This section describes the construction of flexible investment strategies that enable the decision maker to respond to future development of uncertainties.

The flexible network development strategies are designed using the input from the brainstorm session (see appendix 1). The inflexible strategy is perceived wise in case of strong urban growth, the expected construction of the railtangent and no metro on the Oude lijn. However, this strategy is very risky as it is expected to be very cost inefficient if another scenario becomes reality. In order to enable the decision maker to adapt the network development project to future circumstances, flexible development strategies including real options are designed.

This chapter starts with a review of the outcomes of the brainstorm session regarding network development in several scenarios (Table 5-4). Next, the flexible strategies which are constructed based on these outcomes are presented.

Table 5-4 possible decision based on scenarios

Scenario	Impact	Possible decision
Railtangent with station Stadionpark, but no metro on the Oude Lijn (but PHS 6xpu or like now F=4)	The connection between Stadionpark and Blaak is weak resulting in people still transferring at Zuidplein or somewhere else to tram to go to the city center via metro D/E and the Erasmusbrug connection. This is already a overcrowded part so this is an undesired result.	The connection from Blaak and Feijenoord to Stadionpark has to be improved, either via bus or via tram. In a low growth (housing) scenario bus 66 can be rerouted to go via or towards and end at Stadionpark. If a BRT or tram system is already build between Blaak and Zuid it can be extended to Stadionpark. An additional measure could be to stop operating bus 66 because it might have become too unprofitable. Instead of bus 66 Demand Responsive Transit services can be implemented.

Railtangent with station Stadionpark and a metro on the Oude Lijn	Bus 66 is only useful for the people that don’t want to walk far but probably the new connection to Zuidplein via Stadionpark has become more attractive and takes over many of the current users of bus 66. Depending on the remaining travel demand (high or low housing) for bus 66 it might become not profitable enough to keep on operating it.	Consider to stop operating bus 66 and replace the service by DRT and other shared systems. These systems offer people a door to door connection, what might fill the gap of missing bus 66. A BRT system with less stops than bus 32 can still offer people from the Noordereiland and within Feijenoord and Entrepot a fast connection to Blaak and Stadionpark.
No railtangent, and no metro on the Oude Lijn		A BRT or tram system can be very wise to offer a fast and reliable service to the people going from and to Feijenoord.

The flexible strategy starts with the investment in a BRT (bus rapid transit) system between station Blaak and Feijenoord. A BRT system requires lower investment cost than a tram, but later on tram rails can be built on the dedicated lanes for the BRT system (phasing option). After the first decision moment it is possible to wait for new information and decide to defer or abandon the plan to invest in a tram. It is also possible to stick to that plan and build the tram, but later (defer option). It is also possible to extend the BRT or tram system at the second decision moment (expand/growth option).

1. BRT “32” + Bicycle Sharing Systems

In the BRT “32” intervention the network becomes coarser. The current route of bus 32 is straightened. The bus is running via the Oranjeboomstraat instead of the Nassauhaven. The number of stops served by the bus service is limited to Blaak, Willemsbrug, Roentgenstraat (Entrepot) and Station Zuid. The length of the route is 2,7 km. A visualization of the intervention is shown in Figure 5-7. The frequency of the BRT service is modelled as 12 per hour during the peak. Furthermore it is assumed that shared bicycles are available according to the IDTP planning guide guidelines (IDTP, 2018).

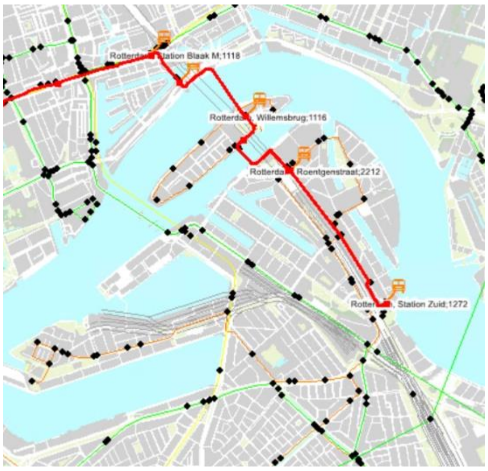


Figure 5-7 BRT "32"

2. BRT “32” extended to Stadionpark + Bicycle Sharing Systems

The development strategy involving the extension of BRT “32” to Stadionpark is identical to the BRT “32” service explained previously but with an extension to Stadionpark. This results in a total length of 4,3 km for this section. In the transport model the BRT stop Stadionpark offers a fast transfer to stop ‘Feyenoord Stadion’ served by tram 23 and to the stop served by the railtangent using access links and fast walk links. It is chosen to do this as the exact location of Stadionpark is not known yet, the exact origins of people boarding at the currently existing stop Feyenoord Stadion is not known and the transfer connections can be made very fast using for instance escalators.

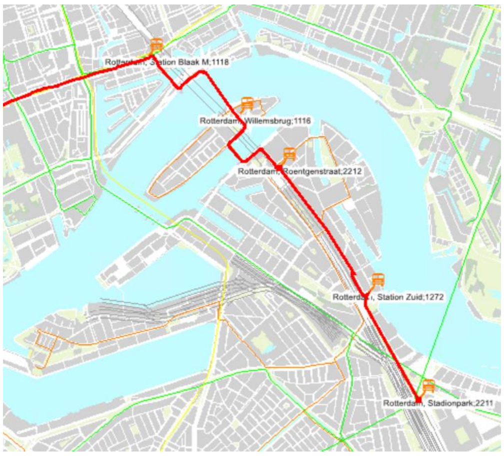


Figure 5-8 BRT "32" extended to Stadionpark

3. Tram “32” extended to Stadionpark + Bicycle Sharing Systems

For the strategy including the tram “32” extended to Stadionpark intervention the exact same route is modelled as for the BRT “32” with extension. The only difference is the frequency of the service. Where the frequency was 12 per hour for BRT, for tram it is 8 per hour as the RET offers services according to demand.

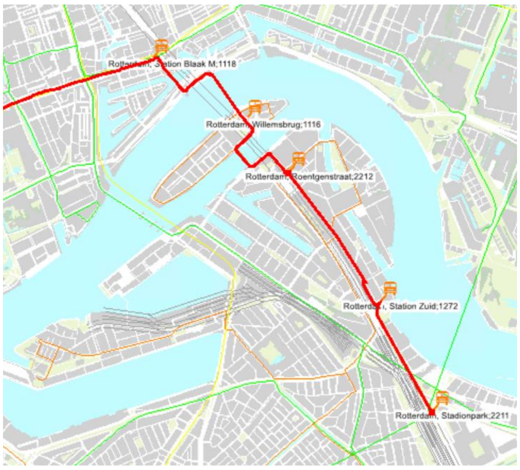


Figure 5-9 Tram extended to stadionpark

5.4 Decision tree

This section presents the decision tree that is constructed using the input from the previous sections. The decision tree consists of decision nodes, represented by squares, from which investment decisions arise, and probability nodes, indicated by circles, from which potential future scenarios arise. The tree must be read from left to right as it implies time. The next page shows the developed decision tree.

The decision tree starts with the first decision node on the most left followed by the now to be made decision. The first decision includes the decision to directly invest in a tram (inflexible strategy) or to invest stepwise by starting with BRT (flexible strategy). The upper branches, indicated in black, represent the inflexible strategy. The lower branches, indicated in blue, represent the flexible strategies, which include the possibility to make a second decision based on new information regarding the scenarios. Depending on the future scenarios, the flexible strategy provides the possibility to choose among three options: or to not extend the BRT to the new to be developed neighborhood Stadionpark, or to extend the BRT to Stadionpark, or to transform BRT into LRT/tram and extend it to Stadionpark.

An important remark for the remaining of this report is that, of which investment the flexible strategy exactly consists, depends on the future scenarios. The following classification of strategies is made which will be used in the remaining of the report:

1. Inflexible strategy: tram
2. Flexible strategy 1: BRT Blaak – Zuid + Transform BRT to tram and extend to Stadionpark OR do nothing
3. Flexible strategy 2: BRT Blaak – Zuid + Extend BRT to Stadionpark OR do nothing

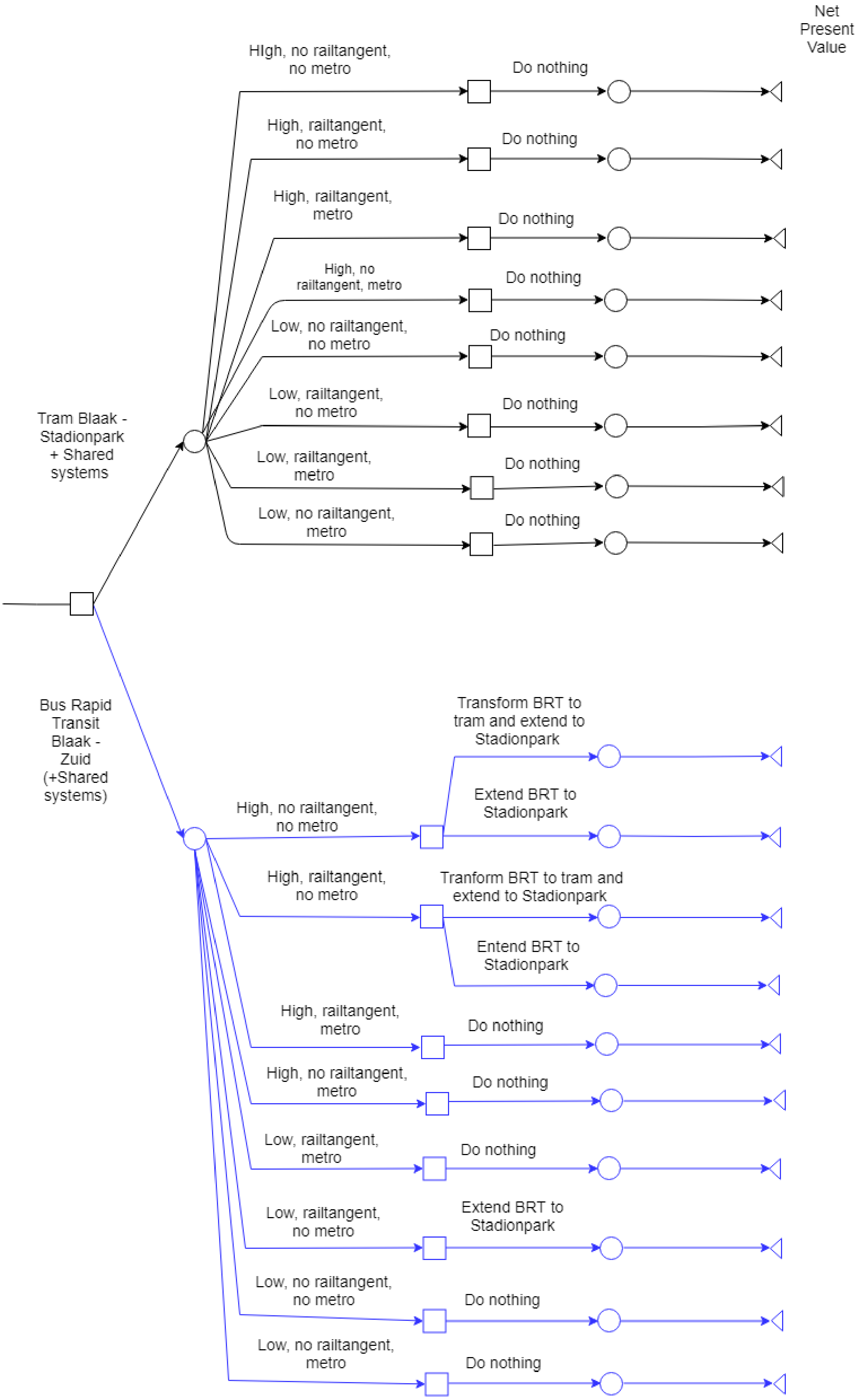

Net Present Value
HIgh, no railtangent, no metro
Do nothing
High, railtangent, no metro
Do nothing
High, railtangent, metro
Do nothing
High, no railtangent, metro
Do nothing
Low, no railtangent, no metro
Do nothing
Low, railtangent, no metro
Do nothing
Tram Blaak - Stadionpark + Shared systems
Low, railtangent, metro
Do nothing
Low, no railtangent, metro
Do nothing
Transform BRT to tram and extend to Stadionpark
Bus Rapid Transit Blaak - Zuid (+Shared systems)
Extend BRT to Stadionpark
High, no railtangent, no metro
High, railtangent, no metro
Tranform BRT to tram and extend to Stadionpark
Entend BRT to Stadionpark
High, railtangent, metro
Do nothing
High, no railtangent, metro
Do nothing
Low, railtangent, metro
Do nothing
Low, railtangent, no metro
Extend BRT to Stadionpark
Low, no railtangent, no metro
Do nothing
Low, no railtangent, metro
Do nothing

Figure 5-10 Decision event tree

5.5 Conclusion

This chapter reported the process and the outcomes for the first three steps of the methodology to construct a decision tree. Firstly, an inventory of investment alternatives to improve the public transport network in the case study are was made. Secondly, an inventory of uncertain factors that influence the alternatives was made in order to create scenarios. Finally, in the third step an inflexible and a flexible investment strategy were defined. The inflexible strategy includes real options to adapt future decisions to future scenarios.
An important remark for the remaining of this report is that, of which investment the flexible strategy exactly consists, depends on the future scenarios. The following specification of strategies is made which will be used in the remaining of the report

1. Inflexible strategy: tram
2. Flexible strategy 1: BRT Blaak – Zuid + Transform BRT to tram and extend to Stadionpark OR do nothing
3. Flexible strategy 2: BRT Blaak – Zuid + Extend BRT to Stadionpark OR do nothing

The aim of this chapter was to answer the following subquestion:

1. What kind of real options do public transport operators and other stakeholders have for the improvement of an urban public transport network?

The answer for the case study is that urban public transport stakeholders have the option to delay, the option to invest in phases, the option to grow by increasing the capacity of the system or by extending a line to serve new demand in new neighborhoods.
In the next chapter the operationalization of the strategies and the precise methodology to quantify the branches of the decision tree in order to calculate the decision criterion is described.

6. Experimental design: Operationalization investment strategies and scenarios

This chapter describes the operationalization of investment strategies and scenarios for the case study in order to apply societal cost benefit analysis. Spreadsheets are used to calculate the cost and benefits of the strategies for different scenarios. For some purposes extra tools such as transport models were required. Section 6.2 discusses the way strategies are modeled in the transport model and in the spreadsheets. Later on, in section 6.3, the approach to model and operationalize the scenarios is elaborated on.

6.1Tool design

For the application of societal cost benefit analysis and decision tree analysis a tool is created in Microsoft Excel. The tool is based on existing tools for societal cost benefit analysis, but supplemented with multiple decision moments and events per analysis. It implements the decision event tree constructed in the previous chapter. Every branch of the decision tree has its own spreadsheet. In such a spreadsheet the NPV is calculated based on the discounted cash flows occurring each year for each of the included indicators described in chapter 4. The time horizon and discount factor applied in this study are based on Dutch SCBA guidelines provided by (C. J. J. Eijgenraam et al., 2000).For the analysis a time horizon of 21 years is chosen, starting in 2019 and ending in 2040. A discount factor of 4.5 is applied to discount the money over time. Table 6-1 shows a timeline of the years in which decisions, events and other for the SCBA analysis important things happen.

Table 6-1 Flows of information, decisions and events

Year	Event in the model Flexible strategy 1	Event in the model Flexible strategy 2	Event in the model Inflexible strategy	Events
2019				Start analysis
2020	Decision BRT “32”	Decision BRT “32”	Decision tram	
2021	Start operation BRT “32”			
2022	Start elastic demand BRT “32”	Start elastic demand BRT “32”	Start operation tram	
2023			Start elastic demand tram	Information available -High or low urban development -Decision metro Decision railtangent
2025	Decision moment 2: 1. do nothing 2. or extend BRT to stadionpark	Decision moment 2: 1. do nothing 2. or transform BRT Into LRT and extend to Stadionpark		Growth of demand

2027				Start operation metro (or not) ➔ Decrease of demand due to metro
2040				Last year of analysis

6.2 Operationalization strategies

This subsection describes the operationalization of the investment strategies that were designed in chapter 5 with the purpose of developing the network. In SCBA analysis, the welfare effects of a project for society are compared to a reference situation to identify the net effect of a project. Hence this section starts with a description of the reference alternative considered in this study followed by descriptions of the interventions the development strategies consist of. Travel data used for calculations is obtained from RET. More details concerning the calculations can be found in appendix 3.

6.2.1 Operationalization indicators

For the societal cost benefit analyses key figures and parameter values found in literature from other research are used (see chapter 4). The data input that is required to calculate the magnitude of the welfare effects of the different investment strategies is shown in Table 6-2.

Table 6-2 Indicators used in case study for cost and benefits

Indicator	Input
Travel time savings Blaak-Zuid	- Demand current inhabitants Feijenoord - Elastic demand due to quality improvements - Demand new inhabitants Feijenoord and Kop van Zuid-Entrepot - Value of Time for PT - Travel time saving per trip
Travel time savings Blaak-Stadionpark	- Current demand Stadionpark - Blaak (tram 23) - Demand new inhabitants Stadionpark area - Value of Time for PT - Travel time saving per trip
Net passenger revenues BRT/tram	- Net revenue per passenger km for RET - Current demand - Elastic demand due to quality improvements service - Demand new inhabitants

The rest of this section elaborates on the calculations of the indicators in the case study. A distinction is made between the area of Feijenoord,, which is currently being served by bus 32, and the Stadionpark area, which is currently being served by tram 23.

6.2.1.1 Blaak - Zuid

Travel time savings per trip

First the current total travel times (on average using an average access distance) are calculated for each stop currently served by bus line 32 within Feijenoord until Blaak.
The next step was to calculate travel times for a new bus service (BRT) having less stops and a higher operational speed and thus resulting in a lower in-vehicle travel time. This is done by looking at current car distance and travel time Figure 6-1. The average access time is calculated for the new stops. The average access distance has increased due to the new service with less stops resulting in a higher average access time compared to the reference scenario. The introduction of a BSS (Bicycle Sharing System) results in a first mile trip consisting of a short walking part to a BSS Hub (on average 150 meter) and a cycling part following to a stop of BRT nearby.

The travel time savings are calculated for the new stops using a new average access distance. The travel times savings for users of removed stops are calculated by comparing the old travel times to new travel times of a stop most nearby.

The people experiencing the travel times savings by transforming bus 32 into an HOV bus service between station Zuid and station Blaak are the people who travel (partially) over that part of the service. The travel time savings depend on the stop they enter the bus and the stop they egress.

By using obtained Origin-Destination data for Feijenoord the travel time savings can be made specific for each trip and added up to the total travel time savings for the HOV bus service.

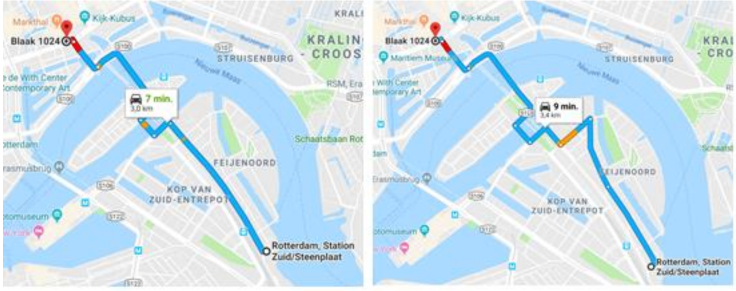


Figure 6-1 Left: current car distance. Right: current bus 32 distance

The generalized journey times (GJT) for the reference situation and the situation with an intervention are shown in

Table 6-3. The GJT is the perceived travel time, which is the sum of the different trip element multiplied by the weight people assign to each element. The table also shows the travel time savings caused by the projects from the investment strategies. More detailed numbers about the calculation of travel time savings can be found in Appendix 3. A more detailed description of how these numbers are obtained follows in the following subsections.

Table 6-3 Travel time and travel time savings reference and strategies to station Zuid

	Reference bus 32		**BRT "32" + BSS (F=12)**			**Tram "32" + BSS (F=8)**	
Stop	In-vehicle time to station Blaak [minutes]	GJT (weighted) [minutes]	In-vehicle time to station Blaak [min]	GJT with BSS [min]	Travel time savings [min]	GJT with BSS [min]	Travel time savings [min]
Station Zuid/Steenplaat HA0354	11	26	7	18	8	21	6
Rose-Spoorstraat HA0672	10	25			7		5
Persoonsdam HA0622	7	22			5		3
Nassauhaven HA0621	6	21			5		3
Roentgenstraat HA0620	5	21	4	16	5	19	2
Koninginnebrug HA2664	4	21					
Willemsbrug HA2392	2	19	2	14	5	16	3
Willemswerf	1	18					
Average		22		16	6	16	6

Reliability savings per trip

For trips from Feijenoord (originally bus 32 trips) different methods are used for the reliability savings of respectively bus into BRT and bus into tram.
For bus into BRT the expected additional waiting time at stop Station Zuid is calculated. The expected additional waiting time was found to be 67 seconds for the current service by bus 32. For the expected variation in waiting time for the new BRT service a value of 30 seconds is used, based on the results of a study performed by (Devillers, van Dijk, Modijefsky, & Spit, 2011) for another project, namely the SCBA Uithoflijn. For the Uithoflijn SCBA a value of 0.5 for the expected additional waiting time for the BRT service was used, compared to 1.4 for the reference alternative of traditional bus.

For bus into tram a pragmatic way of calculating the effect of reliability using average values for reliability of buses in the Hague found by (van Oort & van Nes, 2006). This study depicted that the average variability in travel time is 17,6 s/km for bus and 11,1 s/km for tram. The average savings of 6,5 seconds per km multiplied by the length of the route in km are used as reliability savings per trip. Multiplying the time savings by the VoR of €3,75 per hour this results in a saving of €0,06 per trip.

Number of trips

In order to calculate the total travel time savings and reliability savings, the savings per trip are multiplied with the number of trips. The number of trips is based on OV-chipkaart data concerning the current number of people boarding and alighting bus 32 per stop. Due to this detailed information, the travel time savings are also calculated in detail per stop multiplied by the number of people boarding/ailighting at that specific stop.

6.2.2.2 Blaak -Stadionpark

Number of trips

Where for users of bus 32 it is known who's benefiting of a faster running time of the service, it is more complicated to predict this for users from Stadionpark. For the travelers entering bus 32 currently the travel time savings are based on a generalized travel time without egress time. For the travel time savings for travelers boarding at Stadionpark the egress time is included too. The reason for this choice is that the potential demand is estimated by starting to investigate which OD pairs would potentially use the service. From analysis performed in transport model OV-Lite it was found that there is a large passenger flow between Stadionpark and de Meent that theoretically would benefit from the extension of bus 32 to Stadionpark. .

Extending bus 32 to Stadionpark provides a direct connection between Stadionpark and Stadsdriehoek via station Blaak. This has at least two effects:

1. Firstly this new connection provides a direct PT connection for travelers originating in the Stadionpark area.
2. Secondly, the new connection provides a faster route for travelers between Feijenoord and other parts of Rotterdam. This faster route can occur either by transferring to tram 23/25 at Stadionpark or by transferring to or from the new to be build railtangent.

3 Thirdly, the new connection can provide a shortcut for OD-pairs currently using other routes in the PT network, the so called through traffic. They can transfer at Stadionpark

Travel time savings

The effect of adaptations in the network on the travel time for every OD pair is estimated using the transport model OV-Lite. This model enables to estimate aggregated, weighted travel time savings for OD pairs.

The travel times for the reference situation and the situation with an intervention are shown in Table 6-4. This table also shows the travel time savings due to the interventions. More detailed numbers about the calculation of travel time savings can be found in Appendix 3.

Table 6-4 Travel time and travel time savings reference and strategies including Stadionpark

To Meent (via Blaak)	**Reference: tram 23 + metro**	**Tram Stadionpark - Blaak F=8**		**BRT Stadionpark - Blaak F=12**	
	Average GJT [minutes]	Average GJT [minutes]	Experienced travel time savings incl railbonus	Average GJT [minutes]	Travel time savings [minutes]
Stadionpark	41	27	14	35	6

Reliability savings

For the trips originating from the Stadionpark are (currently the stop Stadion Feyenoord) the same savings as for bus 32 are used.

6.4 Operationalization scenarios

Within this study a distinction can be made between uncertain factors related to the transport system and uncertain factors related to the development of new houses. The parameter values that are used in the societal cost benefit analysis to determine the exact magnitude of urban development and the impact of the rail tangent and metro variables are presented in Table 6-5.

This section will elaborate further on the operationalization of the uncertain variables in the spreadsheet mode that was used for the analyses.

Table 6-5 Parameter values original model setup

Parameter	Value original model setup
Household size:	2
Mode share BRT/tram in case of metro:	0.5
Mode share BRT/tram in case of metro + railtangent:	0.5
Mode choice bike sharing system of demand for BRT/ tram	0.5

Transport system

The following list of transport related scenarios all required a slightly different approach to calculate the impact on costs and benefits of developments strategies.

1. No railtangent and no metro
2. Railtangent, no metro
3. Railtangent and metro

For the first case, no railtangent and no metro, the cost and benefits of interventions could be calculated mostly manually using Excel. However, for the strategies including an extension of bus 32/tram “32” to Stadionpark it was necessary to get an idea of possible demand for bus/tram 32. For this purpose a transport model containing information about current passenger flows from centroids in the Stadionpark area was required. More information about the approach used for these scenarios is described later in this section.

For the second group op scenario’s including a railtangent but no metro, it became more complicated. In the previous scenario’s only current passengers boarding and alighting on a currently operating PT service were topic of interest. Scenarios including the railtangent involve the emergence of new routes for many travelers making it very complicated to estimate which OD pairs are benefiting from the interventions. As a result of this complexity it is difficult to estimate the travel time savings experienced by travelers for these OD pairs. The available transport model for this research (OV-Lite) did not yet offer the jobs to obtain the required output. A new job was written to obtain the travel time matrices for aggregated OD pairs making it possible to analyze the effect of the interventions on total generalized travel time.

For the third scenario group it was a relatively small addition to the approach for the second scenario group. Ex-post evaluation of the impact of de Noord/Zuidlijn in Amsterdam revealed that tram line 24 that runs parallel to the new metro line lost half of its passengers two months after the Noord/Zuidlijn started operating (Duursma, 2018). Due to a lack of other ex-post evaluations of trams or buses operating parallel to new metro’s it is decided for this study to apply a factor 0,5 to the passenger revenues obtained for tram, BRT and bus 32 after the metro starts operating.

Housing

Several documents containing urban development plans for Rotterdam and the neighborhoods Feijenoord, Kop van Zuid-Entrepot and Stadionpark are consulted to calculate the future number of inhabitants and potential public transport demand. The planning capacity following the Verstedelijkingsalliantie in 2018 was given in Table 5-2.
The calculated number of inhabitants in Feijenoord and Kop van Zuid-Entrepot for the housing scenarios is shown in Table 6-6. Within this study the number of houses build in the low

scenario is one period behind the current planning. For the high scenario it is assumed that urban development will happen according to planning. The growth rate for inhabitants is used to calculate the growth in trips made by bus 32.

Table 6-6 Number of inhabitants in Feijenoord and Kop van Zuid-Entrepot for high and low housing scenarios

	Low			**High**		
Period	New houses Willem-as after period	Number of inhabitants after period	Growth rate	New houses Willem-as after	Number of inhabitants after period	Growth rate
2015	15544	15544		15544	15544	
2018-2024		15544	100%	1030	17604	113%
2025-2029	1030	17604	113%	320	18244	117%
2029+	320	18244	117%	290	18824	121%
2040	290	18824	121%		18824	121%

For the new neighbourhood it is relevant to know what the demand for the public transport system through Feijenoord might be. For this purpose the passenger flows between the tram stop Feyenoord Stadion and the rest of Rotterdam is analyzed in a transport model (OV-Lite). The flow that is currently going to the city Centre is assumed to potentially gain travel time savings from the new route through Feijenoord via Blaak.
For the increase of inhabitants around this tram stop the growth factor method is applied to estimate the future PT demand.
As stated in the previous section, for the travelers going to Meent the bus or tram connection from Stadionpark to Blaak and further would potentially provide travel time savings.

6.5 Conclusion

This chapter described the operationalization of the scenarios and network development strategies for the societal cost benefit analysis. It is explained how the current travel times and the travel times due to investment alternatives are calculated. Hereby a distinction is made between the travel times for inhabitants of the areas Kop van Feijenoord and Kop van Zuid-Entrepot and the travel times for inhabitants in the area Stadionpark. Also the calculation of reliability benefits is described and specified for the distinguished areas.

Within Feijenoord, the benefits between BRT and tram do not differ (much), while for the Stadionpark area, tram provides more GJT savings than BRT (14 compared to 6) as can be seen in table 6-7.
The savings in Generalized Journey Time (GJT) per trip for the inhabitants in Feijenoord and for the inbitants in Stadionpark are shown in

Table 6-7

Table 6-7 Travel time savings per neighborhood and per investment option

	Reference bus 32	**Reference: tram 23 + metro**	**BRT + BSS (F=12)**		**Tram + BSS (F=8)**	
Stop	GJT [min]	GJT [min]	GJT with BSS [min]	GJT time savings [min]	GJT with BSS [min] (including rail bonus)	GJT savings [min]
Average Feijenoord - Blaak	22		16	5.9	16	5.7
Stadionpark - Meent		41	35	6	27	14

7. Results

This chapter includes an analysis of the indicators following from the application of the societal cost benefit analysis and decision tree analysis to the case study. The aim of this chapter is to answer the following subquestion:

2. How do future scenarios affect the performance of investment strategies in urban public transport network design and planning?

The analysis is divided into five sections, of which the first three are related to subquestion 2, while the fourth section gives a reflection on the methodology and the outcomes.
Specifically, in section 7.1 the outcomes of the cost benefit analysis per investment strategy for each scenario are presented. These outcomes include the cost, the benefits and the net present value (NPV) for each investment strategy per scenario. Section 7.2 gives insight into which investment strategy is preferred under which distribution of scenario probabilities by presenting the expected NPVs per investment strategy. Thirdly, to identify tilting points for which the preferred strategy changes, additional analyses are performed. The results from these analysis are discussed in section 7.3. Finally, in section 7.4, the results are discussed based on a reflection on the scenarios and development strategies.

Interemezzo
An important remark for the remaining of this report is that, of which investment the flexible strategy exactly consists, depends on the future scenarios. The following specification of strategies is made which will be used in the remaining of the report

1. Inflexible strategy: tram
2. Flexible strategy 1: BRT Blaak – Zuid + Transform BRT to tram and extend to Stadionpark OR do nothing
3. Flexible strategy 2: BRT Blaak – Zuid + Extend BRT to Stadionpark OR do nothing

7.1 Experiment setup

This section describes the setup of the experiments that are performed to analyze the outcomes of the societal cost benefit analysis and the decision tree analysis.

7.1.1 Estimated costs, benefits and NPV per strategy

In order to find out for each scenario which investment strategy is economically most efficient, societal cost benefit analysis (SCBA) is performed. The result of the SCBA are the costs, the benefits and the NPV for each strategy per scenario.

7.1.2 Expected NPV and preferred strategy

In order to find out which investment strategy is preferred under which distribution of scenario probabilities, the expected NPVs are calculated. The expected NPV per strategy is calculated as proposed in chapter 4. Probabilities are assigned to the scenarios leading to a weighted decision tree. Hence the expected NPV is the sum of the probability that a scenario comes true multiplied with the NPV of the decision that would be taken in case of that scenario. The probability distribution schemes that are applied in this analysis are presented in Table 7-1. It is chosen to look at the decision outcome for equal scenario probabilities and for extreme scenario probabilities. Testing for these scenario probabilities gives a rough insight into the sensitivity for the scenarios.

Table 7-1 Probability distribution schemes for the scenario set including isolated metro scenarios

Probability distribution schemes	**1.Equal probabilities**	**2.Railtangent high, metro low**	**3.Metro and railtangent very high**	**4.High probability high housing**
Low, noRM	12.5%	1.0%	2.0%	6.3%
High, noRM	12.5%	1.0%	2.0%	18.8%
Low RM	12.5%	3.0%	40.0%	6.3%
High RM	12.5%	3.0%	40.0%	18.8%
Low RnoM	12.5%	45.0%	4.0%	6.3%
High RnoM	12.5%	45.0%	4.0%	18.8%
Low MnoR	12.5%	1.0%	4.0%	6.3%
High MnoR	12.5%	1.0%	4.0%	18.8%

7.1.3 Tilting points

In order to analyze the sensitivity of the decision model for the scenarios, additional analyses are performed. In the previous section it was observed that the inflexible strategy never performed better with respect to the NPV than the flexible strategies (phased tram and phased BRT). To investigate if there are tipping points for which the inflexible strategy performs better than the flexible strategies, the societal cost benefit analysis and decision tree analysis are performed again, but with adapted scenarios and experiment settings. The section starts with the impact of houses and ends with an analysis of the impact of the rail tangent and metro scenarios.

More specifically, section 7.3.1 elaborates on the impact of the housing factor, or in other words, the magnitude of the housing construction. Section 7.3.2 concerns the impact of the difference between the high and the low housing construction scenarios. In section 7.3.3 elaborates on the impact of metro/

7.1.3.1 Magnitude of housing construction

The impact of the housing construction factor is analyzed by increasing the household size in the model. Originally this was set to 2 but for this analysis it is tested for multiplication factors of respectively 10 and 50. This is interesting because it gives an indication for the optimal strategy for even higher urban development plans. The expected impact is that both low and high housing scenarios will obtain higher benefits and higher NPVs and that also the difference in output between high and low scenarios will increase.

7.1.3.2 Rail tangent and metro: decision moments and time between events

To analyze the impact of metro and rail tangent on the outcomes of the SCBA and decision model, some analyses are performed in which the events related to metro and rail tangent occur later. In this way the impact of metro and rail tangent after a second decision is investigated.

Three new scenarios are introduced: noRM+R', 'noRM+M' and 'noRM+RM'. It is expected that both the negative impact of metro as well as the positive impact of railtangent will become smaller if these events occur later in time. Therefor it is interesting to compare the results for scenarios RM, MnoR and RnoM with noRM+RM, noRM+M and noRM+R to see the effect of time on the NPVs and the preferred alternative.

7.1.3.3 Impact modal split metro

To test the sensitivity of the model for the metro scenario it is tested what the impact on NPVs is and what the preferred strategy becomes if different values are used for the parameter “modal split tram/BRT if metro”. In the original settings the value is 0.5, for the tests the value 0.1 is used for both ‘modal split if rail tangent and metro’ and ‘modal split if metro’.

7.2 Estimated cost, benefits and NPV per strategy

The most striking result is that strategy 3 (flexible BRT + extension BRT or nothing) has the highest NPV for every scenario (

Table 7-2). This means that flexible strategy 3 BRT is the preferred strategy in every scenario and is a no-regret investment strategy.

Another important result is that every NPV is negative, implying that none of the investment strategies is economically beneficial for society. An explanation for this can be found in the high cost of the investment alternatives compared to the relatively low benefits. Also the NPV of the flexible strategy 3 is always negative and varies between -33.5 and -21.1 million euros.

Remarkable is that the NPV of the inflexible strategy is about three times lower than that of the 3th flexible strategy. Looking at the cost and the benefits, the inflexible strategy has the highest cost, but also the highest benefits in most of the cases. Striking is that the highest benefits are found within the 2nd flexible strategy in which a tram is constructed after the second decision moment.

Moreover, the benefits of the inflexible strategy are highest for every scenarios, except two. For the secnarios ‘High, noRM’ and ‘High, RnoM’ inflexible strategy 2 tram has the highest benefits. This can be explained by the fact that BRT provides slightly higher travel time savings than tram (5.9 vs. 5.7 minutes) for current users of bus 32, which have an origin or destination in Feijenoord/Kop van Zuid-Entrepot

Table 7-2 Cost and benefits for the inflexible alternative tram and two flexible strategies. Assumed is that the scenarios are known in respectively 7 and 12 years

(in million €)	1.Inflexible: Tram	2. Flexible: BRT + extension tram or nothing	3..Flexible: BRT + extension BRT or nothing
Net Investment cost	€ -49.4	€ -57.7	€ -26.7
Net Onderhoudskosten	€ -22.1	€ -17.2	€ -0.9
Net Exploitatie kosten	€ -27.2	€ -31.0	€ -10.4
Total net cost	€ -107.0	€ -114.9	€ -46.9
Benefits			
High, noRM	€ 15.0	€ 15.6	€ 14.6
Low, noRM	€ 13.7	€ 9.8	€ 9.8
High RM	€ 17.7	€ 10.4	€ 10.4
Low RM	€ 16.4	€ 10.1	€ 10.1
High MnoR	€ 15.0	€ 10.4	€ 10.4
Low MnoR	€ 13.7	€ 10.1	€ 10.1
High RnoM	€ 18.4	€ 18.9	€ 15.0
Low RnoM	€ 17.2	€ 13.4	€ 13.4
NPV			
High, noRM	€ -91.9	€ -99.3	€ -32.3
Low, noRM	€ -93.2	€ -21.7	€ -21.7
High RM	€ -89.9	€ -21.2	€ -21.2
Low RM	€ -91.2	€ -21.4	€ -21.4
High MnoR	€ -92.0	€ -21.1	€ -21.1
Low MnoR	€ -93.3	€ -21.4	€ -21.4
High RnoM	€ -88.5	€ -96.0	€ -31.9
Low RnoM	€ -89.8	€ -33.5	€ -33.5

What is very remarkable, is that the lowest benefits do not occur for the theoretically worst scenario, namely: low housing, no rail tangent, but a metro. The benefits of the investment strategies per scenario vary between 9.8 (low, noRM) and 18.9 (high, RnoM) million euros. The lowest benefits occur for the scenario in which the least things happen, namely a low degree of houses being constructed, no construction of a railtangent and no transformation of the Oude Lijn into a metro system. Two explanations can be found. Firstly, the time between events plays a role in the results. The time between the year in which the analysis starts (2019) and the start of operation of the metro (2027) is 8 years. The time between the tram starts operating (2022) and the opening of the metro (2027) is only five years. The time between start of operation of BRT “32” (2021) and metro (2027) is six years. Secondly, in the model the metro does only affect the passenger revenues of the PT services (so, not the BSS service). Hence, the loss of passenger revenues apparently does not weigh up against the travel time savings, reliability savings, and BSS revenues in a high housing scenario including metro compared to a low metro scenario without a metro.

Moreover, it is interesting that the impact of metro is relatively low. The expected benefits of the inflexible strategy (direct tram) vary between 17.7 in scenario ‘high, RM’ and 18.4 for scenario ‘High, RnoM’. While, if there is neither a rail tangent or a metro constructed the benefits are only 15.0 million. The benefits of high, norm and high, MnoR are in fact (almost) equal and both 15 (in more decimals it is 15.04 versus 14.96).

7.3 Expected NPV and preferred strategy

The main finding is that flexible strategy 3 (BRT + extension BRT or do nothing) has the highest expected NPV for every distribution of scenario probabilities (see Table 7-3). This means that investing in BRT followed by either a BRT extension or do nothing, is the optimal strategy in every included distribution of scenario probabilities tested in this study. Conducting this strategy can save up to 70.2 million euros. By assigning probabilities to the scenarios, the preferred development strategy might have changed. However, this only holds if the preferred alternative would depend on the scenario, which is not the case here These results are in line with the results in the previous section, which indicated that flexible strategy 3 is a no-regret strategy and is always the preferred alternative for this experiment setup.

The expected NPV per strategy, the expected benefits per strategy, and the expected savings from investing following flexible strategy 3 instead of inflexible (this is the regret if one would have invested inflexible) are presented in Table 7-3.

Table 7-3 Expected (net) benefits in million € per development strategy

		1.Inflexible:	2.Flexible:	3.Flexible:	Expected savings
Scheme probability distributions		Tram	BRT + extension tram or nothing	BRT + extension BRT or nothing	Inflexible instead of 3:flexible
1	Benefits	15.9	12.3	11.7	-4.2
Equal probabilities	NPV	-91.2	-42.0	-25.6	65,6
2	Benefits	17.4	15.0	13.5	-3,9
Railtangent high, metro low	NPV	-89.6	-57.6	-30.6	59
3	Benefits	14.8	10.6	10.5	-4,3
Railtangent low, Metro high	NPV	-92.2	-24.6	-22.0	70.2
4	Benefits	16.2	13.1	12.2	-4
High high housing and low low low housing	NPV	-90.9	-50.7	-26.1	64.8

7.4 Tilting points

This section discusses the results for the analyses that are performed in order to find tilting points for which a shift in preferred strategy occurs.

Although a no-regret investment strategy was found in the previous sections, there are reasons to perform additional analyses to find tilting points. One of those reasons is that the benefits of flexible strategy 3 are not the highest for every scenario, but since the cost of the inflexible strategy are much higher, within the original model setup the NPV of the inflexible strategy does not become higher than the NPV of the flexible strategy.

Information about break-even points is provided by a rather simple calculation based on the estimated cost and benefits found in section 7.2. The total net cost of the inflexible strategy are 2.3 times the cost of the flexible strategy, while the benefits of the inflexible strategy vary between 1.03 and 1.71 times the benefits of the flexible strategy. Calculation gives that the benefits roughly on average have to increase by a factor 2.3/0.4=5.7 for the inflexible strategy to compete with the flexible strategy within this study. More details about this calculation can be found in Appendix 9. This section sheds light on how the parameters in the model setup can contribute to an increase (or decrease) of benefits resulting in a shift in optimal investment strategy.

magnitude of housing construction

For an urban development scenario 10 and 50 times the expected magnitude, a tilting point in strategy with the highest expected benefits is found. The flexible strategy has the highest expected benefits for the second probability distribution scheme in which the probability for rail tangent is high and for metro is low (Table 7-4;

Table 7-5). In the original model setup with household size 2, the inflexible strategy had the highest expected benefits for this scenario probability distribution.
However, the preferred development strategy remains the same as for the original scenarios (Table 7-4). Above a shift in highest expected benefits the design with a household size multiplied by 50 also reveals an interesting shift in strategy with the highest expected NPV (net benefits) towards the inflexible strategy.

The results of the decision model of an increase of model-based household size a factor 10 the size of the original analysis (20 instead of 2) are shown in Table 7-4.

Table 7-5 does the same but for a household size multiplied by a factor 50 (100). Both tables provide a comparison with the results for household size 2.

Table 7-4 Expected (net) benefits in million € per development strategy per probability distributions with the housing scenario times a factor 10 (household size 20)

		Household size 20			Household size 2		
Scheme probability distributions		1.Inflexible: Tram	2.Flexible: BRT + extension tram or nothing	3.Flexible: BRT + extension BRT or nothing	1.Inflexible: Tram	2.Flexible: BRT + extension tram or nothing	3.Flexible: BRT + extension BRT or nothing
1	Benefits	34.6	27.0	24.0	15.9	12.3	11.7
Equal probabilities	NPV	-72.7	-27.3	-13.3	-91.2	-42.0	-25.6
2	Benefits	36.7	39.5	33.9	17.4	15.0	13.5
Railtangent high, metro low	NPV	-70.4	-33.2	-10.2	-89.6	-57.6	-30.6
3	Benefits	32.9	16.4	15.9	14.8	10.6	10.5
R low Metro high	NPV	-74.2	-18.8	-16.6	-92.2	-24.6	-22.0

Table 7-5 Expected (net) benefits in million € per development strategy per probability distributions with the housing scenario times a factor 50 (household size 100) and the original settings (household size 2)

Scheme distributions	probability	Household size 100 1.Inflexible: Tram	 2.Flexible: BRT + extension tram or nothing	 3.Flexible: BRT + extension BRT or nothing	Household size 2 1.Inflexible: Tram	 2.Flexible: BRT + extension tram or nothing	 3.Flexible: BRT + extension BRT or nothing
1	Benefits	117.8	92.1	78.4	15.9	12.3	11.7
Equal probabilities	NPV	9.9	37.8	41.1	-91.2	-42.0	-25.6
2	Benefits	122.5	148.4	124.9	17.4	15.0	13.5
Railtangent high, metro low	NPV	15.1	75.7	80.8	-89.6	-57.6	-30.6
3	Benefits	113.4	42.0	39.8	14.8	10.6	10.5
Railtangent low Metro high	NPV	5.9	6.8	7.4	-92.2	-24.6	-22.0

Looking at the NPVs per strategy per scenario, a second tilting point can be found. The NPV for the flexible BRT strategy has become almost positive (Table 7-6). This means that for this model setup it is almost profitable for society to invest in a BRT system, even in phases. From this finding it can be concluded that phased investment in BRT can be compared to direct investment in BRT for the model setup with housing scenarios more than a factor 10 the size of the housing scenarios in this case study.

Table 7-6 Benefits and NPV per strategy for each scenario for household size 20 (in million €).

(in million €)	1.Inflexible: Tram	2.Flexible: BRT + extension tram or nothing	3.Flexible: BRT + extension BRT or nothing
Benefits			
High RM	€ 41.3	€ 15.5	€ 15.5
Low RM	€ 28.1	€ 13.0	€ 13.0
High MnoR	€ 38.5	€ 15.6	€ 15.6
Low MnoR	€ 26.2	€ 13.0	€ 13.0
High RnoM	€ 43.9	€ 59.8	€ 46.4
Low RnoM	€ 30.9	€ 29.9	€ 29.9
NPV			
High, noRM	€ -66.5	€ -58.3	€ -0.9
Low, noRM	€ -79.4	€ -19.1	€ -19.1
High RM	€ -67.1	€ -16.0	€ -16.0
Low RM	€ -79.9	€ -18.5	€ -18.5
High MnoR	€ -68.4	€ -15.9	€ -15.9
Low MnoR	€ -80.8	€ -18.5	€ -18.5
High RnoM	€ -63.1	€ -55.1	€ -0.5
Low RnoM	€ -76.0	€ -17.0	€ -17.0

Railtangent and metro: decision moments and time between events

For the Inflexible direct tram strategy the NPVs are lower for the scenarios with delayed events (Table 7-7). For the flexible strategies most of the NPVs are higher for the delayed strategies. These results indicate that more delayed options are interesting for this case study and can be interesting to analyze for other public transport development projects.

A remarkable result is that the inflexible strategy has the highest expected NPV in case of delayed events and a high probability that a scenario including metro becomes reality (

Table 7-8). This result can be explained by the fact that within the flexible investment strategies, the flexible option to extend the BRT from Zuid to Stadionpark is only executed in two scenarios. While the benefits from serving the demand in the Stadionpark area are substantial, especially if the magnitude of housing construction increases. This result also suggests that the benefits of the tram together with the lower cost of direct investment compared to phased investment outweigh the negative impact of metro on passenger revenues.

Table 7-7 NPVs strategies per scenario and in case of 2nd scenario for household size 2

(in million €)	1.Inflexible: Tram	2.Flexible: BRT + extension tram or nothing	3.Flexible: BRT + extension BRT or nothing
NPV			
High, noRM	€ -91.9	€ -99.3	€ -32.3
Low, noRM	€ -93.2	€ -21.7	€ -21.7
High RM	€ -89.9	€ -21.2	€ -21.2
Low RM	€ -91.2	€ -21.4	€ -21.4
High RnoM+M	€ -88.9	€ -96.5	€ -32.1
High MnoR	€ -92.0	€ -21.1	€ -21.1
Low MnoR	€ -93.3	€ -21.4	€ -21.4
High RnoM	€ -88.5	€ -96.0	€ -31.9
Low RnoM	€ -89.8	€ -33.5	€ -33.5
High noRM+RM	€ -90.3	€ -21.3	€ -21.3
Low noRM+RM	€ -91.8	€ -21.5	€ -21.5
High noRM+M	€ -92.0	€ -21.3	€ -21.3
Low noRM+M	€ -93.3	€ -21.5	€ -21.5
High noRM +R	€ -90.0	€ -75.4	€ -30.5
Low noRM+R	€ -91.2	€ -71.2	€ -29.9

Table 7-8 Expected NPV per strategy for each probability distribution. Second events are delayed by 5 years. (household size 100 both

		Delayed			Original		
Scheme probability distributions		1.Inflexible: Tram	2.Flexible: BRT + extension tram or nothing	3.Flexible: BRT + extension BRT or nothing	1.Inflexible: Tram	2.Flexible: BRT + extension tram or nothing	3.Flexible: BRT + extension BRT or nothing
1 Equal probabilities	Benefits	118.4	96.7	74.5	117.8	92.1	78.4
	NPV	11.1	40.3	38.1	9.9	37.8	41.1
2 Railtangent high, metro low	Benefits	121.7	164.1	113.5	122.5	148.4	124.9
	NPV	14.5	84.6	72.2	15.1	75.7	80.8
3 Railtangent low Metro high	Benefits	115.7	42.1	38.6	113.4	42.0	39.8
	NPV	8.6	6.6	6.3	5.9	6.8	7.4
4 High high and low low	Benefits	135.1	113.6	89.6	133.8	115.8	95.2
	NPV	28.0	51.7	52.1	25.8	52.0	57.0

Impact modal split metro

The flexible strategies become more economically efficient compared to the inflexible strategy if the demand for the invested service drops from modal split 0.5 to 0.1. For the parameter value 0.1 it is expected that the impact of scenarios including a metro increases. As can be observed from Table 7-9, the impact of metro on expected (net) benefits has indeed increased, especially for probability distribution schemes with a high probability for a scenario including a metro. The effect is better visible for household size 100. As can be seen the expected NPV Inflexible tram strategy for 'Railtangent Low, metro high' is -0.4 for modal split 0.1 compared to an expected NPV of 5.9 for modal split 0.5.

Table 7-9 Expected (net) benefits for both modal split metro and metro+railtangent 0.1 compared to 0.5.

		Household size 100, modal split if metro =0.1, modal split if metro+railtangent =0.1			Household size 100, modal split if metro =0.5, modal split if metro+railtangent =0.5		
in million € Scheme probability distributions		1.Inflexible: Tram	2.Flexible: BRT + extension tram or nothing	3.Flexible: BRT + extension BRT or nothing	1.Inflexible: Tram	2.Flexible: BRT + extension tram or nothing	3.Flexible: BRT + extension BRT or nothing
Equal probabilities	NPV	6.5	38.8	42.1	9.9	37.8	41.1
Railtangent high, metro low	NPV	14.1	76.0	81.1	15.1	75.7	80.8
Railtangent low Metro high	NPV	-0.4	8.6	9.1	5.9	6.8	7.4

7.5 Validation

In order to validate the outcomes of the applied methodology, a workshop is held with mobility advisors from RET. The results of the workshop was that the method provides useful decision information. The case study shows that flexible investment strategies can be more economically efficient than inflexible, direct investment, strategies in urban public transport development.
Further, the usefulness of the inflexible strategy within the experiment design was debated, because the inflexible strategy tram has a lower NPV than the flexible strategies for each scenario included in the analysis.. During the workshop it was argued that an inflexible strategy consisting of direct investment in a BRT system for the complete section Blaak-Zuid-Stadionpark would be (economically) interesting to include in the analysis.

For RET it is interesting to see in which future circumstances an inflexible strategy becomes interesting. Therefor the analyses to find tilting points

Current practice is that public transport operators make business cases to decide if they want to operate on a certain line or area of a transport system. From the reflection session it became clear that travel time savings are not explicitly included at the moment, but the impact of this on the expected number of new trips on a line is. Increase of accessibility is included in other ways at the moment, for instance the number of jobs reachable within an hour.

7.6 Conclusion

To summarize, this section aimed to answer how the scenarios affect the performance of investment strategies. This section provides the main findings from which the second subquestion in this research is answered.

Estimated costs, benefits and NPV per strategy
For the original model setup, the flexible investment strategy (BRT + extension BRT or nothing) results in the highest Net Present Value (NPV) in every scenario. This result would indicate that this strategy is a no-regret strategy and the preferred investment strategy. However, although this strategy results in the highest NPV, this is a negative NPV and hence an economically inefficient investment strategy in the analysis. An explanation can be found in the high net cost of the investment strategies compared to relatively low benefits.

The investment decision is found to be insensitive for the scenario probabilities. From the sensitivity analysis concerning scenario probabilities, there is no indication that another strategy becomes more interesting for different scenario probabilities. This finding follows from the result that the flexible strategy, which only includes BRT, has the highest NPV for every scenario.

Looking at the benefits of the strategies, the inflexible strategy results in higher benefits for almost every scenario. This suggests that there might be scenarios, out of the scope of this study, for which the inflexible strategy is preferred over the flexible strategies. However, because the cost of the inflexible strategy are 2.3 times the size of the cost of the cheapest flexible strategy, while the benefits are only around 1.04 times the benefits of the flexible strategy, the inflexible strategy does never perform best for the scenarios that were argued to be realistic for this study.

Tilting points
This chapter presented results of additional analyses, in which the model-based layout of the scenarios was changed, in order to get insight in the impact of the scenarios on the outcome of the decision model. To be more specific, it was investigated what the impact of the

magnitude of urban development, different scenarios after the second decision moment, and the mode share parameter for the investment when the metro and/or rail tangent are build.

With respect to the layout of the scenarios, one tilting point in optimal investment strategy was found. The inflexible strategy was found to have the highest expected NPV for a high probability that a scenario including metro becomes reality, in which the opening of the metro is delayed by five years, and in which the housing construction is multiplied by a factor 50. Apparently delayed scenarios result in a higher NPV for direct investment. This result can be explained by the fact that within the flexible investment strategies, the flexible option to extend the BRT from Zuid to Stadionpark is only executed in two scenarios. While the benefits from serving the demand in the Stadionpark area are substantial, especially if the magnitude of housing construction increases. This result also isuggests that the benefits of the tram together with the lower cost of direct investment compared to phased investment outweigh the negative impact of metro on passenger revenues.

On top of that, the additional analyses did reveal for which level of urban development the cheapest flexible strategy becomes economically efficient for the case study. It was found that for an increase of inhabitants by a factor 10, the NPV of the preferred flexible strategy becomes almost positive for the scenarios “High no rail tangent, no metro” and “High, railtangent but no metro”.

Moreover, it is interesting that the impact of metro is relatively low. An explanation for this observation is that the only impact of metro in the decision tree analysis is that demand drops and hence the passenger revenues for the operator decrease.

8 Conclusion and recommendations

In this study the applicability and usefulness of real options analysis for public transport development is assessed by means of application to a case study. Based on an analysis of uncertain urban development, both inflexible investment strategies as flexible investment strategies, which have the option to respond to those uncertainties, are designed These strategies are quantified and monetized using societal cost benefit analysis. In order to determine the economically optimal investment strategy, decision tree analysis is applied using the net present values (NPVs) from the SCBA as input.

This study contributed to both research and society. With respect to research this study contributed in insights about the usefulness of real options analysis in urban public transport systems. Besides, the research gives insights in how to apply these type of analysis in this field of operation. For society this research has proven that real options analysis can help in saving public money by preventing afterwards unnecessary investments in urban public transport. Moreover it helps transport authorities and operators to think about potential flexible, phased development options for urban transport and provides a method to asses these options.

This chapter summarizes the main findings, provides answers to the research questions, discusses the limitations of the research and gives recommendations for further research.

8.1 Conclusion

To answer the main research question, two subquestions were formulated. The subquestions are shortly discussed followed by an answer to the main research question. The first question focused on how flexibility can be incorporated in the design of urban public transport networks.

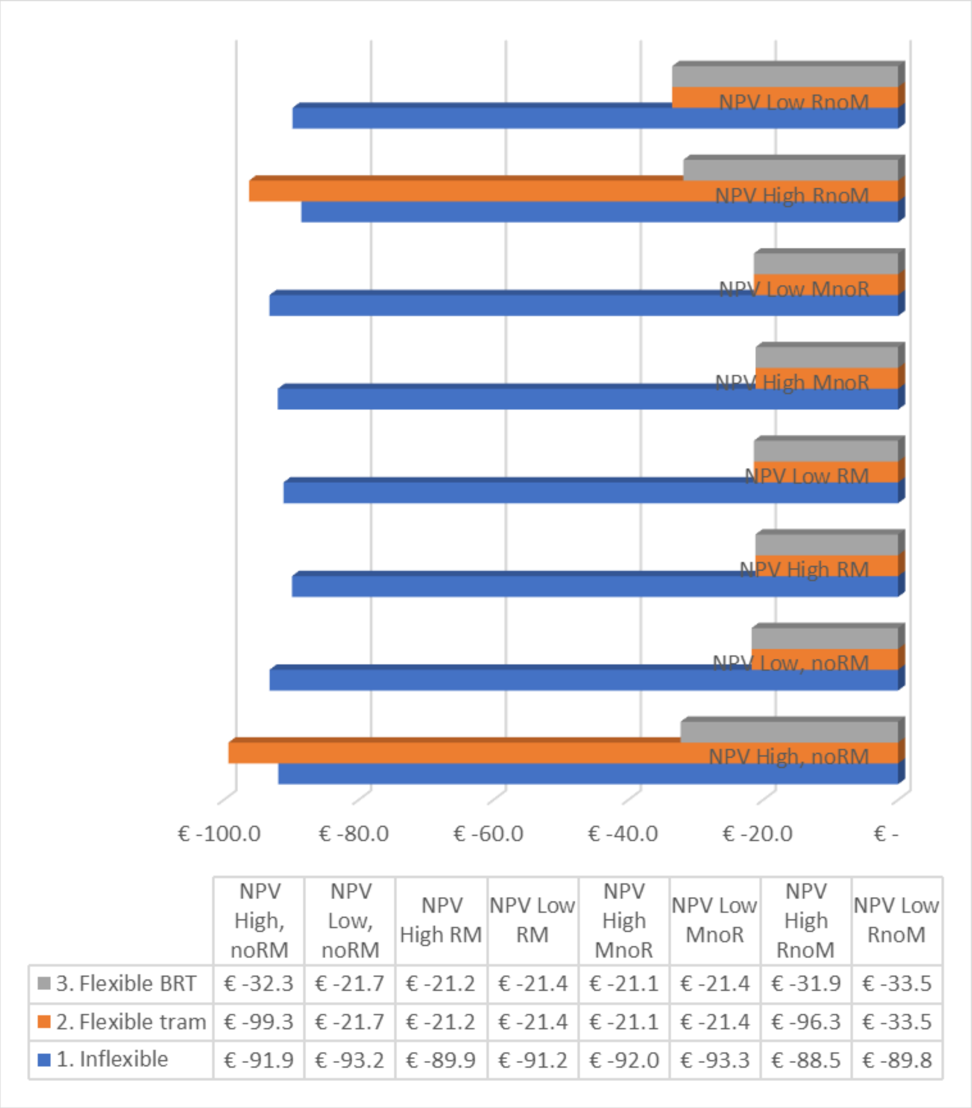
1. What kind of real options do public transport operators and other stakeholders have for the improvement of an urban public transport network?

With respect to existing type of real options, the option to defer, the staged investment option and the growth option seem to reflect the real options in public transport network design best. Regarding the options to improve urban public transport systems, it was found that Light Rail Transit (LRT) and Bus Rapid Transit (BRT) are considered to be high quality transport systems which can improve public transport systems for each stakeholder. These systems offer flexibility in design, which can be used to design and adapt the system following the development of uncertainties such as travel demand.

Staged development of public transport can be explained as the construction of a BRT or LRT system on a section in two (or more) phases. This can be done by starting with the construction of the first part of a section and later on extend the system with the construction of the final part of the section. This is very interesting if it uncertain when and where new houses or even a whole new neighborhood are going to be build. There is also an option to defer the construction of the second part of the section, for instance if no urban development takes place anymore at all. Moreover, BRT can also be seen as a stage within the construction of LRT. Then the system is not only expanded by constructing the second part of the section, the capacity of the system is also increased by transforming BRT into LRT. This option within the planning strategy can be interpreted as a growth option

2. How do future scenarios affect the performance of investment strategies in urban public transport network design and planning?

Flexible, and cheaper, investment strategies perform best, regardless of the scenario (Figure 8-1). Although the flexible strategy results in higher Net Present Values (NPVs), it is the inflexible strategy that results in higher benefits for almost every scenario. Not only the benefits but also the cost of the inflexible strategy are higher than those of the flexible strategy. Since the difference in cost is larger than the difference in benefits, the inflexible strategy is never optimal in the experimental setup studied in this research.



	NPV High, noRM	NPV Low, noRM	NPV High RM	NPV Low RM	NPV High MnoR	NPV Low MnoR	NPV High RnoM	NPV Low RnoM
◼ 3. Flexible BRT	€ -32.3	€ -21.7	€ -21.2	€ -21.4	€ -21.1	€ -21.4	€ -31.9	€ -33.5
🟧 2. Flexible tram	€ -99.3	€ -21.7	€ -21.2	€ -21.4	€ -21.1	€ -21.4	€ -96.3	€ -33.5
🟦 1. Inflexible	€ -91.9	€ -93.2	€ -89.9	€ -91.2	€ -92.0	€ -93.3	€ -88.5	€ -89.8

Figure 8-1 NPVs of each investments strategy per scenario

Nevertheless, it was found that scenarios for urban development have the potential to increase the benefits and hence the NPV of investment strategies. However, the method is not very suitable when there are uncertainties regarding other, competing, transport projects. The impact of other, competing, transport projects was found to be rather small. As discussed in the discussion chapter, in a scenario including the construction of a metro, only the passenger revenues of the studied investment are affected, while the other benefits remain equal.

Tilting points in optimal investment strategy only occur for very high housing construction scenarios. In the decision tree, the real options are only executed in two of the eight possible scenarios. While in case of extremely high housing construction scenarios, substantial benefits can be achieved from a transport service that serves the whole section and not just a part of it as is done in the flexible strategies.

After answering all the subquestions the main question can be answered.

To what extent is real options analysis useful to develop public transport networks?

The first conclusion is, application of real options analysis in urban public transport systems is possible. Moreover, it helps to think about how flexibility can be incorporated in the design of public transport networks.

Secondly, application of the method gives insight in the expected (net) benefits of a set of network development strategies including real options and hence can prevent decision makers from doing in hindsight unnecessary investment. With respect to the case, purely economically advice would be do nothing because every NPV is negative. However, it can be argued that public transport has also other values and NPVs resulting from SCBA are not the only criterium for society to invest in public transport. If it is desired to invest in public transport even though the NPV Is negative, implementing the flexible strategy is most economically efficient. This case study showed that implementing the flexible strategy can save almost 70 million euros in comparison to the inflexible strategy.

Thirdly, real options analysis falls short as an evaluation method because it is biased towards phased strategies in the field op urban public transport. The reason for this is that it opts for the cheapest (hence flexible, staged) strategy if each strategy is economically inefficient, while urban public transport projects are very often not economically efficient but executed because of other reasons such as fairness.
If investing is found to be economically inefficient, the result of real options analyses is that investing the least is the optimal strategy. The flexible strategy provides the possibility to only construct a part of the project (for instance 4 km tram of a project that involves a total of 8 km in the inflexible strategy) and gives the option to defer the construction of the other part. In other words, if the cost are higher than the benefits for every strategy (e.g. negative NPV), it is economically optimal to choose the cheapest strategy, which is the flexible strategy including the defer option. In such a case, an analysis comparing a flexible, phased investment strategy with an inflexible investment strategy will give the result that the flexible strategy is optimal.

Further, the method is proven to be useful to find tilting points for which a shift in optimal investment strategy occurs. This is the investment strategy with the highest expected NPV based on scenario probabilities. One of the tilting points found for the case is that the inflexible strategy became preferred in one of the scenarios given housing construction scenarios a factor 50 the expected magnitude. Also, if housing is multiplied by a factor 50, the results of the experiment with a delay of scenarios by 5 years show that the direct investment in tram is becoming a competitor to phased development.

Based on the results from the reflection workshop, the method is found to be useful in practice to get an idea of the threshold value for number of passengers after which it becomes interesting to lobby for tram instead of BRT. However, the method has some disadvantages for application in practice. The method is very data intensive and the more strategies and scenarios are developed, the more complex and unclear it gets.

8.2 Discussion

Having summarized the conclusions in the previous section, this section presents a discussion of those results and the assumptions made to obtain them. The section starts by looking into the suitability of real options analysis (and implicitly economic evaluation) for public transport projects. The second part looks at the assumptions that were made.

First, as argued in the conclusion, real options analysis falls short towards evaluation of transport projects because it is a (societal) economic evaluation method, while investments in public transport are not conducted for purely economic reasons. In fact, half of all the transport projects has a negative cost benefit balance (NPV) (Rienstra, 2008). By applying societal cost benefit analysis also societal cost and benefits are monetized, but this method does still not properly monetize all of the important benefits such as equity (van Wee, 2012). If public transport has higher costs than benefits, the NPV is negative. If the NPV of each strategy is negative, decision tree analysis will opt to go for the cheapest options, which is the phased strategy in which there is the option to defer the construction of the second part and hence construct only the first part of the project.

Within the analyses it was assumed that no new events happen after the second decision moment, while in reality many things can happen in the years between 2026 and 2040. Those event may heavily influence the outcome of the decision analysis,

In our research, metro is included as an external event causing knowledge uncertainty, while one can argue that it is not external and more a policy uncertainty. Policy uncertainties are better to tackle by means of agreements and covenants (Bos et al., 2016). Also, the impact of the metro on the benefits of our strategies is rather small, while RET thinks that the investment options considered in this study are unnecessary in the presence of the metro. The small impact of the metro on the benefits can partially be explained by the assumptions made in the societal cost benefit analysis. Within our analysis, a metro scenario only affects the passenger revenues, which, based on the results, leads to a small decrease of benefits. The results showed that high housing scenarios including a metro and low housing scenarios without a metro have roughly similar benefits. To summarize, the model is verified for metro senarios but the outcomes are not completely valid.

Finally, a specific difficulty in public transport systems has to do with trade-offs in public transport design. The effect of adaptations to currently operating PT lines is very complex. Transport models often reveal a loss of passengers for adaptations making the network coarser and rerouting of current lines because this disturbs existing travel patterns. Currently the transport model used by RET only includes walking as an access mode while literature suggests people are willing to travel larger distances possibly by bike for a transport service that is faster and has a higher frequency. vel further to a faster service with less stops. For the calculation of travel time savings for the connection to Stadionpark the access distance was not included. for the section Blaak-Zuid the elastic demand and the total travel time savings for BRT and tram are calculated manually (with the assumtion that half of the trips made by bus 32 was made by travelers willing to use shared bikes to stops). For the calculation of travel time savings due to the connection with the railtangent however, the limitations of the model did result in a limitation. Travel time savings for trips made from Feijenoord and Kop van Zuid-Entrepot due to the railtangent are obtained as output from transport model OV-Lite in which the access time is larger than manually calculated with the availability of shared bikes This model problem is partially solved by adding fast walking links with a cycling speed of 15 km/h in the transport model.

Within our study it was assumed that phased investment does not demands additional cost of replacement transport, nuisance, and so on. In reality phased strategies may raise additional cost and should be included. In our study this would have led to higher cost and because of that lower NPVs of the flexible strategies. If those additional cost are very high, especially if the construction takes long, the inflexible, direct investment strategy may be more attractive.

8.3 Limitations

This study has a few limitations. This section starts with model input such as scenarios, real options and projects that were not included in the analysis.

First of all, not all the effects of public transport are included in the analysis. For instance capacity is not included, though seat probability is a welfare effect on which tram performs better than BRT due to a higher vehicle capacity.

Besides the effects, also not every thinkable uncertain factor is included and hence neither every scenario. Also technological development, for instance automated driving technology, is uncertain but may have a big impact on ridership for public transport. Also trends like shared mobility may influence the ridership of traditional public transport services such as BRT and LRT.

On top of that, neither all the real option categories and investment alternatives are considered in the analysis. One can think of including direct investment in BRT as an inflexible strategy. Also including delay options may give interesting results.

Moreover, the analysis does not reflect the advantages of direct investment over phased investment. In reality, constructing a tramway or exclusive bus lane at once is cheaper and politically easier to achieve than constructing in phases. In the analysis in our study it is assumed that the investment costs only depend on the number of km tramway or bus lane. On top of that, neither the additional cost of replacement transportation and the loss of passengers during the transformation of exclusives bus lanes into tramway are included.

What is currently not reflected in the model properly is the potential demand between Feijenoord and the new area of Stadionpark. The new demand between those areas is not incorporated in the model. The model only reflects the demand within Stadionpark for the faster route to the city center via the new connection through Feijenoord. The potential attraction Stadionpark will have from Feijenoord (and other zones) is not included in the model. If this is assumed being very high, the benefits in the model and the preferred strategy might change.

8.4 Recommendations for practice

The following recommendations are given with respect to the case study. One of the main findings is that the flexible strategy, in which is invested in BRT In phases, is a no-regret strategy as it has the highest NPV for every scenario. However, since there is not a single strategy having a positive NPV the ‘do nothing strategy’ would probably be optimal if it was included. Further it is observed that the expected benefits of each strategy do not differ much per scenario, indicating that the development of uncertain factors is not so relevant for the network development of public transport. That is, for this case study and following from the model used in this study.

If the urban development would explode in this area and more than 50 times as many people will start living in the case study area or start traveling towards the area for whatever reason, it may be recommended to apply the inflexible development strategy.

8.5 Recommendations for further research

Based on the results and the discussion the following recommendations for further research can be given.

In this study a simplified societal cost benefit analysis is executed due to a lack of data and time. The result of this is that the NPVs may not give a fair comparison of strategies and that every investment strategy was found economically inefficient and hence the cheapest strategy was the optimal choice in every scenario. It is recommended to include more and/or other welfare effects in further research, like comfort based on the capacity.

As not all the effects of public transport, like equity, can be monetized correctly in societal cost benefit analysis, this is a limitation for real options analysis within this field. Based on this limitation, it is recommended to explore if there are ways to monetize the wider benefits of urban public transport. If this is possible, the real options analysis becomes more useful for decision making in urban public transport investment.

Real options analysis may in the future be applied to new, innovative and complex urban public transport services such as shared and on demand transit services. Before such research can be conducted, transport models have to be improved to enable better and more detailed analysis of the effect of coarser networks complemented with new modes such as shared and on-demand services as access and egress modes.

Next studies may want to include other investment strategies, like direct investment in BRT, and flexible strategies including real options that weren't included in our research. Within this study only staged and growth investment options were included in the analyses. Future studies can investigate the impact of for instance delay options.

Within this study, not every uncertain variable was included. Further research may want to analyze the impact of other uncertain variables and scenarios on the decision outcomes. Interesting uncertainties to include may be technological development and the popularity of shared mobility. Decision tree analyses is more relevant when there are uncertainties that actually influence the outcome of the analysis. If there is a no-regret strategy, a strategy that has the highest NPV in every scenario, it doesn't matter for decision-making what the scenario probabilities are or what happens in the future. Then it is clear which investment should be done.

The negative NPVs for every branch provide some implications for more interesting case studies for further research. Since travel time savings are among the largest contributors to benefits, it can be recommended to use a case study in which the current PT service is of low quality and the potential travel time savings for new services are big.

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Appendix 1. Analysis Current situation

The current situation consists of the current supply and the current use of the supplied transport system. The current transport network consists roughly of public transport system, roads for cars and roads for active travelers and pedestrians.

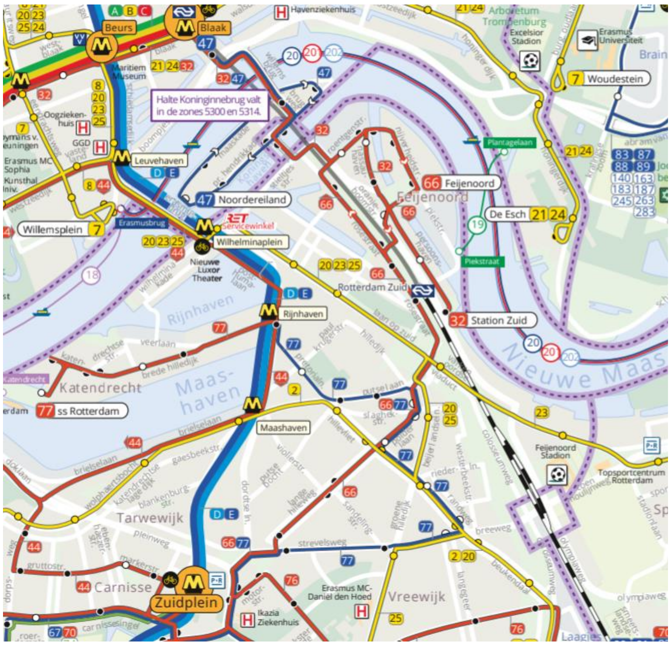


Figure 1. Public transport network: Part of Lijnennetkaart RET (Adopted from: https://www.ret.nl/fileadmin/user_upload/Documenten/PDF/Kaarten_en_plattegronden/RET_lijnennetkaart_2018.pdf)

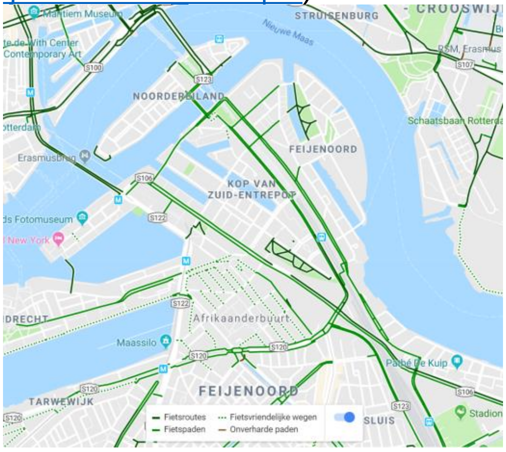


Figure 2. Bicycle network in Feijenoord, adopted from maps.google.com

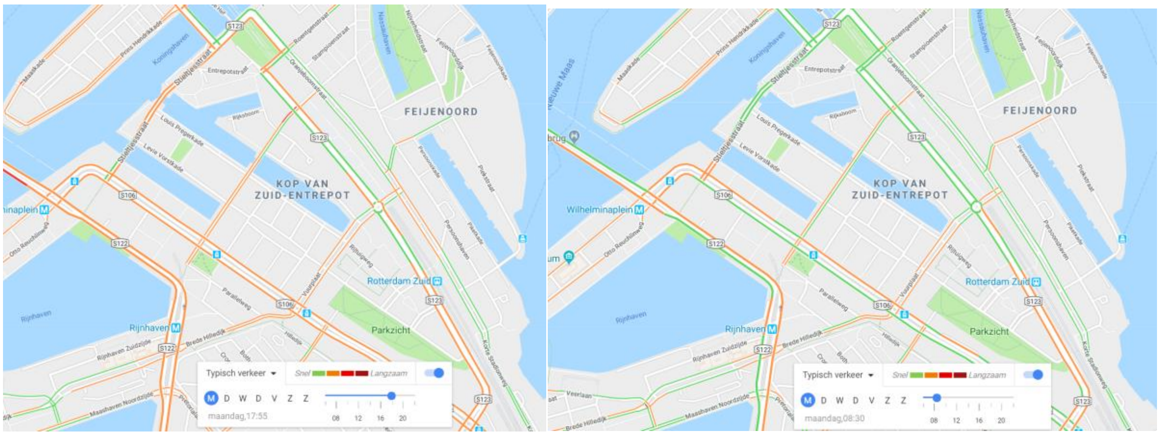


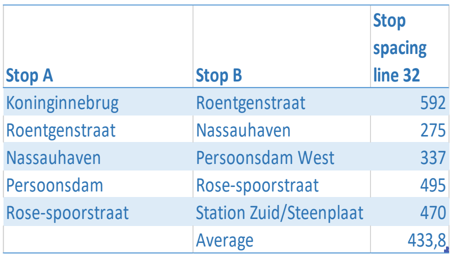
Figure 3a (left) 3b (right). Typical car traffic in Feijenoord

Stops

Analysis supply: stop spacing

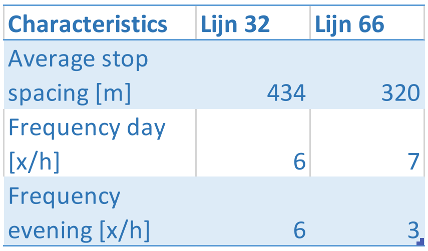
T*able 1. Stop spacing line 66 (left) and Stop spacing line 32 (right)*

Stop A	Stop B	Stop spacing line 66
Station Zuid/Rosestraat	Burgdorfferstraat	383
Burgdorfferstraat	Vrij Entrepot	598
Vrij Entrepot	Roentgenstraat	175
Roentgenstraat	Nassauhaven	300
Nassauhaven	Zinkerstraat	328
Zinkerstraat	Persoonsdam	237
Persoonsdam	Damstraat	353
Damstraat	Burgdorfferstraat	200
Burgdorfferstraat	Station Zuid/Rosestraat	383
Station Zuid/Rosestraat	Spoorweghaven	247
	Average	320,4



Stop A	Stop B	Stop spacing line 32
Koninginnebrug	Roentgenstraat	592
Roentgenstraat	Nassauhaven	275
Nassauhaven	Persoonsdam West	337
Persoonsdam	Rose-spoorstraat	495
Rose-spoorstraat	Station Zuid/Steenplaat	470
	Average	433,8

Table 2. Average stop spacing and frequency line 66 and 32



Characteristics	Lijn 32	Lijn 66
Average stop spacing [m]	434	320
Frequency day [x/h]	6	7
Frequency evening [x/h]	6	3

Analysis use of supply:

Where do people enter the system? What are the origins of travelers and where do they want to go to?

Number of people boarding and alighting

From OV-chipkaart data it is possible to extract the number of people boarding and alighting at the different stops part of a bus service. Such an extraction is done for bus line 32 and 66. Analyzing the results gives insight in the important stops and travel patterns of users of these bus services. For station Zuid there are three different bus stops which are shown in figure X. Of those stops one is part of line 32 and two are part of line 66.

For bus 66 Spoorweghaven is a very busy stop. The people boarding and alighting at this stop can either come from or go to Station Zuid to travel further or have their destination at for instance Albeda college.

Looking at the origins and destinations matrix for line 32 it is striking that most people alight at stop Station Blaak, which is really the stop connecting the bus to the higher level metro and train network. The busiest stops in Feijenoord are Roentgenstraat, followed up by Persoonsdam and Willemsbrug.

Table 3a (left) and 3b(right). Total of people boarding on an average weekday at the different stops within Feijenoord served by bus line 32 (left) and 66 (right).

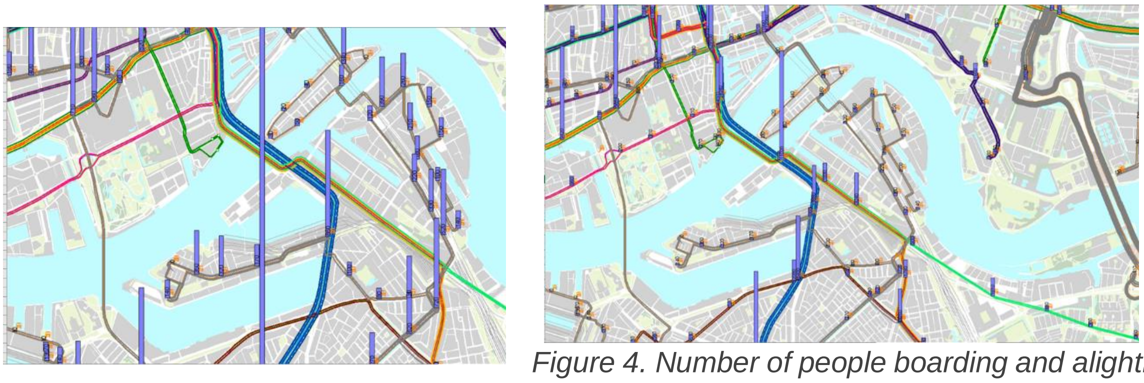


Figure 4. Number of people boarding and alighting at each stop. Bus (left) and bus+tram+metro (right)

Table 4a(left) and 4b(right). Number of trip destinations from Entrepot (left) and Feijenoord (right)

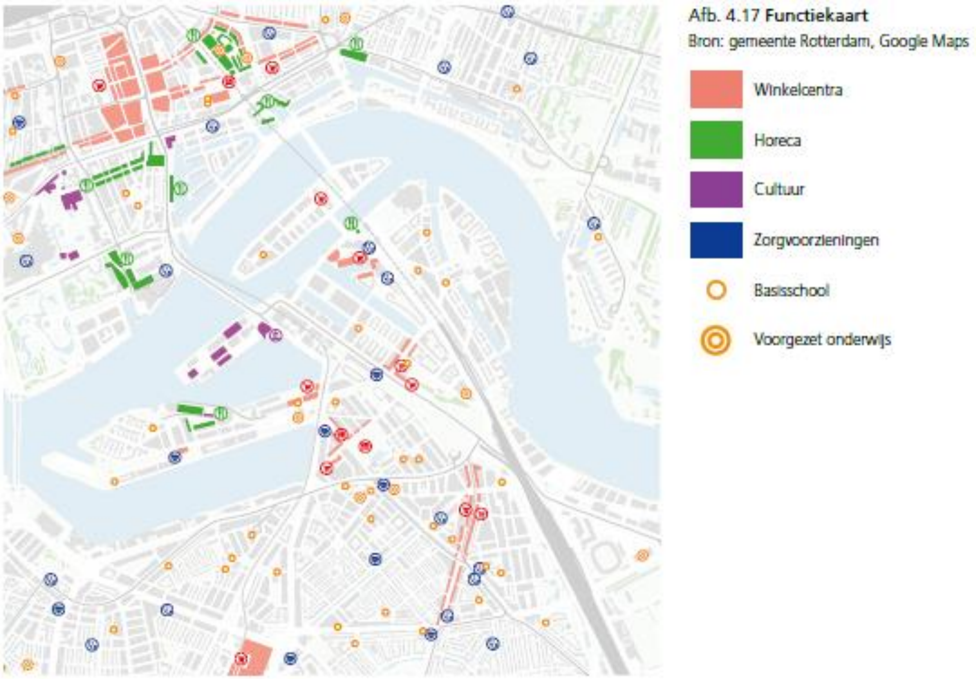


Figure 5. Functions within the case study area

Routes

Analysis of supply: line spacing

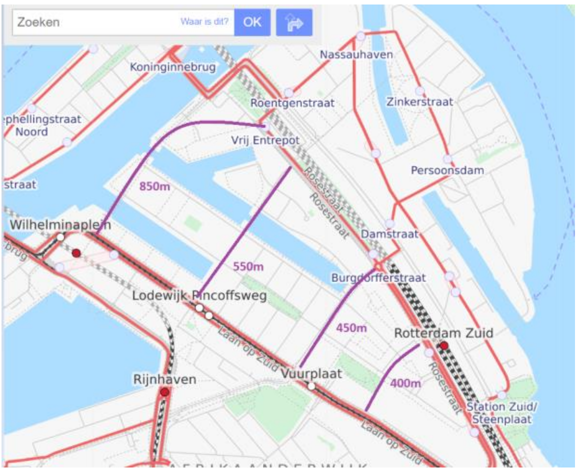


Figure 6. Distance between tram over Laan op Zuid and bus 66 over Rosestraat

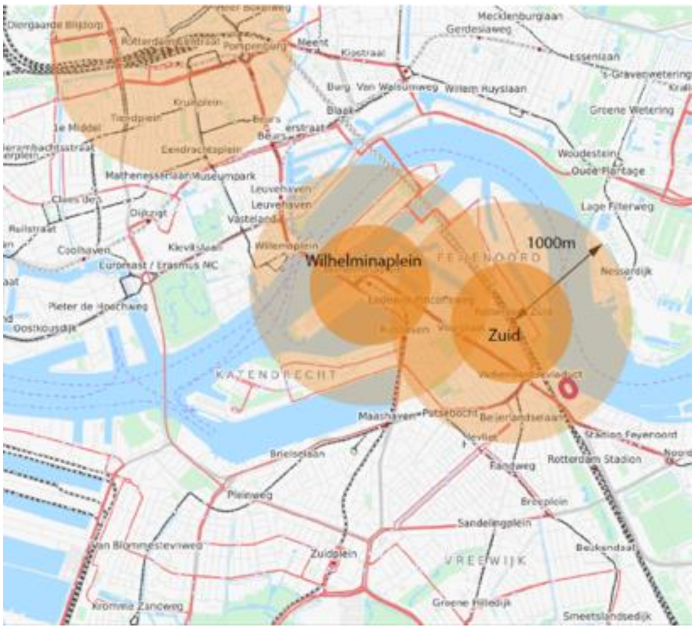


Figure 7. Catchment area current stations of rail systems

Analysis of use of supply
Which routes are there for travelers from a certain origin to a certain destination? What are the characteristics of these route and how does it perform? What is the travel time on this route? How many transfers are required? How large is the detour? How large is the frequency of the system operating on the route?

Figure 8. 24-hour occupation bus (left) and bus+tram+metro (right)

Analysis future situation and observed problems

Supply if nothing changes besides the measures from the OV-visie

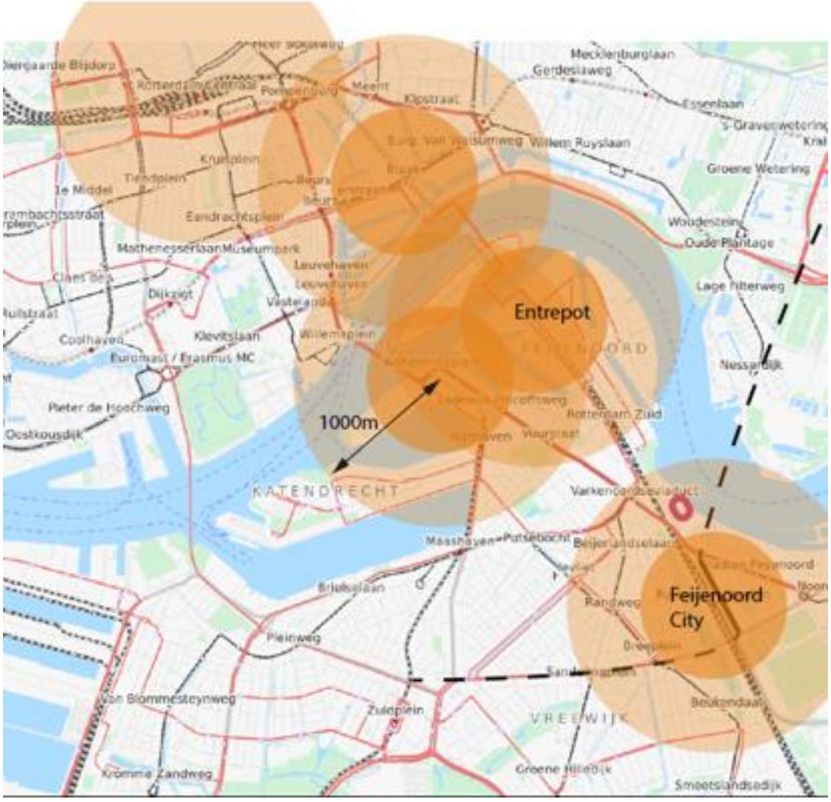


Figure 9. Catchment area 1000m and 500m from planned rail stations

As can be oberserved in figure 9, a gap occurs around the old station Zuid location if the measures within the OV-visie are realized. Except for station Entrepot, there is no connection within Feijenoord to station Feijenoord city.

Appendix 2 Approach and results brainstorm session

Participants (name, function):
Jeroen Henstra, Senior adviseur
Halmar Kranenburg, Policy advisor
Theo Konijnendijk, Sr advisor transport planning/innovation
Sidney Huddleston Slater, Product manager first & last mile transport

session/workshop 15 oktober 2018

During the brainstorm session the participants were asked to restructure the public transport network when the plans from the OV-Visie 2040 are realized. This means they were asked what to do with the transport services in Feijenoord if the plans, like metro and rail tangent, from the municipality and MRDH are being realized in the future. The OV-visie sets the higher level network plans, the participants in the workshop were asked to design the underlying network.

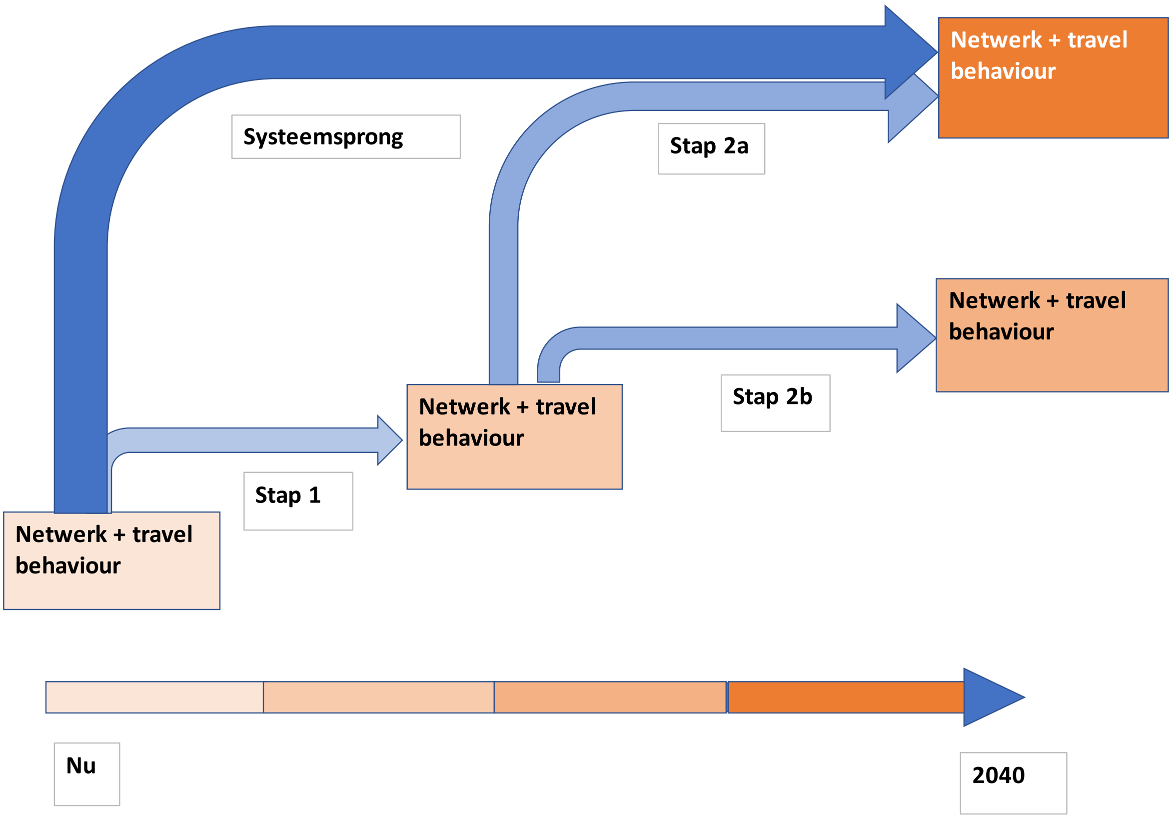


Figure 10. Scheme staged development or big bang development.

As shown in figure 10, there are two possible strategies to develop the network. The first strategy concerns a big bang investment in which immediately is chosen to invest in the network that suits the network the way it is expected/supposed to be in 2040 following the OV-visie 2040. The second strategy concerns a phased development strategy in which not one decision moment, but multiple decision moments until 2040 are taken into account. Hereby the first decision moment concerns the question which investments are necessary to offer a transport system that suits the OV-visie plans for a certain phase between now and 2040. Afterwards there will be a second decision moment in the future when that in-between phase is reached, on which it Is discussed which investment are then required. Hopefully more information is available at that moment about which plans are realized and how fast the realization is going.

Next, the scenarios that were used during the brainstorm as well as the network design proposal that were developed by the participants for each scenario during the session will be explained.

1. Big bang investment towards 2040
2. Network design until an intermediate phase (phase 3, 2030)
3. Network design after intermediate phase towards 2040 scenario a
4. Network design after intermediate phase towards 2040 scenario b

1. *Big bang investment towards 2040*

In the big bang investment strategy to 2040, a situation is assumed in which all measures from the public transport vision up to the final phase have been implemented as shown in table 5.

Table 5.. Maatregelen OV-visie 2040 ingedeeld in fases.

Fase	Maatregel	2018-2022	2023-2029	2030-2040	Na 2040
1	HOV-bus Willemsbrug	X			
1	Versterken busstructuur op Zuid (bundelen en strekken)	X			
2	HOV-bus Maastunnel, Willemsbrug en Zuidplein-Feyenoord City	X	X		
3	Nieuwe Oostelijke oeververbinding + HOV-rail Hart van Zuid - Feyenoord City - Kralingse Zoom		X		
3	Uitvoering Programma Hoogfrequent Spoor: frequentie sprinters 6xpu + IC 8xpu (N.B. is referentie)		X		
3	Nieuw (lightrail) station Feyenoord City		X		
3	Nieuwe tramverbinding Hart van Zuid-Feyenoord City ('Coen Mou-lijn')		X		
3	HOV-rail nieuwe Oostelijke Oeververbinding (Hart van Zuid-Feyenoord City-Kralingse Zoom)		X		
4	Deels geautomatiseerde trams		X	X	
5	Verplaatsen bestaand station Zuid richting Entrepotgebied (nieuw lightrail station)			X	
5	4 sporigheid 12x/u, lightrail			X	

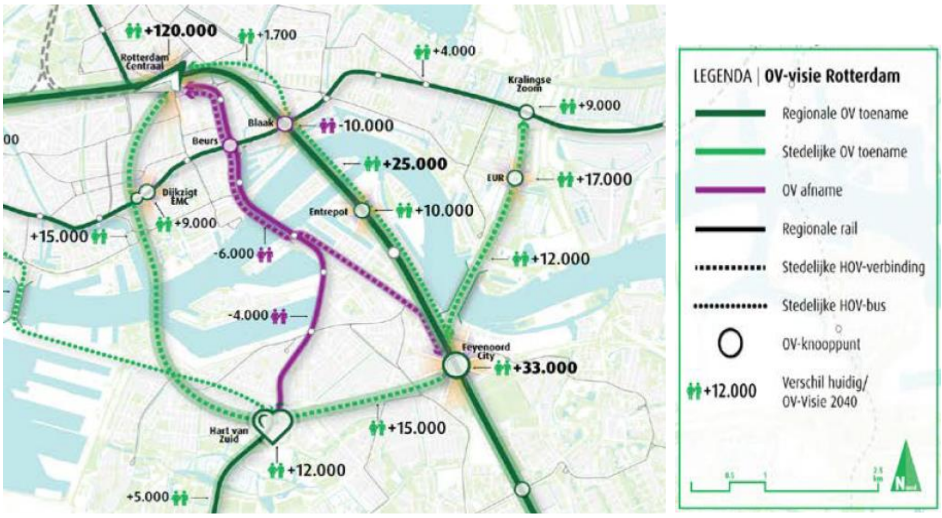


Figure 11. Plans visualized

In this scenario, station Zuid has been relocated to the Entrepot area, the Feijenoord City (Stadionpark) station has been opened and the tangent rail connction from Kralingse Zoom via Feijenoord City to Zuidplein has been realized. IN the meantime, a form of light rail or metro is operating on the Oude Lijn which a frequency of 12/h, which is amongst others serves station Entrepot and Feijenoord City.

The idea is that a sort of empty area with regard to public transport will arise between Entrepot and Feijenoord city around the former station Zuid. In addition, there is no connection between the former station Zuid and Feijenoord City apart from the light rail on the Oude Lijn, although that could become an important station and an important destination in view of all planned developments. Travelers between Feijenoord and Zuidplein obtain roughly two travel options. The first option is over the Oude Lijn from Entrepot to Feijenoord City where they can transfer to the new HOV rail connection to Zuidplein. The second option is with bus line 66 as is already possible now. The latter option will probably remain faster and the advantage remains that no transfer is required.

How much transport demand remains for bus? Which transport relations remain for bus? There are roughly two mindsets for the network in the situation:

1. High quality bus (Dutch: HOV) like bus rapid transit (joint bus 32 and 66), with a lower frequency (6 or 4 times per hour)
2. No more bus lines, there are two rail lines and an attempt is made to optimally use and feed them. Tackle and feed at stations where Entrepot acts as a kind of hub for the neighborhood. Everyone goes with subsystems (bicycle, scooter, scooter, etc). There are also robot taxis who pick people up and drop them off at their door, but those systems are slower, mainly for the disabled.

1. High quality bus (joint 32 and 66) frequency 4-6 per hour. (BRT)

A possible development option for local public transport is to upgrade and combine buses 32 and 66 and to continue through Feijenoord City to Zuidplein (green line in figure 12). Another option is to combine these bus lines and continue to Zuidplein along the route of line 66. One option is to have the other side of the bus drive to Eendrachtsplein instead of Overschie. This bus will have to run every 10 to 15 minutes (frequency of 4-6 per hour).

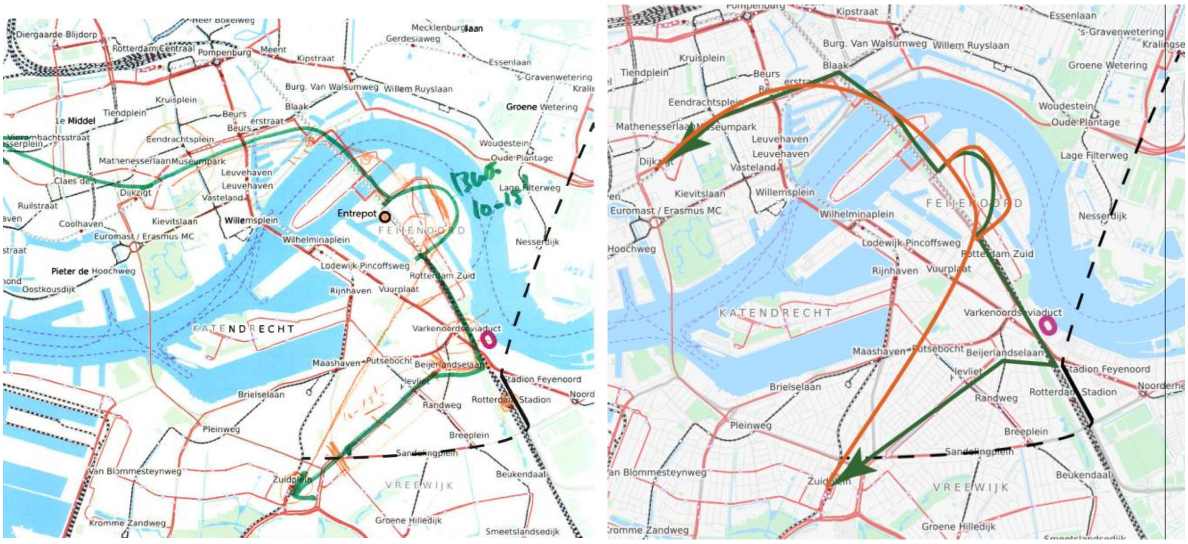


Figure 12. Alternative 1. BRT joint bus 32 and 66

2. Feederen hub station Entrepot using shared systems and autonomous taxis

When this is implemented, the shuttle service will eventually become a bus service that will move from one destination to another with some flexibility. It will be a kind of metro-opening taxi service. (Think of autonomous van such as the bus in Pernis: takes you to location.) But if people are in a hurry, they should better take the bike, own bike or share bicycle (at the station)

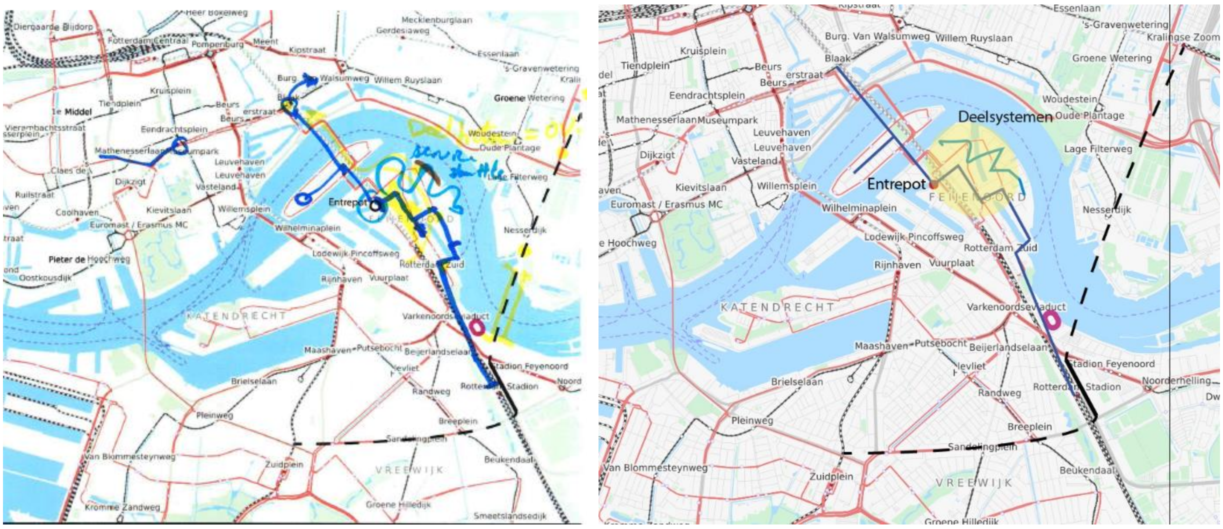


Figure 13. Alternative 2. Feeder services shared systems and autonomous taxis

2. Network design to intermediate phase (phase 3)

After the system jump, it is interesting to look at a phased (step-by-step) development strategy for local passenger transport. For pragmatic reasons, two steps have been chosen with the first step going up to 2030 (phase 3 in Table 6). At this state of the network, the current station Zuid is still in use, but Feijenoord City station is already open and is also connected via HOV rail to Kralingse Zoom and Zuidplein. 6 times per hour now runs a sprinter and 8xpu an intercity. The sprinters stop both at Zuid station and at Feijenoord City station. In the meantime, a lot of spatial development has already taken place and the area surrounding Feijenoord City station has become an attractive destination. Many Feijenoorders (with bus 66) used to go to Zuidplein. An interesting question now is to what extent this is still the case with the arrival of Feijenoord City.

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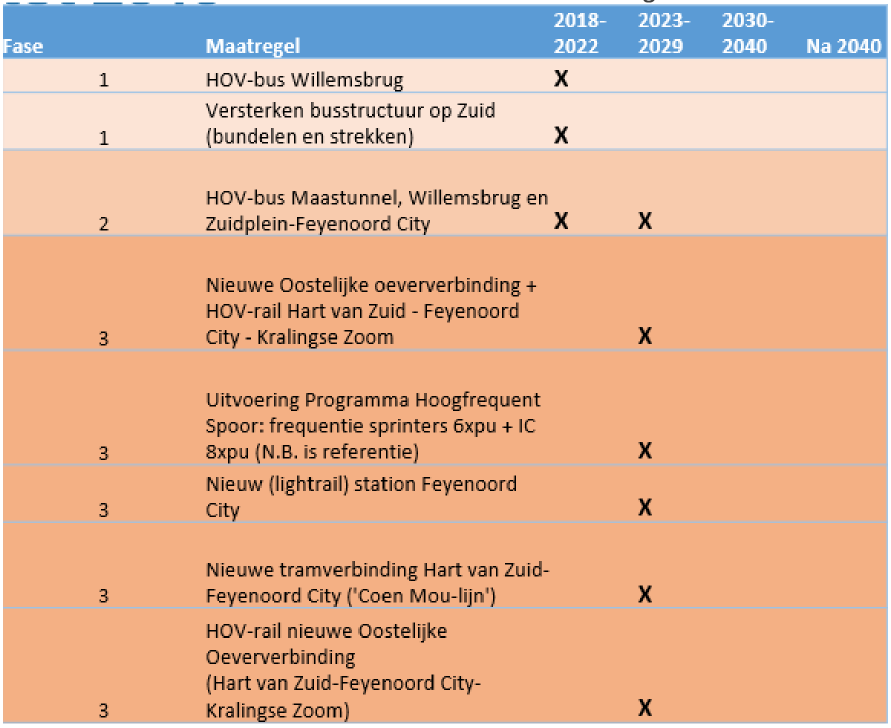
Table 6. Interventions PT-vision until 2030Maatregelen



Fase	Maatregel	2018-2022	2023-2029	2030-2040	Na 2040
1	HOV-bus Willemsbrug	X			
1	Versterken busstructuur op Zuid (bundelen en strekken)	X			
2	HOV-bus Maastunnel, Willemsbrug en Zuidplein-Feyenoord City	X	X		
3	Nieuwe Oostelijke oeververbinding + HOV-rail Hart van Zuid - Feyenoord City - Kralingse Zoom		X		
3	Uitvoering Programma Hoogfrequent Spoor: frequentie sprinters 6xpu + IC 8xpu (N.B. is referentie)		X		
3	Nieuw (lightrail) station Feyenoord City		X		
3	Nieuwe tramverbinding Hart van Zuid-Feyenoord City ('Coen Mou-lijn')		X		
3	HOV-rail nieuwe Oostelijke Oeververbinding (Hart van Zuid-Feyenoord City-Kralingse Zoom)		X		

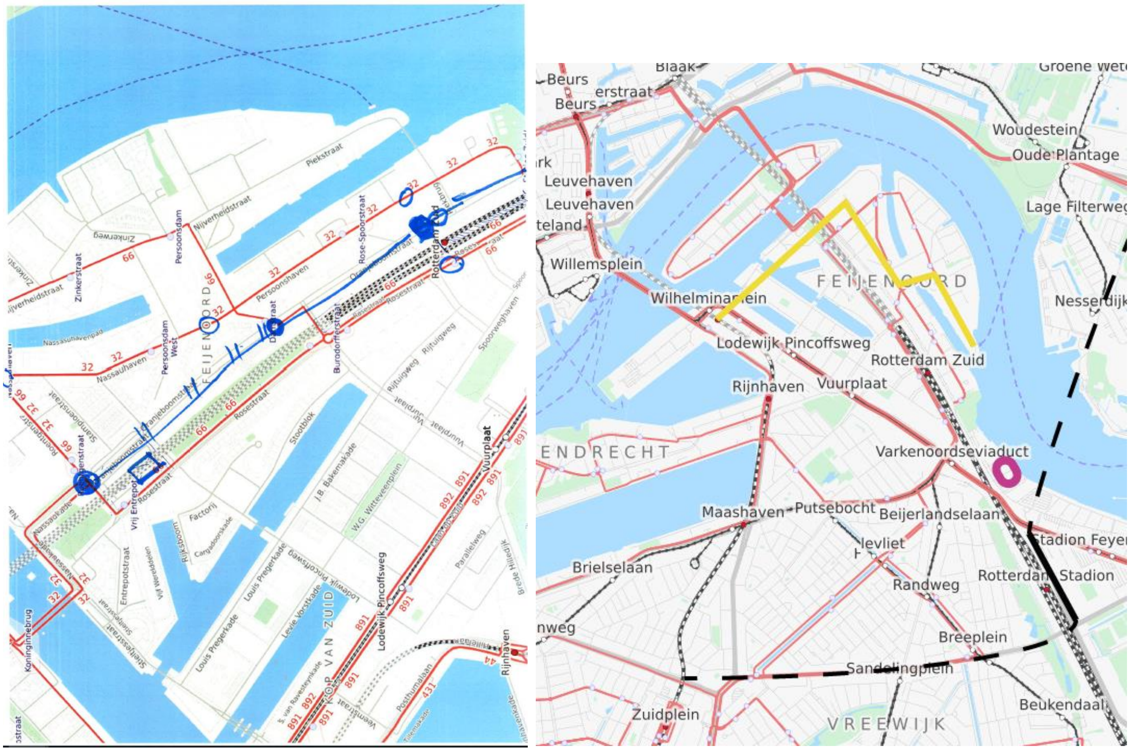


Figure 14. BRT through Feijenoord

Since there is currently a barrier between Feijenoord and Feijenoord City, namely the Varkenoord viaduct environment, it is important to take a good look at it and perhaps improve it.

A Bus Rapid Transit (BR)T service (instead of bus 32) can already serve travelers in the Entrepot area now that there is no station yet. For an exclusive lane for the bus rapid transit a few options are parallel to the track, otherwise the streets are generally not very suitable. Another option is to deploy (autonomous) shuttle services. To make this type of service a success, you probably still need a free job.
A BRT or shuttle service can, for example, follow the route marked with blue in Figure 14. Due to street patterns and harbors, a part remains (along water in the north) that is not well served by public transport. In this area you can only focus on target group transport and subsystems for other residents. Given the changing population in Feijenoord due to spatial development, opportunities arise for these sharing bicycles and other subsystems. These can attract the residents around the not yet existing Entrepot station to the public transport and feed the important, heaviest line in the form of either BRT or Rail on the Oude Lijn.

3. Network design after intermediate phase up until 2040 Scenario A

In this scenario, the Oude Lijn is better used as a local public transport system and metro (-like vehicles) run over it instead of heavy rail sprinters. Each of the station Zuid, Entrepot and Feijenoord City exist and are served by these metros. For this scenario, there are generally two mindsets: one without additional public transport and one with subsystems such as first and last mile transport for the metro on the Oude Lijn. For the disabled and the elderly there are still some kind of taxi services.

Figure 15. Starting point urban development and system + stations Oude Lijn

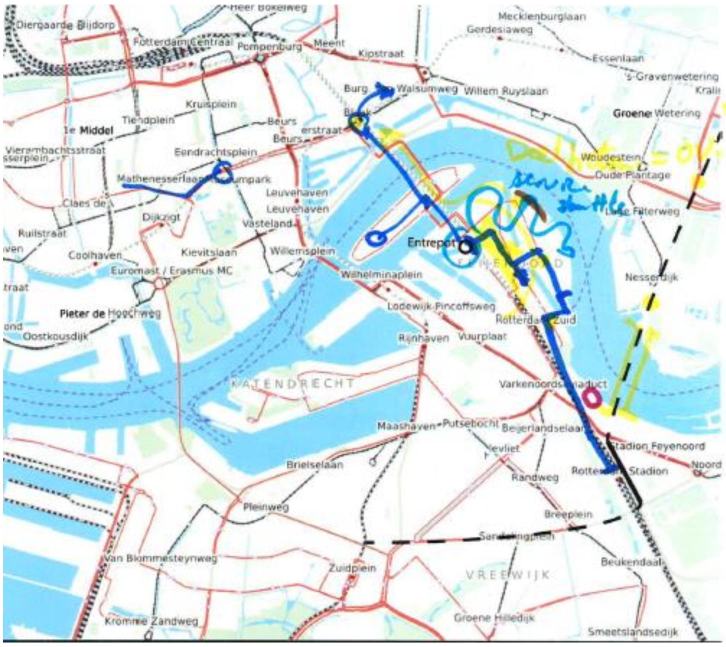


Figure 16. Shared system (yellow) and shuttle services (blue)

4. *Network design after intermediate step up until 2040 scenario B*

The implementation of the local mobility system in Feijenoord becomes more interesting when it is decided not to use both the Zuid and Entrepot stations as stations. In that case, tram 23 can be extended via Entrepot and then with a loop to Rotterdam Zuid to finally end at the new Stadium where this tram takes the route from bus 66.

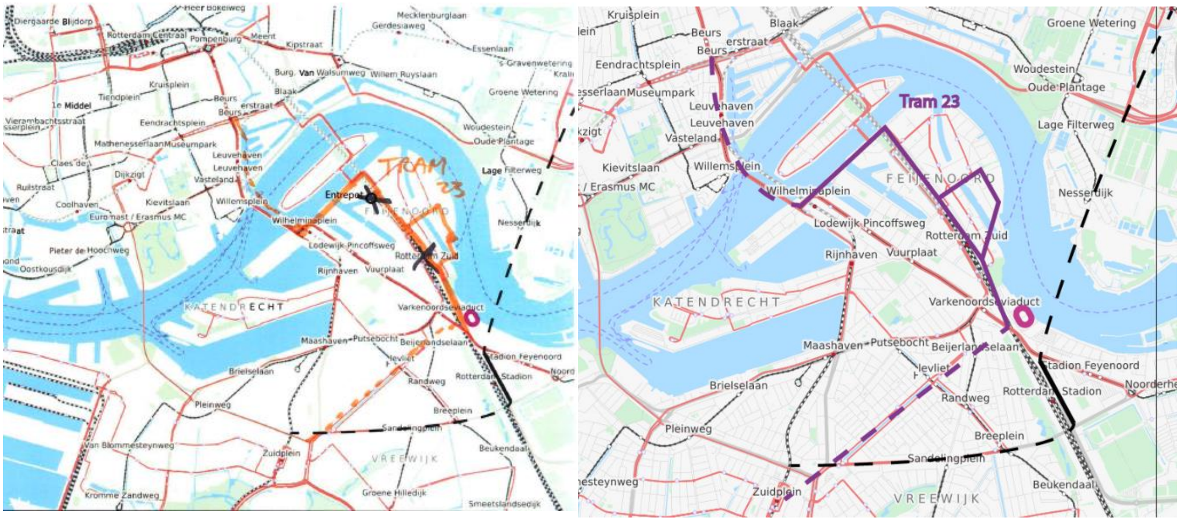


Figure 17. Tram 23 extended to Feijenoord and via Stadionpark/Feyenoord City following the route from bus 66 to Zuidplein

When the Oude Lijn becomes a metro system, there will be an overcapacity in which the various metro systems may be taking away some of the current travelers from tram 23. It is possible to make a BRT axis (possibly for tram 23) from Wilhelminaplein via Unilever terrain to Feijenoord and then via stadium to Zuidplein (orange lines in figure 17). The BRT axis over the Oranjeboomstraat that was laid in step 1 can be used and remains useful. This network design becomes even more interesting if a scenario were to become reality without a station in Feijenoord but only with Feijenoord Stadionpark/Feyenoord CIty.

Reason for a scenario without both Zuid station and Entrepot station: NS / ProRail could not fit 2 stations into the timetable. The connection drawn in Figure 17 is interesting, but perhaps not as a tram but as a bus.

Appendix 3 Operationalization strategies

Results cost benefit analysis strategies per scenario

Table 7. Reference situation

Bus 32	Schedule	Rijtijden (travel times vehicle)	In-vehicle time tot station Blaak [minutes]	Distance to station Blaak [m]	max access time walking [min]	Average access time [min]	Average waiting time [min]	Total travel time(weighted) [min]	Totral travel time (unweighted) [min]
Station Zuid/Steenplaat HA0354	6	0	11	3969	7	3.5	5	26	19.5
Rose-Spoorstraat HA0672	7	1	10	3499	7	3.5	5	25	18.5
Persoonsdam HA0622	8	2	7	3004	7	3.5	5	22	15.5
Nassauhaven HA0621	10	4	6	2667	7	3.5	5	21	14.5
Roentgenstraat HA0620	11	5	5	1800	8	4	5	21	14
Koninginnebrug HA2664	12	6	4	1200	9	4.5	5	21	13.5
Willemsbrug HA2392	13	7	2	1000	9	4.5	5	19	11.5
Willemswerf	16	10	1	220	9	4.5	5	18	10.5
Station Blaak	17	11	0	0	9	4.5	5	17	9.5

BRT Blaak – Zuid

Travel time savings

Table 8

Bus 32	Schedule	Rijtijden	In-vehicle time tot station	Distance to station Blaak [m]	Distance to station Blaak [m]	Average operational speed [km/h]	Average access distance [m]	maximum access distance [m]	Average Access time walking	Maximum access time cycling [min]	Average access time cycling	Average access time BSS [min]	Total access time HO

			Blaak [min]						[min]				V Bus
Station Zuid/Steenplaat HA0354	6	0	7	3000	2700	25.71428571	400	800	6	2.7	1.2	2.25	3.45
Rose-Spoorstraat HA0672	7	1	10										
Persoonsdam HA0622	8	2	7										
Nassauhaven HA0621	10	4	6										
Roentgenstraat HA0620	11	5	4	1800	1500		600	1200	9	3.6	1.8	2.25	4.05
Koninginnebrug HA2664	12	6	4										
Willemsbrug HA2392	13	7	2	1000			550	1100	8.25	3.3	1.65	2.25	3.9
Willemswerf	16	10	1										

First the current total travel times (on average using an average access distance) are calculated for each stop currently served by bus line 32 within Feijenoord until Blaak.

The next step was to calculate travel times for a new bus service (HOV bus / BRT) having less stops and a higher operational speed and thus resulting in a lower in-vehicle travel time. The average access time is calculated for the new stops. The average access distance has increased due to the new service with less stops resulting in a higher average access time compared to the reference scenario. The introduction of a BSS (Bicycle Sharing System) results in a first mile trip consisting of a short walking part to a BSS Hub (on average 150 meter) and a cycling part following to a stop of BRT nearby.

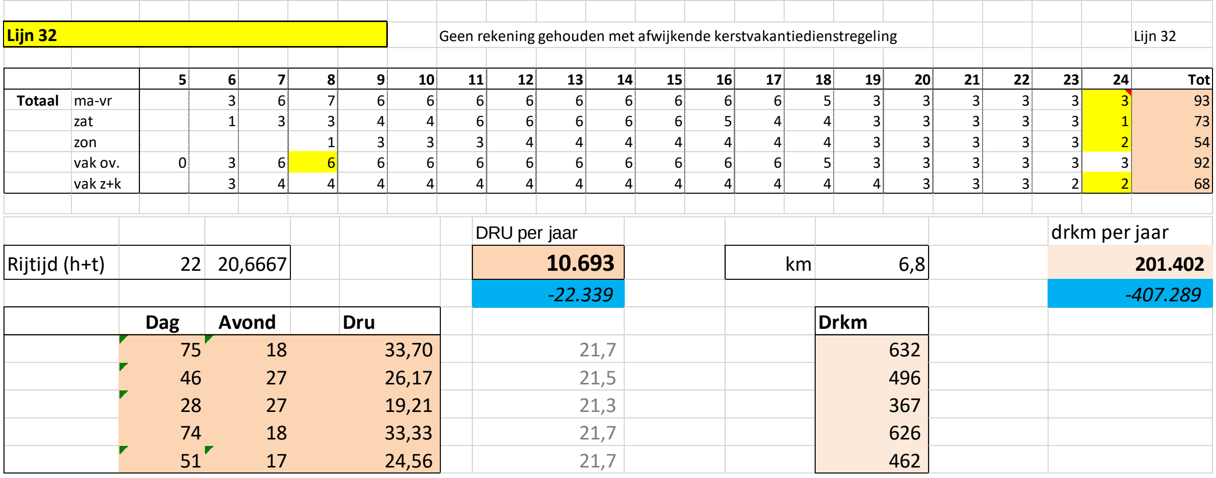
The travel time savings are calculated for the new stops using a new average access distance. The travel times savings for users of removed stops are calculated by comparing the old travel times to new travel times of a stop most nearby.

The people experiencing the travel times savings by transforming bus 32 into an HOV bus service between station Zuid and station Blaak are the people who travel (partially) over that part of the service. The travel time savings depend on the stop they enter the bus and the stop they egress.

By using obtained Origin-Destionation data for Feijenoord the travel time savings can be made specific for each trip and added up to the total travel time savings for the HOV bus service.

Operating cost

Current situation bus 32 Feijenoord part



Lijn 32 Geen rekening gehouden met afwijkende kerstvakantiedienstregeling Lijn 32

		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tot
Totaal	ma-vr		3	6	7	6	6	6	6	6	6	6	6	6	5	3	3	3	3	3	3	93
	zat		1	3	3	4	4	6	6	6	6	6	5	4	4	3	3	3	3	3	1	73
	zon				1	3	3	3	4	4	4	4	4	4	4	3	3	3	3	3	2	54
	vak ov.	0	3	6	6	6	6	6	6	6	6	6	6	6	5	3	3	3	3	3	3	92
	vak z+k		3	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	2	2	68

			DRU per jaar			drkm per jaar
Rijtijd (h+t)	22	20,6667	**10.693**	km	6,8	**201.402**
			-22.339			*-407.289*

	Dag	Avond	Dru		Drkm
	75	18	33,70	21,7	632
	46	27	26,17	21,5	496
	28	27	19,21	21,3	367
	74	18	33,33	21,7	626
	51	17	24,56	21,7	462

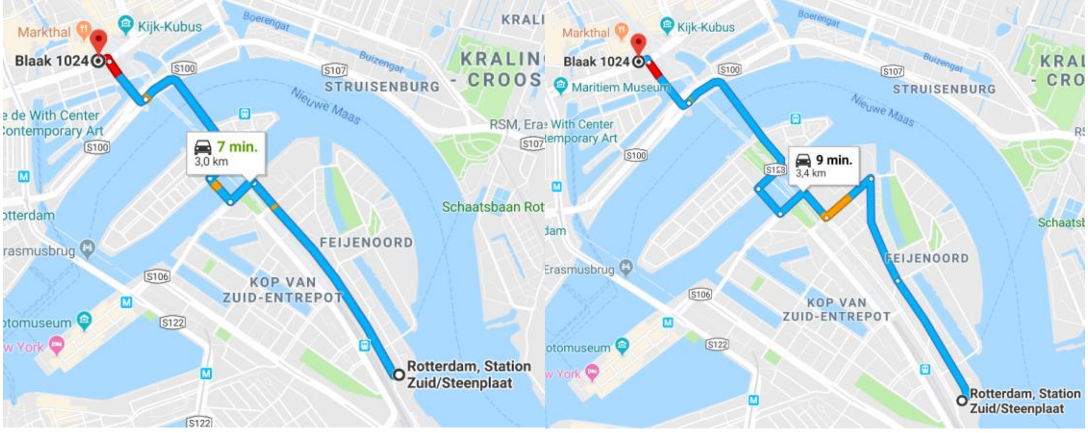
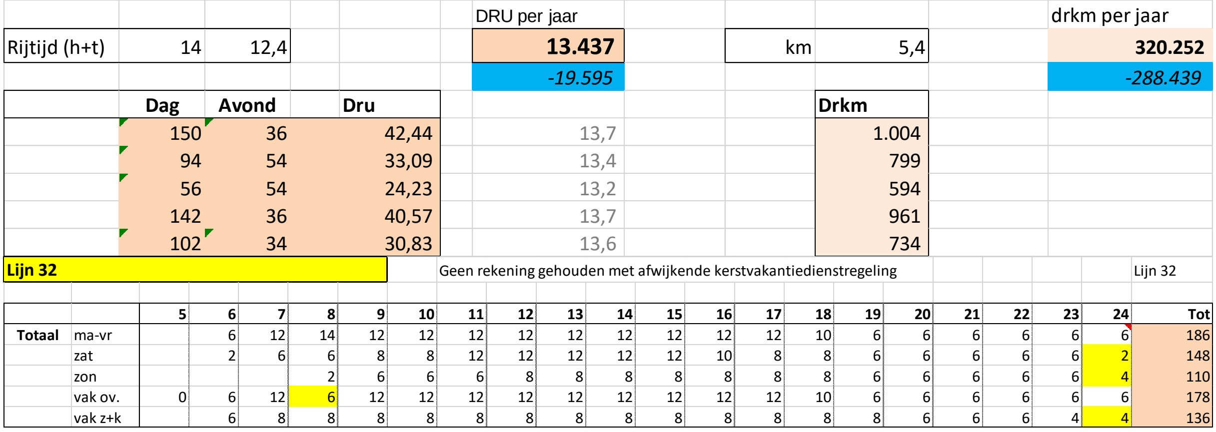


Figure 18 Left: current car distance. Right: current bus 32 distance

DRU model output for new situation

New situation for HOV bus including new bridge

- distance is 2,7 km (3-2*0,16) to stop station Zuid/Steenplaat. Back and forth this makes a distance of 5,4 km
- Frequency is doubled (weekday off-peak from 6 to 12 and so on)
- Rijtijd is based on 7 minutes and thus doubled to 14 minutes for the day



			DRU per jaar			drkm per jaar
Rijtijd (h+t)	14	12,4	**13.437**	km	5,4	**320.252**
			-19.595			*-288.439*

	Dag	Avond	Dru		Drkm
	150	36	42,44	13,7	1.004
	94	54	33,09	13,4	799
	56	54	24,23	13,2	594
	142	36	40,57	13,7	961
	102	34	30,83	13,6	734

Lijn 32 Geen rekening gehouden met afwijkende kerstvakantiedienstregeling Lijn 32

		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Tot
Totaal	ma-vr		6	12	14	12	12	12	12	12	12	12	12	12	10	6	6	6	6	6	6	186
	zat		2	6	6	8	8	12	12	12	12	12	10	8	8	6	6	6	6	6	2	148
	zon				2	6	6	6	8	8	8	8	8	8	8	6	6	6	6	6	4	110
	vak ov.	0	6	12	6	12	12	12	12	12	12	12	12	12	10	6	6	6	6	6	6	178
	vak z+k		6	8	8	8	8	8	8	8	8	8	8	8	8	8	6	6	6	4	4	136

Appendix 4 OV-Lite visuals of variants

Figure 19 Bandwith visualization of difference in travelers between variant and reference over the links in the network for a traffic assignment without elasticities (OV-Lite)
Apparently the extension of bus 32 creating a bus connection between station Zuid and station Stadionpark, which gives access to the new rail tangent, provides a shorter route to 290 (from Stadionpark) and 420 (to Stadionpark) travelers.

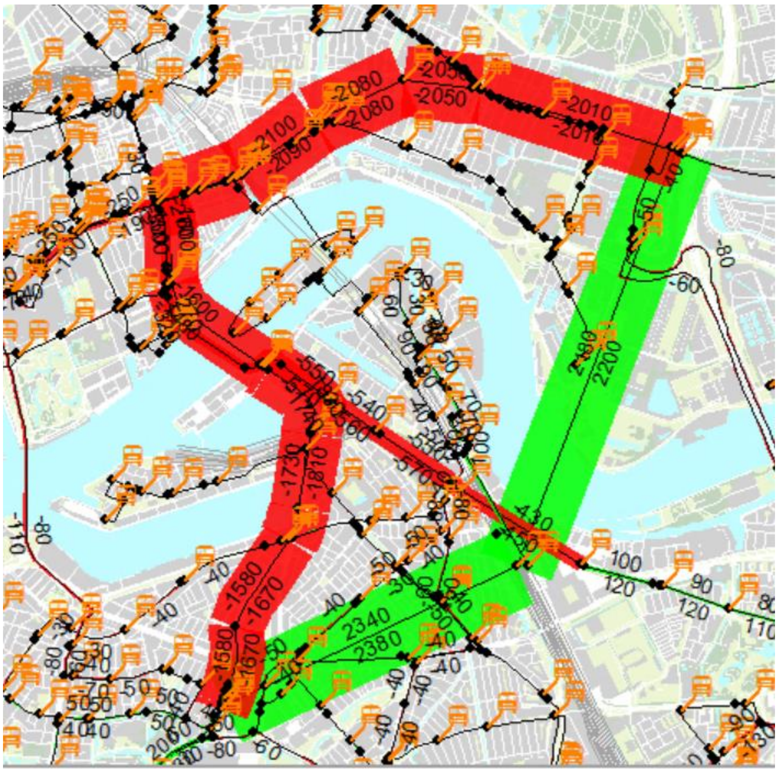


Figure 20. Feijenoord_ext_bus32_railtangent. Assignment without elasticity (cube 105) bandwidth sum(load)

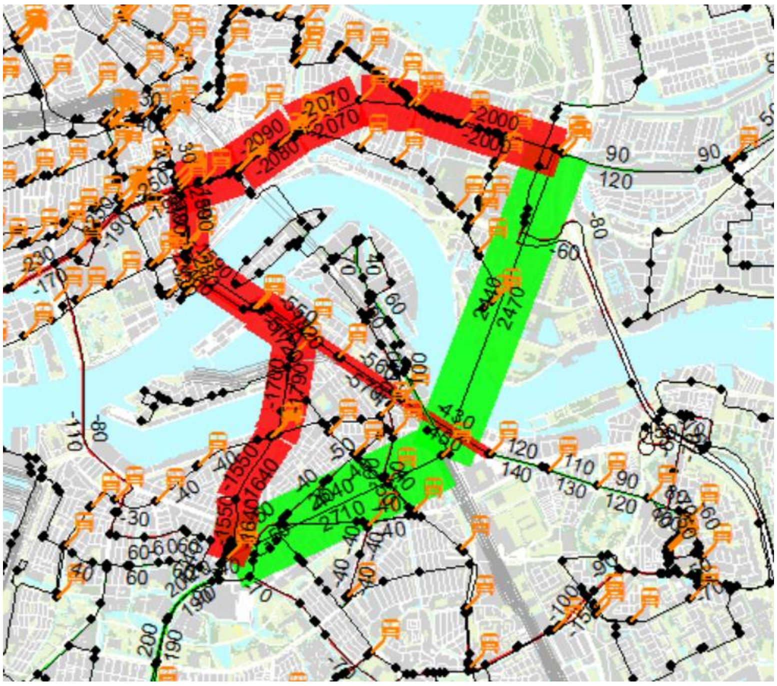


Figure 21 Feijenoord_ext_bus32_railtangent. Assignment with elasticity (cube 115) bandwidth sum(load)

LRT (tram) Blaak – Stadionpark (rerouting trams)

- Rerouting tram 23
- Rerouting tram 25

Deviating tram 23 or 25 via Feijenoord to Stadionpark has the following effects:

- Attract new users because of the new direct connections to Stadionpark
- Attract new users because of the rail bonus
- Reliability benefits because of the more reliable travel times of tram in general and because bus 32 has a higher average deviation of travel times than tram 23 and tram 25.

Estimations for the effect on passenger flows over the network are performed by modeling the network with adaptations in OV-Lite and simulating the travelers over the network.

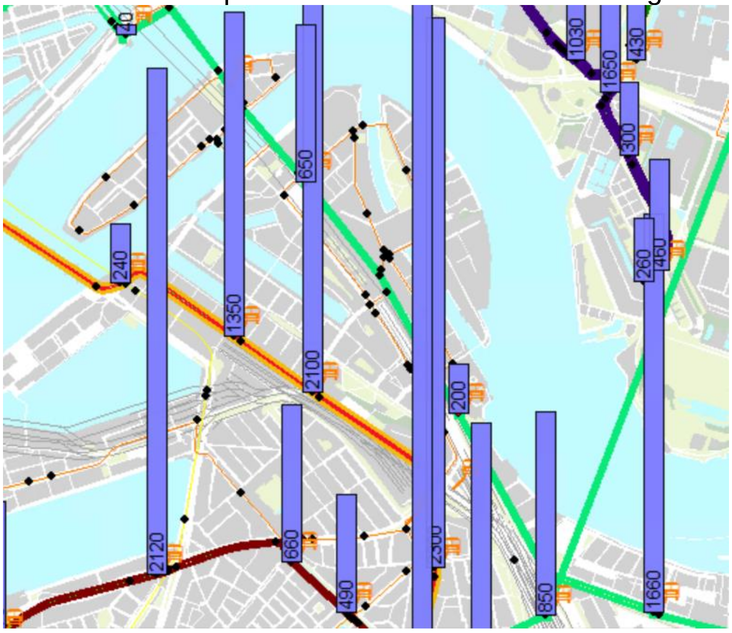


Figure 22 People boarding total on an average workday at tram stops. Rerouted tram 23, assignment without elasticities (OV-Lite)

Dru

For the calculation of annual DRU cost the rerouted tram 23 or 25 is compared to the annual DRU cost for bus 32. All these cost are only compared for the case study area.
The frequency of tram 23 and 25 are kept equal to the current frequency. Rerouting the trams results in more or less the same length of the route and thus DRU cost for operating tram (20), 23 and 25 remain. On the other hand, bus 32 will be operating a shorter route than nowadays. Summarizing, this means that rerouting tram 23 or 25 via Feijenoord results in a decrease of DRU cost. The effect is that DRU cost for operating bus 32 between station Blaak and station Zuid are avoided, while the net change in DRU for tram due to the rerouting is zero

Potential travel demand Stadionpark – Blaak (Meent)

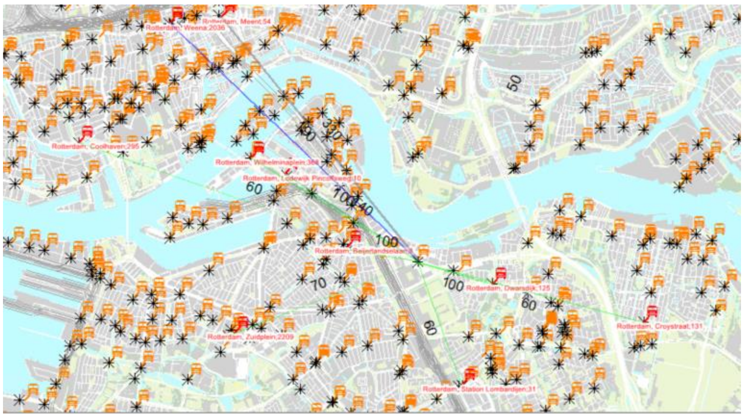


Figure 23. OD patterns From Stadion Feyenoord to other destinations in the reference situation on an average workday. (HBpatronen Gebiedsindeling2 werkdag ref)

Appendix 6 Translation of real options to options owned by RET

There are two lines of uncertainty:

- The expected demand for PT trips
- The expected network supply

For the expected demand, the urban development in the area consisting of plans for housing are important. The municipality is in charge of the first part of this process: providing land for development. After that it is up to other parties to actually be willing to build new houses, which depends on the market and economic situation. (https://www.infomil.nl/onderwerpen/ruimte/ontwikkelingen/)

The expected network supply is complex as in Rotterdam there is a transport authority for the metropole region including the city of Rotterdam. There are several concessions and therefore several parties involved in the supplied infrastructure and transport services. As the case is about total mobility system this means multiple actors are involved. RET has the bus concession until 2034 and the rail concession for tram and metro within the Rotterdam region until 2026 (https://mrdh.nl/project/concessies-openbaar-vervoer). The NS has the operating concession for the transport over the Oude Lijn as well as owning station Zuid. ProRail owns the current heavy rail tracks of the Oude Lijn going through Rotterdam. The OV-visie 2040 published by the municipality of Rotterdam and MRDH is very ambitious compared to other documents. Station Stadionpark is mentioned in many documents but station Entrepot is more uncertain. So, the cost of transforming the Rotterdam part of Oude Lijn into a metro are high (new station in tunnel, changing signaling system, etc.) but it is also a very complex decision making process. Nevertheless, money is not (yet) available.

These different actors with different roles point out that RET does not have the exclusive right for every network development option within the Rotterdam neighbourhood of Feijenoord. Since transforming the heavy rail system into a metro system is a multi-actor problem it is not an exclusive "real option" anyone owns. On the other hand, building new metro tracks along the Oude Lijn might be an option belonging to RET as well as building tram infrastructure and operating trams or buses within Feijenoord. Regarding other non-PT services (shared vehicles/bikes/steps, robotaxi,…) RET does not has the exclusive right to start the service since it is not in the concession.

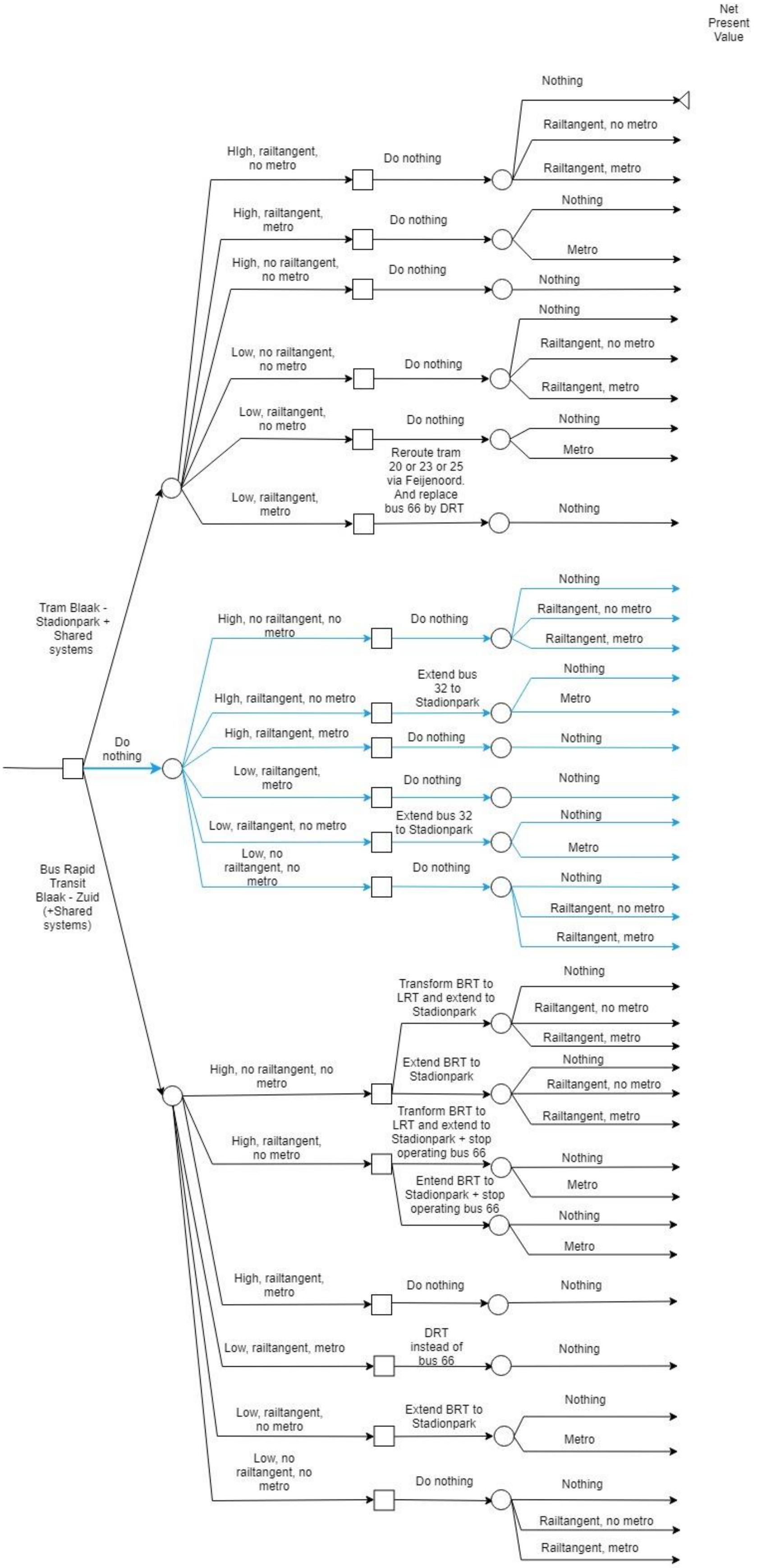
From the latter can be concluded that taking another actor as option owner just makes other factors uncertain. The only real uncertain factor is when houses will be build, at which locations and how many people are going to live there. And then eventually this influences the number of inhabitants and the evolving travel demand.

Definition of a real option:

A real option provides: "The flexibility arising when a decision maker has the opportunity to adapt or tailor a future decision to information and developments that will be revealed in the future. A real option conveys the right, but not the obligation, to take an action (e.g., defer, expand, contract, or abandon a project) at a specified cost (the exercise price) for a certain period of time, contingent on the resolution of some exogenous (e.g., demand) uncertainty." (Chevalier-Roignant & Trigeorgis, 2011).

From the definition it can be concluded that an actual real option for RET should be an opportunity or right they have to take an action at a specified cost for a certain period of time.

Appendix 7. Complete decision event tree



Since every strategy should increase benefits for society, the number of strategies in the decision tree is narrowed down after a few analyses in transport model OV Lite. The final decision tree including the strategy paths included for cost benefit analysis is depicted in the main report.

- The options including rerouting of tram 23 resulted in a loss of passengers in the transport model OV lite which leaded to the decision to exclude this option from further analyses.
- The options including Demand Responsive Transit instead of bus 66 were also excluded from further analyses. The reason for this decision is the difficulty of and lack of knowledge on how to model the influence of DRT on travel times and on potential demand.