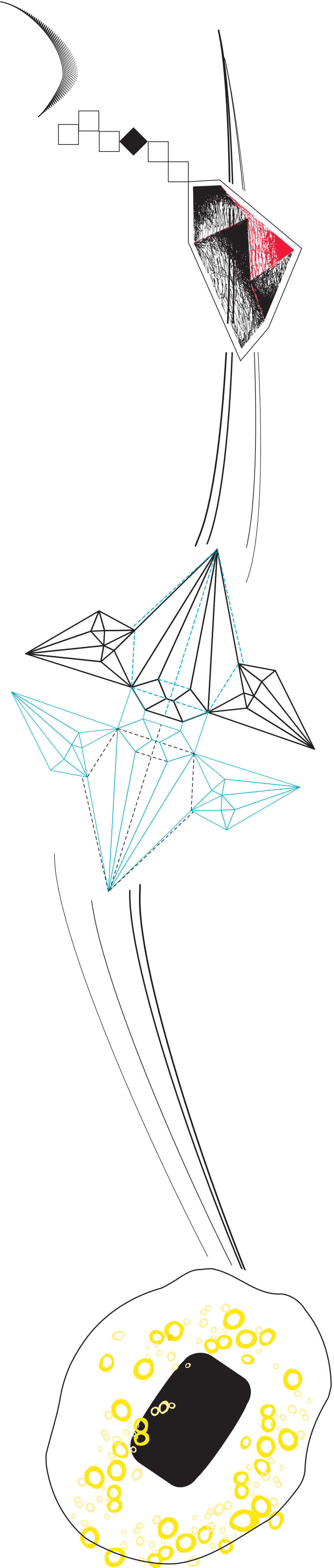

THE INFLUENCE OF THE USE OF INDEX NUMBERS OF MAINTENANCE COSTS OF URBAN PUBLIC TRANSPORT SYSTEMS ON THE OUTCOME OF COST-BENEFIT ANALYSES

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ABSTRACT

In this research the influence of the use of index numbers of maintenance costs on the outcome of cost-benefit analyses (CBAs) is analysed. First the importance of maintenance costs in decision-making is researched. Then, an overview of maintenance costs for various types of infrastructure and vehicles is made. Next, it is tried to explain possible variations in the maintenance costs. Finally, newly estimated maintenance costs are substituted in already existing CBAs, to study its effect on the outcome of these CBAs.

To research if maintenance costs are taken into account in decision-making, twelve interviews are held. The interviews are held with transport authorities, rail operators, a bus operator, municipalities, and a consultancy. Based on these interviews, it can be concluded that in general maintenance costs are taken into account in decision-making. This is mainly the case for bus vehicles, rail vehicles, and bus infrastructure, but less so for rail infrastructure. One way of including maintenance costs in decision-making, is the use of a CBA.

In this study an overview of maintenance costs for five types of infrastructure and eight types of vehicles is made. This overview, which simply is an overview of index numbers of maintenance costs, includes both data of rail systems as well as of bus systems. The maintenance costs of rail infrastructure and vehicles are mostly based on documents of four Dutch urban rail systems. These documents include among others, annual plans, subsidy applications, multi-annual plans, sheets with capital expenses, and financial results. Estimations of maintenance costs for bus infrastructure and vehicles are based on the interviews.

It was found that maintenance costs of both rail infrastructure and rail vehicles are much higher than maintenance costs of bus infrastructure and bus vehicles. Furthermore, metro infrastructure has much higher maintenance costs per kilometre than tram and light rail. Metro vehicles are in contrast, when looking at standardised vehicles with a length of 30 meter, slightly cheaper to maintain than tram and light rail vehicles.

Some variation in maintenance costs was observed among modes, among companies, and among municipalities. Based on the data and the interviews, multiple factors are given which can explain these and other variations in maintenance costs.

An example is the large variation in maintenance costs between underground and aboveground metro. The maintenance costs for underground metro can be up to eighty percent higher than the estimated average maintenance costs for metro, where costs for aboveground metro can be around ten to twenty percent lower than the estimated average.

Finally, the estimated maintenance costs were substituted in CBAs, to find potential influence of the use of these index numbers on the outcome of the CBAs. It was shown that the total maintenance costs in these evaluated situations deviate from the original results, with results ranging from a decrease of 97 percent to an increase of 85 percent. Most projects, including all bus and metro projects and some light rail projects, showed a decrease in maintenance costs.

These changes in maintenance costs did also result in changes in the benefit-cost ratio (b/c-ratio) of the CBAs. This effect is relativity small for light rail and metro projects, with a maximum change of 0.13. This change is much larger for bus projects, with a change of up to 1.20. However, in none of the cases a change in b/c-ratio from below 1 to above 1, or vice versa, was observed.

SAMENVATTING (DUTCH)

Openbaar vervoer speelt in Nederland een belangrijke rol, met dagelijks rond de één miljoen gebruikers. Bus, tram en metro zijn samen goed voor ongeveer een half miljoen gebruikers. (CPB and KiM, 2009)

Uiteraard zijn er kosten verbonden aan het bouwen, aanschaffen, gebruiken en onderhouden van de voertuigen en de infrastructuur van de verschillende openbaarvervoersystemen. Al bij het ontwerpen van een nieuw openbaarvervoerlijn of -systeem is het van belang om kosten en baten goed in kaart te brengen. Eén van de mogelijkheden om dat te doen is met een kosten-batenanalyse (KBA). Eén specifiek type kosten, de onderhoudskosten, worden in dit onderzoek nader onderzocht.

Onderzoeksdoel

Binnen dit onderzoek zijn er twee hoofddoelen. Het eerste doel is het creëren van een overzicht van kengetallen van de onderhoudskosten van de verschillende stedelijke openbaarvervoersystemen. Het tweede doel is om, op basis van die kengetallen, bestaande KBA's te evalueren.

Deze doelen worden met vier onderzoeksvragen verder uitgewerkt. Ten eerste, wat is de invloed van onderhouds- en vervangingskosten van openbaarvervoersystemen op de besluitvorming? Ten tweede, hoe groot zijn die onderhouds- en vervangingskosten? Ten derde, hoe kunnen verschillen in die kosten worden verklaard? Ten vierde, wat is de invloed van het gebruik van de kengetallen van de onderhoudskosten op de uitkomst van KBA's?

Onderzochte systemen

In dit onderzoek wordt gekeken naar Nederlandse stedelijke openbaarvervoersystemen. Daaronder vallen bus, tram, lightrail en metro.

Wat betreft infrastructuur wordt er gekeken naar bus rapid transit, met vrije busbanen van asfalt of van beton, naar tram, naar lightrail en naar metro.

Bij de voertuigen wordt gekeken naar acht verschillende soorten voertuigen. Daarvan zijn er vijf soorten bussen: standaard (12 meter), gelede (18 meter) en dubbelgelede (25 meter) dieselbussen, standaard (12 meter) elektrische bussen en standaard (12 meter) gasbussen. Daarnaast zijn er trams, lightrailvoertuigen en metro's.

Soorten onderhoudskosten

Zowel voor de infrastructuur als voor de voertuigen zijn de onderhoudskosten in kaart gebracht. Voor de infrastructuur is onderscheid gemaakt in beheerkosten, dagelijks onderhoud en groot onderhoud. Daarnaast is er onderscheid gemaakt in kosten voor de baan, kosten voor haltes en stations, en overige kosten. Voor de voertuigen is gekeken naar beheerkosten, dagelijks onderhoud, groot onderhoud, levensduurverlenging en vervanging van de voertuigen zelf.

Interviews

In totaal zijn er twaalf interviews gehouden met verschillende groepen: vervoersautoriteiten, bus- en railvervoerders, gemeenten en een consultant. Deze interviews zijn zowel gebruikt om informatie te verzamelen betreffende de onderhoudskosten zelf, als wel om het belang van onderhoudskosten in de besluitsvorming te onderzoeken.

Op basis van de interviews kan worden geconcludeerd dat onderhoudskosten over het algemeen worden meegenomen bij de besluitvorming. Dat geldt voornamelijk voor busvoertuigen, railvoertuigen en businfrastructuur, maar minder voor railinfrastructuur. Ook de waarde die bij de besluitvorming wordt gehecht aan de onderhoudskosten verschilt sterk. Een van de manieren om onderhoudskosten mee te nemen in de besluitvorming is het toepassen van een KBA.

Gebruikte data

De in dit onderzoek gebruikte gegevens zijn gebaseerd op zowel documenten als interviews. De gebruikte documenten zijn onder andere jaarplannen, subsidieaanvragen, meerjarenplannen, overzichten van kapitaalkosten en financiële overzichten. Daarbij kan worden opgemerkt dat de resultaten voor de railsystemen grotendeels zijn gebaseerd op de documentatie, waar resultaten voor de bussystemen zijn gebaseerd op de interviews.

Wat betreft de railsystemen gaat het om vier Nederlandse stedelijke systemen: GVB in Amsterdam, RET in Rotterdam, HTM in Den Haag en U-OV in Utrecht. Voor businfrastructuur is informatie verzameld op basis van interviews met de gemeente Almere, de gemeente Enschede en de gemeente Arnhem. Voor busvoertuigen is er gebruikt gemaakt van een interview met Qbuzz.

Berekening onderhoudskosten

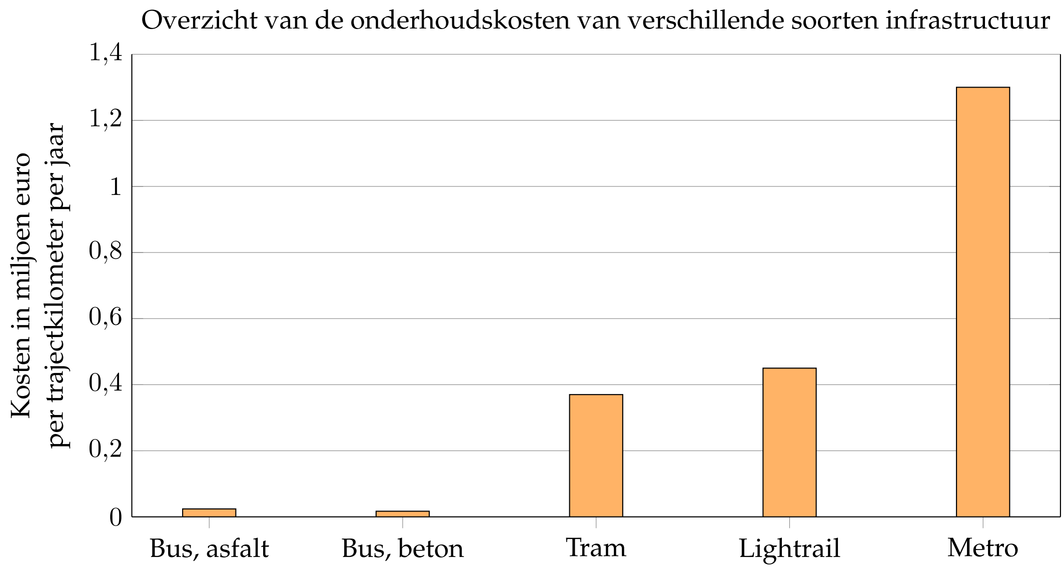
Om op een eerlijke manier de onderhoudskosten te kunnen vergelijken zijn er een aantal verdere stappen nodig. Een van die stappen is de toepassing van een inflatiecorrectie, om kosten uit verschillende jaren goed te kunnen vergelijken. Als peiljaar is daarvoor het jaar 2017 gebruikt.

Daarnaast zijn de kosten uitgedrukt in steeds dezelfde eenheid. Voor infrastructuur zijn dat de kosten in euro per trajectkilometer per jaar. Voor voertuigen zijn de onderhoudskosten uitgewerkt in euro per 30-meter voertuig per jaar en de vervangingskosten in euro per 30-meter voertuig. Praktisch betekend het dat voor de railinfrastructuur de onderhoudskosten van het gehele netwerk gedeeld zijn door de lengte van dat netwerk. Voor railvoertuigen zijn de kosten gedeeld door het aantal voertuigen van 30 meter. Voor de bussystemen hebben de verzamelde gegevens voor een deel een ander formaat, bijvoorbeeld de onderhoudskosten per vierkante meter, maar ook die gegevens zijn omgezet in de genoemden eenheden.

Ten slotte zijn er per soort infrastructuur en per soort voertuig gemiddelde waardes uitgerekend. Dat is gedaan op basis van één of meerdere resultaten. Voor bijvoorbeeld de metro gaat het dan om het gemiddelde van GVB uit Amsterdam en RET uit Rotterdam.

Overzicht onderhoudskosten infrastructuur

De onderhoudskosten voor de vijf soorten infrastructuur zijn weergegeven in figuur 0.1. Duidelijk is te zien dat er een enorm verschil zit in de onderhoudskosten van businfrastructuur en railinfrastructuur. Verder is het opvallend dat het verschil tussen tram en lightrail relatief klein is, terwijl het verschil tussen tram en lightrail enerzijds en metro anderzijds juist behoorlijk groot is.

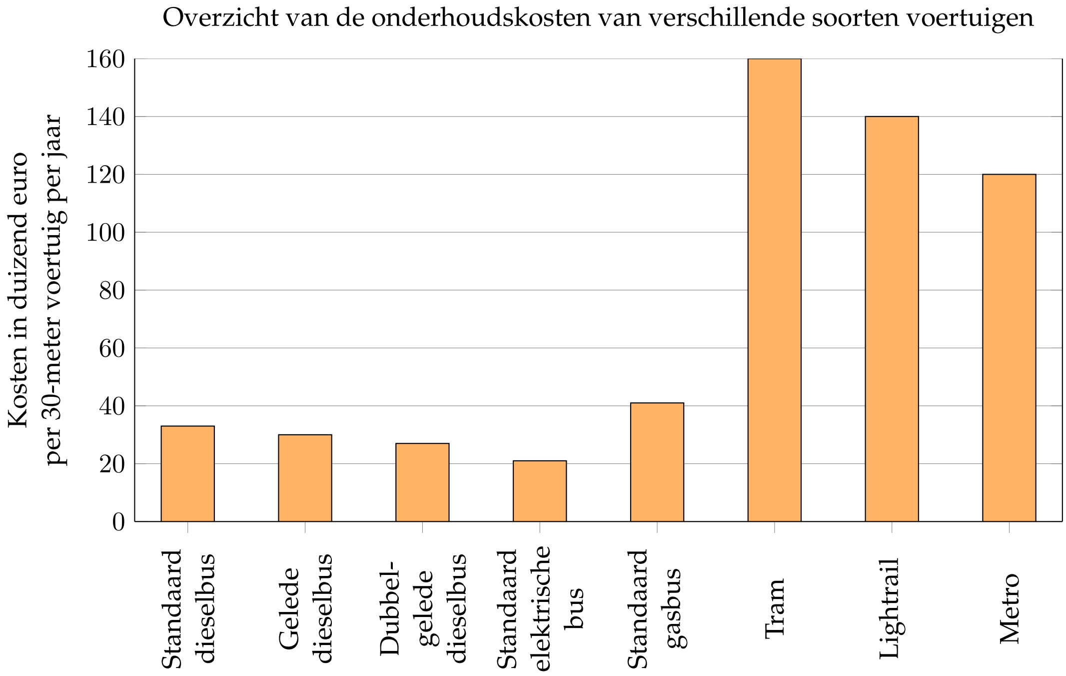


Figuur 0.1: overzicht van de onderhoudskosten van verschillende soorten infrastructuur in miljoen euro per trajectkilometer per jaar. Onderhoudskosten voor een busbaan op asfalt, een busbaan op beton, tram, lightrail en metro zijn respectievelijk 24.000, 17.000, 370.000, 450.000 en 1.300.000 euro per trajectkilometer per jaar, prijspeil 2017.

Overzicht onderhoudskosten voertuigen

De onderhoudskosten voor de acht soorten voertuigen zijn weergegeven in figuur 0.2. Wederom is een duidelijk verschil te zien tussen bus en rail, hoewel het verschil wel beduidend kleiner is dan bij de infrastructuur. Verder is het opvallend dat wat betreft onderhoud de tram juist duurder is dan lightrail en metro. Een mogelijke verklaring is dat metro in het algemeen rechtere lijnen met ruimere bochten heeft dan tram, wat zou kunnen leiden tot minder onderhoud. Ook bevinden ov-chipkaartsystemen zich bij tram vaak in het voertuig en bij metro vaak op de stations.

De vervangingskosten van de verschillende typen bussen liggen tussen de 0,72 en 1,4 miljoen euro per 30-meter voertuig. Vervangingskosten voor trams, lightrailvoertuigen en metro's zijn respectievelijk 2,3, 3,4 en 2,8 miljoen euro per 30-meter voertuig. Het relatieve verschil in aanschafkosten tussen bus en rail is daarmee kleiner dan het relatieve verschil in onderhoudskosten.



Figuur 0.2: overzicht van de onderhoudskosten van verschillende soorten voertuigen in duizend euro per 30-meter voertuig per jaar, prijspeil 2017. Onderhoudskosten voor de standaard, de gelede en de dubbelgelede dieselbus, de elektrische bus en de gasbus zijn respectievelijk 33.000, 30.000, 27.000, 21.000 en 41.000 euro per 30-meter voertuig per jaar. Onderhoudskosten voor trams, lightrailvoertuigen en metro's zijn respectievelijk 160.000, 140.000 en 120.000 euro per 30-meter voertuig per jaar.

Variatie in kosten

Naast de variatie in kosten tussen verschillende soorten infrastructuur en tussen verschillende soorten voertuigen, is er ook variatie in kosten tussen verschillende bedrijven en gemeenten, en is er variatie in kosten mogelijk binnen een bedrijf.

Opvallend is het verschil in onderhoudskosten tussen ondergrondse en bovengrondse metro. Kosten voor bovengrondse metro kunnen rond de tien tot twintig procent lager zijn dan het gemiddelde voor metro, waar de resultaten laten zien dat kosten voor ondergrondse metro juist tot tachtig procent hoger dan het gemiddelde kunnen zijn.

Evaluatie van KBA's

De ingeschatte onderhoudskosten zijn gebruikt om KBA's te evalueren. Voor elke KBA is de originele inschatting van de onderhoudskosten vervangen door een inschatting op basis van de kengetallen uit dit onderzoek. In totaal zijn er uit vijf rapporten zeventien KBA's gebruikt. In vier raporten gaat het om maatschappelijke kosten-batenanalyses (MKBA's) in één raport wordt er gesproken van een kengetallen kosten-batenanalyse (KKBA). Het gaat bij de KBA's om bus-, lightrail-en metroprojecten.

De verschillen tussen de originele inschatting van de onderhoudskosten en de inschatting op basis van de kengetallen uit dit onderzoek zijn groot. Het verschil varieert tussen een afname van 97 procent en een toename van 85 procent van de onderhoudskosten. De meeste projecten, waaronder alle bus- en metroprojecten en een deel van de lightrailprojecten, lijken de onderhoudskosten te overschatten.

Als er wordt gekeken naar de verandering in de baten/kosten-verhouding lijken de verschillen kleiner. Voor lightrail- en metroprojecten is de verandering relatief klein: een maximale verandering van 0.13 is gevonden. Voor bus kan die verandering een stuk groter zijn, tot maximaal 1.20. In geen van de onderzochte projecten ging de baten/kosten-verhouding echter van onder de 1 naar boven de 1, of omgekeerd. Daarnaast lijkt voor railprojecten de fout in de inschatting van de investeringskosten minstens zo belangrijk te zijn voor de baten/kosten-verhouding als de fout in de inschatting van de onderhoudskosten.

Conclusie

Al met al is het in dit onderzoek gelukt een inschatting te maken van de onderhoudskosten van verschillende stedelijke openbaarvervoersystemen. Die onderhoudskosten zijn in kaart gebracht voor vijf soorten bus- en railinfrastructuur en acht soorten bus- en railvoertuigen.

Bij de evaluatie van KBA's kwam naar voren dat er grote verschillen zijn tussen de originele inschatting van de onderhoudskosten en de inschatting op basis van kengetallen uit dit onderzoek. Over het algemeen zijn de verschillen in de uiteindelijke baten/kosten-verhouding echter een stuk kleiner.

Dit onderzoek kan gebruikt worden om een eerste inschatting te maken van de onderhoudskosten van een aan te leggen stedelijke openbaarvervoersysteem of -lijn, of juist om een al gemaakte inschatting te beoordelen.

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1. INTRODUCTION

Public transport plays an important role in the Netherlands: around one million people a day make use of it. Urban public transport systems like the bus, tram, and metro are used by around half a million people a day. The modal share of public transport, in terms of passenger kilometres, is around ten percent. There are however some notable outliers for which public transport has a much higher modal share. For example the trips larger than ten kilometres in the morning peak, towards the five urban agglomerations of Amsterdam, Rotterdam, Den Haag, Utrecht, and Eindhoven. For these specific trips, modal share of public transport is around forty percent. (CPB and KiM, 2009)

To have an efficient public transport network, it seems logical to make the right design choices for new transport connections. For example regarding the choice of the type of transport systems that are included in the network: bus, tram, light rail, metro, etcetera. Other design choices are also important, for example the amount of dedicated lane, the choice between level or grade separated crossings, and the amount of priority at level crossings.

More or less objective insights in the utility of different systems for a certain transport connection can be provided by a cost-benefit analysis (CBA). To have a trustworthy CBA, it is important to make reliable estimations of costs and benefits. Important costs concern construction, maintenance, replacement, and operational costs.

In the remaining part of this chapter, first a short introduction of the scope of this research is given. Then, the state of the art is introduced and discussed. Finally, the research objective is given, including four research questions.

1.1. Scope of the research

In this research an overview of maintenance costs of Dutch urban public transport systems will be made. The following costs will be included in this research: management and maintenance costs of infrastructure, and management, maintenance, life extension, and replacement costs of vehicles. Variation in results will be discussed and explained.

Next to that, an analysis will be made of the role of maintenance costs in decision-making on new public transport connections. This will be made practical by applying estimations of the maintenance costs in CBAs.

The scope of this research is on public transport systems in the urban environment. These include bus, bus rapid transit, tram, light rail, and metro systems. Regional and national systems, for example on heavy rail, are excluded.

1.2. State of the art

Three main areas of interest for this research are reviewed using the available literature, and a subsequent summary is made. These areas include: forecasting costs and demand, maintenance costs in public transport, and cost-benefit analysis.

Forecasting costs and demand

Reliably estimating costs, benefits, and travel demand is important to properly evaluate transport projects. However, construction costs seem to be underestimated (Flyvbjerg et al., 2003) and travel demand forecasts seem to be inaccurate (Flyvbjerg et al., 2005).

First of all, the construction costs are underestimated: Flyvbjerg et al. (2003) found statistical evidence that construction cost overrun exist in transport infrastructure projects. This research was based on a sample of 258 projects, of which 181 European, 61 North American, and 16 from other countries. Cost overrun of 45 percent was found for rail projects, 20 percent for road projects, and 34 percent for bridges and tunnels.

Secondly, there is overestimation of, and/or inaccuracy in, travel demand forecasts. Flyvbjerg et al. (2005) showed that for rail projects the actual observed traffic was on average 51 percent lower than estimated in the forecasts. For road traffic there was no significant underestimation of traffic, but estimations were still inaccurate: for 50 percent of the projects a difference larger than 20 percent was found between forecast and actual traffic. According to Flyvbjerg et al. (2005) accurate forecasts are important for effective use of funds. They report that both over and under dimensioning of infrastructure is inefficient: over dimensioning leads to higher construction, maintenance, and operating costs; under dimensioning is undesirable as adding capacity later on is more expensive than building properly dimensioned infrastructure right a way.

Based on the fact that no significant decrease in cost overrun is found over time, Flyvbjerg et al. (2003) conclude that no learning effect take places. For traffic forecasts a similar result is found by Flyvbjerg et al. (2005), also concluding that these did not improve over time.

Cantarelli et al. (2012) showed that cost overrun in the Netherlands is lower than cost overrun in the rest of the world. It must be noted that this result was statistical significant for rail projects, but not for road projects, tunnels, and bridges. The costs overrun of rail projects in the Netherlands was given as 11 percent, in contrast to 38 percent for projects in the rest of the world.

Construction costs are underestimated and travel demand forecasts are overestimated and/or inaccurate. It is therefore not unreasonable that maintenance costs are also underestimated and/or inaccurately estimated.

Maintenance costs in public transport

There are several interesting topics related to maintenance in public transport. Topics concern for example the comparison of different public transport systems, estimation of life cycle costs, and index numbers regarding maintenance and other costs.

A comparison of costs between heavy rail, light rail, and bus rapid transit is made by Tirachini et al. (2010). This theoretical model includes infrastructure costs, operating costs, and maintenance costs. The maintenance costs were based on guidelines provided by the Australian transport council.

Life cycle costs are researched by Koushki et al. (1999) and Banar and Özdemir (2015). An estimation of life cycle costs for buses in Kuwait was made by Koushki et al. (1999). It was based on a combination of capital costs, salvage value, and maintenance and fuel costs. The maintenance and fuel costs were between 14 and 27 percent of the estimated life cycle costs of the different buses. Labour and fuel cost in Kuwait are both probably relatively low compared to the Netherlands.

Another research concerning life cycle costs is made by Banar and Özdemir (2015). It concerns both high speed rail and conventional rail in Turkey. They found that for high speed rail, construction of infrastructure was 65 percent of the total cost, infrastructure maintenance 4 percent, disposal related to infrastructure 3 percent, rail operations 28 percent, and other costs around 1 percent. For conventional rail, operation of rail was the largest expense, being 74 percent. Next to that, 6 percent was related to vehicle maintenance, 5 percent to infrastructure maintenance, and 15 percent to infrastructure construction. The remainder was related to some minor other costs.

There are some Dutch publications on index numbers regarding costs in public transport. A relatively recent publication is the one by CROW-KpVV (2015), which is a revision of an older publication by CVOV (2005). In these reports, investment and maintenance costs of infrastructure is considered, as well as purchase and operation costs of vehicles. It includes information on bus, tram, metro, and regional train systems.

To summarise, for different types of transport systems, large differences exist in relative spending to construction, maintenance and operation. Furthermore, maintenance costs are in general only a small part of the total costs. There are furthermore some reports available which include index numbers of construction and maintenance costs for multiple public transport systems.

Cost-benefit analysis

Performing a good ex ante evaluation of mega projects is important in decision-making (Van Wee and Rietveld, 2013). They state that in most western countries a CBA is used for that purpose, a method which includes pros and cons of a certain project in an economic framework.

Van Wee and Rietveld (2013) describe three main advantages of CBAs: most costs and benefits included are relatively well known, transport models are available, and it has a neutral character. They also mention some disadvantages, among them that some effects are hard to monetize, for example innovation, image, and prestige. Distribution effects, for example related to region or income, are not taken into account. It is also questioned if long term effects are properly considered.

In Van Wee and Rietveld (2013) it is described that many CBAs include a period after project realisation of a few decades and some use a period of 100 years. According to Romijn and Renes (2013), discounting is necessary to compare costs and benefits over a longer period of time, as costs and benefits in the future are valued lower than current costs and benefits. They state that the current value of future costs and benefits can be determined using an annual discount rate. Koopmans and Rietveld (2013) describes two approaches to create a discount rate. The first approach, related to market behaviour, leads to relative high discount rates. A second approach, more related to sustainability, leads in general to lower discount rates. According to Koopmans and Rietveld (2013) it is possible to give different discount rates to environmental or long term effects.

Although CBAs are worldwide often applied, Annema (2013) states that in an international context CBAs are not used as an important source in decision-making. In that research it is furthermore stated that in the Dutch context the use of CBAs had some impact on decision-making, but its use is at best limited. They think the role of CBAs in planning of megaprojects will always be modest.

Koopmans (2010) is however more positive about Dutch CBAs, stating that CBAs have stopped bad investment plans. It is argued that the Dutch situation, were a second opinion is given by the CBP, leads to good quality of CBAs made by consultants.

Eliasson and Lundberg (2012) state that CBAs seem to play a role in the screening and selection of investments by planners. However, they also find that for investments directly selected by politicians, no relation between CBAs with a high benefit-cost ratio and selection can be found.

In summary, an ex ante evaluation of a project can be performed by a CBA. CBAs are often applied, and can be used to monetize effects over a longer period of time. CBAs can play a role in the selection of projects, but seem to have limited influence on the decision-making.

1.3. Research objective and research questions

This research has two main aims. The first aim is to create an overview of the maintenance and replacement costs of five types of public transport systems, for both the infrastructure and the vehicles. Secondly, find out if there is an influence of using these estimations of the index numbers of the maintenance costs on the outcome of cost-benefit analyses. It is tried to achieve these goals by answering the following four research questions:

1. What is the importance of maintenance and replacement costs of urban public transport systems on decision-making?
2. How large are these maintenance and replacement costs?
3. How can variations in these maintenance and replacement costs be explained?
4. What is the influence of using index numbers of maintenance and replacement costs on the outcome of cost-benefit analyses?

2. SCOPE

In this chapter the scope of the research will be described. Started is with a framework which describes the main scope and background of this research. Then, it should be determined which public transport systems are included in this research and how they are defined. It should furthermore become clear what differentiates one system from another.

This is followed by providing definitions of the included types of infrastructure and the included types of vehicles. Finally, it should be made clear which type of maintenance costs are included, and what typical characteristics of these costs are.

2.1. FRAMEWORK

In the following paragraphs a description of the theoretical framework will be given. This framework is used to describe the scope and background of this research. The graphical representation of this framework is shown in figure 2.1.

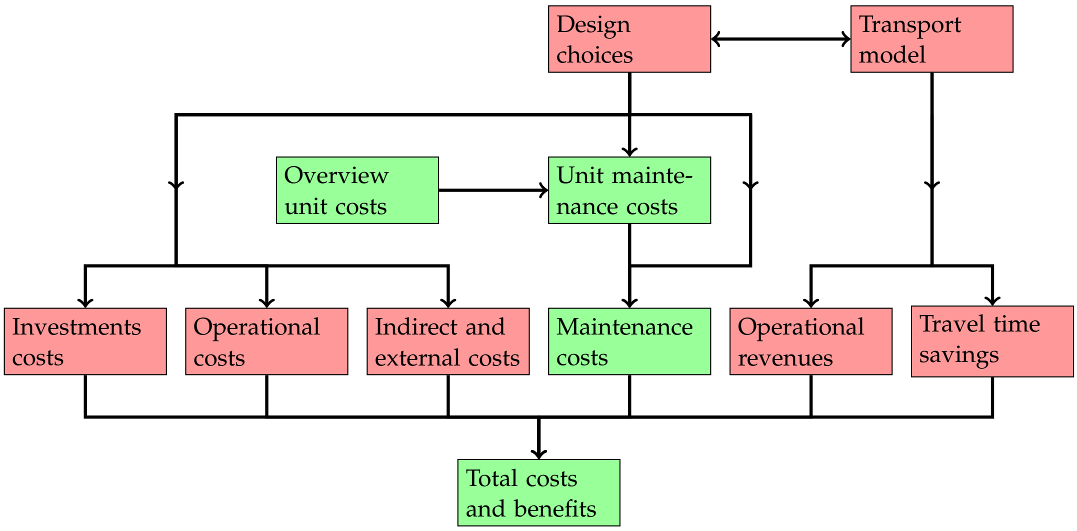

Figure 2.1: the theoretical framework of this research.

Four steps can be distinguished in the framework, which is shown in figure 2.1:

- When designing a new public transport connection, a first step is to estimate its demand. Based on this estimated demand, the design of the system can be changed, and again a new estimate of the demand can be given. This iterative process should lead to a proper design and dimensioning of the proposed transport connection;
- Based on the design of the transport connection, including the type of infrastructure and the type of vehicles, the unit maintenance costs can be estimated. These estimations are based on an overview or database of maintenance costs for several types of infrastructure and vehicles;
- Based on the design choices and unit maintenance costs, the total maintenance costs can be estimated. Next to that, also other costs, revenues, and savings can be estimated;
- Finally, the total costs and benefits of a public transport connection can be estimated as the sum of the already calculated costs and benefits.

In this research not the whole described process is studied. The focus is on the maintenance costs, shown in green in figure 2.1. Therefore, it is assumed that the design of a new public transport connection is already made. Transport modelling is thus not important in this research.

A model will be made to estimate the maintenance costs of a certain transport connection. In order to do this, an overview of maintenance costs of infrastructure and vehicles is needed. It is also a important part of this research to make such an overview.

This project will furthermore not focus on the process of calculating the other costs and benefits. The total costs and benefits are of interest in this research, because the total costs can change when the maintenance costs are changed. This could influence the outcome of a cost-benefit analysis (CBA), which will be analysed in this report.

2.2. Urban public transport systems

The scope of this research is narrowed down to public transport systems in the urban environment. The following five systems will be included in the research: bus, bus rapid transit, tram, light rail, and metro. The definitions of these five systems are given next. It must be noted that these systems are defined based on the type of vehicles and infrastructure they use. The definitions for the vehicles and infrastructure themselves are presented after that.

The five public transport systems are:

- Bus system: it has bus vehicles, which drive on shared road infrastructure;
- Bus rapid transit system: a system with bus vehicles, which drive on its own bus infrastructure;
- Tram system: an urban rail system, with tram vehicles on tram infrastructure;
- Light rail system: an urban rail system, with either tram and/or light rail vehicles on light rail infrastructure, or tram and/or light rail vehicles on a combination of tram, light rail, metro, and train infrastructure;
- Metro system: an urban rail system, with metro vehicles on metro infrastructure.

It must be noted that the focus of this research is on urban systems. Regional or national public transport systems are excluded. Heavy rail, as for example both the intercity and sprinter services in the Netherlands, is thus not part of the scope of this research. Smaller urban systems, for example with mini or midi buses, are excluded from this research as well.

Secondly, a broader definitions of light rail can be made, as for example in Railforum (2010). They consider tram, tramtrain, traintram, trammetro, and metrotram systems, all as light rail. Thereby is tramtrain a tram vehicle on train infrastructure, and traintram a train vehicle on tram infrastructure. A similar logic holds for the trammetro and metrotram. In this research we defined the tram system as being a separate category. Railforum (2010) gives no Dutch examples of a traintram or a trainmetro. There seems to be no operation of train vehicles on tram, light rail, or metro infrastructure in the Dutch situation. These kind of (light) rail solutions are therefore excluded from this research.

Thirdly, it must be noted that there is a large variation possible within a category. The category bus rapid transit can include a 12 meter electric bus as well as a 25 meter double articulated diesel bus. The reverse is also possible: a similar type of bus can be used in an ordinary bus system as well as in a bus rapid transit system. There is thus some variation possible within the categories, depending on the exact combination of infrastructure and vehicles. Therefore, also variations in maintenance costs are expected within a category.

2.3. Infrastructure

After defining the five urban transport systems, the following step is to create definitions of the various types of infrastructure. Four main types of infrastructure can be determined: bus, tram, light rail, and metro.

For bus, a distinction can be made between infrastructure shared with other vehicles, and infrastructure specifically meant for bus operation. When looking to the dedicated infrastructure, a further distinction can be made to asphalt bus lanes and concrete bus lanes.

The distinction between bus and rail infrastructure is straightforward, the first has paved lanes, the second a railway track. The distinction between tram, light rail, and metro is a bit harder. Multiple sources will be introduced, which contain characteristics of tram, light rail, and metro infrastructure. After that, a decision will be made regarding the definitions that will be used in this research.

In Van der Bijl and Van Oort (2014) a distinction is made between tram, metro, and train. They state that light rail is a hybrid form of tram, metro, and/or train, where light rail includes the tram, combinations of tram and train, and combinations of tram and metro. A selection of the characteristics of tram, light rail, and metro, derived from Van der Bijl and Van Oort (2014), is given in table 2.1.

It can be seen in table 2.1 that both tram and light rail are integrated in the environment. Light rail systems have however less level crossings, more priority, and more signalling than tram systems. Their stop distance is in general also larger. The table shows that metro is very different from both tram and light rail. It uses a closed track, meaning that there are no level crossings, and signalling is always used. Stop distances of metro are however similar to those of a light rail system.

Table 2.1: characteristics of tram, light rail, and metro, as derived from Van der Bijl and Van Oort (2014).

System	Environment	Crossings	Priority	Signalling	Stop distance (m)
Tram	Integrated	Many	Sometimes	Sometimes	200 - 800
Light rail	Integrated	Several	Often	Often	400 - 2000
Metro	Exclusive/closed	None	NA	Always	400 - 2000

A report by Railforum (2010) also gives some characteristics of different rail systems for the Dutch situation. A selection of these are shown in table 2.2. It can be seen that route lengths and stop distances are in general larger for light rail and metro than for tram. Light rail and metro use a 750 volt energy supply, were tram systems use a 600 or 750 volt system. Both tram and light rail systems drive mainly on sight, in contradiction to metro which drives on a full train protection system. It must also be noted that the average speed of tram systems is lower than that of light rail and metro.

Table 2.2: characteristics of tram, light rail, and metro, as given by Railforum (2010).

System	Length (km)	Voltage (V)	Stop distance (m)	Average speed (km/h)	Signalling
Tram	5 - 15	600 - 750	200 - 600	$\leq$20	On sight, traffic lights
Light rail	10 - 30	750	400 - 2000	30 - 45	On sight, light/full train protection
Metro	5 - 30	750	400 - 1000	30	Full train protection

The definitions for tram, light rail, and metro infrastructure, as used in this research, are given in table 2.3. To have a sharper separation between tram and light rail, tram infrastructure is defined as having a stop distance less than 800 meter, were light rail and metro starts at a stop distance of 800 meter. Furthermore, average speed of tram is below 20 km/h, but that of light rail above 20 km/h. Metro discriminates itself from tram and light rail because it has no level crossings and uses third rail instead of overhead wires. The operational name of the system is also taken into consideration.

Table 2.3: definitions of tram, light rail, and metro infrastructure as used in this report.

System	Stop distance (m)	Average speed (km/h)	Power supply traction	Name
Tram	200 - 800	$\leq$ 20	Overhead wires	Tram
Light rail	800 - 2000	$\geq$ 20	Overhead wires	Light rail
Metro	800 - 2000	$\geq$ 30	Third rail	Metro

2.4. Vehicles

Similar to making the definitions for infrastructure, also definitions for vehicles should be made. Four main types of vehicles can be determined: bus, tram, light rail, and metro.

For the three types of rail vehicles, no further distinction is made. For bus vehicles a further distinction can be made based on two characteristics. The first characteristic is the type of engine: diesel, electric, gas, or hybrid. The second characteristic is its format and length. Types include a standard 12 meter bus, an articulated bus with a length of around 18 meter, and a bi-articulated bus with a length of around 25 meter. Buses like the mini- and midi-bus are excluded from this research, as their capacity is relatively low. Double-decker buses are quite uncommon in public transport in the Netherlands and are therefore also excluded from this research.

Defining a vehicle as a bus or rail vehicle is quite straightforward. Differentiating between a tram, a light rail, and a metro vehicle is a bit more difficult. Therefore, a source is introduced, to help making the definitions for tram, light rail, and metro. Based on Railforum (2010), table 2.4 gives characteristics of tram, light rail, and metro vehicles. It can be seen that tram vehicles are in general shorter than light rail vehicles. Metro vehicles are in general longer and wider than light rail vehicles.

Table 2.4: characteristics of rail vehicles. In Railforum (2010) two light rail systems, being ‘sneltram’ and ‘regiotram/light rail’, are given, in this report both are considered light rail.

Rail type	Length (m)	Width (m)
Tram	25 - 45	2.40 / 2.65
Light rail (”sneltram”)	25 - 75	2.40 / 2.65
Light rail (”Regiotram/Light rail”)	25 - 75	2.65
Metro	50 - 150	2.65 / 3.00

In table 2.5 the final definitions of rail vehicles are given. It is expected that, regarding the width of the vehicles, light rail is somewhere in between tram and metro. Therefore, tram is defined as having a width smaller than 2.65 meter, light rail as having a width of around 2.65 m, and metro as having a width equal to or larger than 2,65 m.

Trams can be operated on tram track, and use a pantograph for energy supply. Metros are operated on metro track with grade separated crossings, and use third rail for its energy supply. Light rail vehicles can be operated on multiple types of track. They have a pantograph for operation on tram and light rail track, and some can use third rail for operation on metro track. Possible adjustments to vehicles or track may be necessary for reliable operation. The operational name of the vehicles is also taken into account.

Table 2.5: definitions of rail vehicles. Light rail vehicles can drive on multiple types of infrastructure: tram, light rail, train, and metro track.

Vehicle type	Width (m)	Energy supply	Name
Tram	$<$2.65	Pantograph	Tram
Light rail	$\approx$ 2.65	Pantograph, with sometimes third rail	Light rail
Metro	$\geq$2.65	Third rail	Metro

2.5. Maintenance costs

The costs of maintaining a public transport system will be broken down in the maintenance costs for the infrastructure and the maintenance costs for the vehicles. The infrastructure costs are separated in management, regular maintenance, and major maintenance costs. A further distinction is made in costs related to the track, to stations, and to other costs.

The vehicle costs are separated in management, regular maintenance, major maintenance, life extension, and vehicle replacement. Vehicle replacement is included as a type of maintenance costs, as the life time of the whole system is larger than the life time of a vehicle. In other words, replacement of vehicles is necessary to maintain the systems as a whole.

The just described structure of the costs is also shown in figure 2.2. It must be noted that this structure can not be applied one-to-one on the available data. The next step is to define which type of costs are included in the costs groups as as given in figure 2.2. This is shown in the next paragraphs, first for infrastructure, then for vehicles.

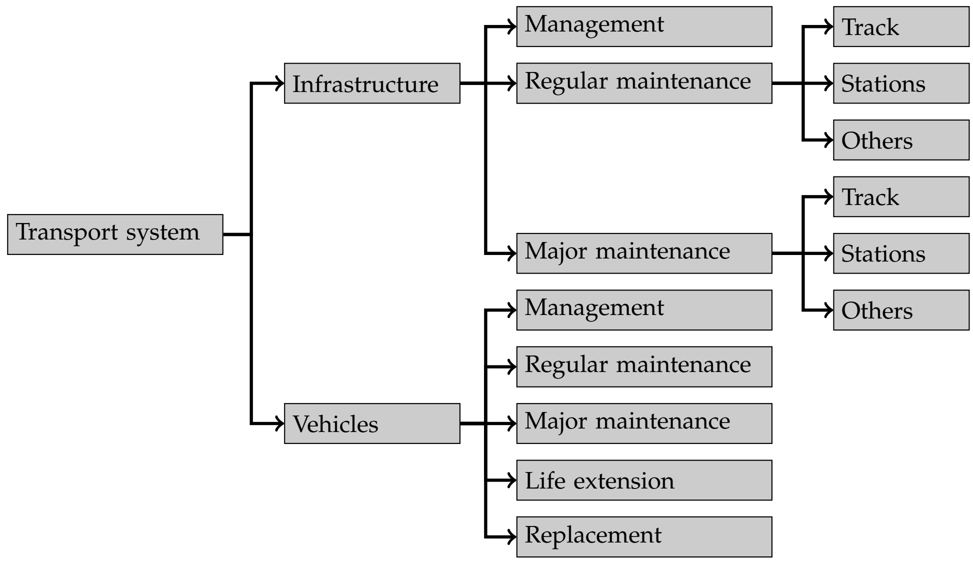

Figure 2.2: overview of the types of maintenance costs included in this research.

Infrastructure

For infrastructure three types of costs can be distinguished: management costs, regular maintenance costs, and major maintenance costs.

Management costs can be seen as the overhead for maintaining the infrastructure. This includes costs for staff, costs for real estate, ICT and data management, and risk margins. Costs for maintenance of the vehicles which are used to maintain the infrastructure, maintenance tools, and a team responsible for measurements and inspections are also included.

Regular maintenance generally includes types of maintenance which takes places on a relatively small scale and with relatively high frequency. Major maintenance includes maintenance taking place on a large scale, with mostly larger costs and lower frequencies. In general the distinction between regular and major maintenance is already made in the used source documents. It is expected that not all the companies use the exact same definitions regarding management, regular maintenance and major maintenance, leading to some differences among them.

Both regular and major maintenance can be broken down further in costs for track, stations, and other costs. Costs for track for example include replacement of track, and welding and grinding of track. Costs for stations include costs on the stations themselves, and also costs for the station systems. Other costs are costs related to energy supply, rail safety, systems, signalling, cleaning, civil structures, and facilities, depots, stabling yards, and workshops. The depots and workshops themselves are related to maintenance of the vehicles, but the related track, overhead wire, etcetera, are related to maintenance of the infrastructure.

Vehicles

For vehicles five types of costs can be distinguished: management costs, regular maintenance costs, major maintenance costs, life extension, and vehicle replacement. Again, some possible variation in definitions among companies is possible.

Management costs can be seen as the overhead to maintain the vehicles. Organizational costs, insurance costs, and capital costs for depots and workshops are included.

Regular maintenance generally includes types of maintenance which takes places on a relatively small scale and with relatively high frequency. This includes cleaning, preventive and corrective maintenance, damage repair, and costs for ICT and telematics.

Major maintenance includes maintenance taking place on large scale, with mostly larger costs and lower frequencies. The following cost are included: modifications, renewal maintenance, investment and value adding maintenance, revision of subsystems, capital costs of subsystems, and midlife revisions.

Life extension is maintenance to extend the lifespan of a vehicle beyond its normal life span. This can be functional maintenance, renewal of interior, and/or renewal of exterior.

Vehicle replacement costs are the costs of replacing a vehicle with a new one. The replacement costs will include the purchase of the relevant systems. Replacement is included, as it is expected to take place during the lifespan of a transport system. For example, when the expected life span of the system is 100 years and the expected life span of the vehicles is 30 years, replacement of vehicles is expected three times: after 30 years, after 60 years, and after 90 years.

3. DATA

In this chapter the study area, the data, and the interviews will be introduced. This chapter will start off with an introduction of the rail infrastructure, followed by an introduction of the rail vehicles. The ratio of vehicles and infrastructure is given as well. After that, a general introduction of the available data concerning maintenance costs is given. This is followed by an introduction of the interviews. Finally an overview is given of the cost-benefit analyses (CBAs) used in this research.

3.1. Study area infrastructure

First, an overview of Dutch urban rail lines will be given. Based on the previously made definitions, it is possible to define each line as tram, light rail, or metro. When this is done, it is possible to calculate the total network length of tram, light rail, and metro, sorted per city.

Overview Dutch urban rail lines

In table 3.1 an overview is given of Dutch urban rail lines. These are lines as they exist today, except for the Hoekse lijn, the Noord/Zuidlijn, and the Uithoflijn. The Hoekse lijn is an old train line which is being converted to light rail, the Noord/Zuidlijn is a metro line under construction, and the Uithoflijn is a light rail line under construction.

The number of stations and the travel times are retrieved from 9292 (n.d.), except for the three new lines mentioned previously. The length of the lines are calculated based on the price retrieved from 9292 (n.d.), the base rate from Trans Link Systems B.V. (n.d.), and a kilometre price retrieved from GVB (n.d.b), RET (n.d.b), HTM (n.d.b), and U-OV (n.d.).

Information for the three new lines are retrieved from Gemeente Amsterdam (n.d.) for the Noord/Zuidlijn, from Hoekse Lijn (n.d.) for the Hoekse Lijn, and from Uithoflijn (2017) for the Uithoflijn.

For the light rail and metro network in Rotterdam and The Hague multiple track plans, including track lengths, were used. RET and HTM (2017), RET (2016d), and RET (2017f), respectively for RET line E and HTM line 3 and 4, for RET line A, B, C, D, and E, and for the Hoekse lijn.

The rail type as used in operation is in general adopted in this report. However, if a line which is operated as metro, uses overhead wires, it will be seen as light rail. The operational name is also not adopted if for a tram or light rail line both stop distance and average speed deviate from the definitions.

Most lines in operation as tram, will also be defined as tram. That is the case for all tram lines, except for GVB line 26, which has both a stop distance above 800 meter, and average speed above 20 km/h, and can thus be seen as light rail. The HTM tram line 19 is used by both tram and light rail vehicles, and has an average speed higher than 20 km/h, but has a stop distance less than 800 meter, and is therefore considered a tram line. HTM tram line 2 is used by both tram and light rail vehicles, however it is considered a tram line due to its low average speed and stop distance. The same is true for the parts of HTM line 3 and 4 on the normal tram network, which have also speed and stop distance belonging to tram infrastructure.

All the in table 3.1 given lines which are considered metro lines, have metro as their operational name, have an average speed over 30 km/h, and have a stop distance between 800 and 2000 meter.

Some light rail lines have metro as their operational name, but have level crossings and overhead wires. These lines are considered light rail lines. This is the case for a part of GVB line 51 (Wikipedia, 2018), parts of RET lines A and B (RET, 2016d), part of RET line E (RET and HTM, 2017), as well as the largest part of the Hoekse lijn (RET, 2017f). The remaining light rail lines have a operational name which is considered light rail: sneltram or RandstadRail. These lines also have an average speed above 20 km/h, and a stop distance larger than 800 meter.

Table 3.1: overview of Dutch urban rail lines. Lines with a star (*) have multiple types of infrastructure and are divided in multiple sections. GVB line 51 is divided in a section Amsterdam CS – Amsterdam Zuid which is metro, and a section Amsterdam Zuid – Amstelveen, which is light rail. RET lines A, B, and E, have light rail sections for respectively Capelsebrug – Binnenhof, Capelse brug – De Tochten, and Melachtonweg – Den Haag CS, the other parts of these lines are metro. The metro section De Tochten - Nesselanden, line A, is not included in this table as it is only 1.5 km long. HTM lines 3 and 4 are for this overview assumed light rail for the part from Den Haag CS to Zoetermeer, and tram from Den Haag CS to Loosduinenen and De Uithof.

Line	Company	Type	L (km)	T (min)	v (km/h)	Stations	Stop dst. (m)
1	GVB	Tram	10.4	37	16.9	23	473
2	GVB	Tram	9.2	36	15.3	22	438
3	GVB	Tram	8.4	35	14.4	21	420
4	GVB	Tram	6.0	28	12.9	18	353
5	GVB	Tram	10.6	40	15.9	26	424
7	GVB	Tram	12.7	47	16.2	31	423
9	GVB	Tram	8.6	33	15.6	20	453
10	GVB	Tram	8.1	33	14.7	21	405
12	GVB	Tram	8.9	38	14.1	22	424
13	GVB	Tram	8.4	37	13.6	21	420
14	GVB	Tram	12.7	47	16.2	31	423
17	GVB	Tram	9.9	37	16.1	22	471
24	GVB	Tram	7.8	32	14.6	18	459
2	RET	Tram	9.6	31	18.6	20	505
4	RET	Tram	10.2	43	14.2	28	378
7	RET	Tram	8.5	34	15.0	22	405
8	RET	Tram	12.3	49	15.1	31	410
20	RET	Tram	9.0	29	18.6	16	600
21	RET	Tram	17.1	61	16.8	37	475
23	RET	Tram	15.3	54	17.0	30	528
24	RET	Tram	18.0	64	16.9	40	462
25	RET	Tram	17.4	54	19.3	28	644
1	HTM	Tram	19.9	64	18.7	39	524
2	HTM	Tram	12.8	43	17.9	31	427
3*	HTM	Tram	9.2	29	19.0	21	460
4*	HTM	Tram	8.3	27	18.4	17	519
6	HTM	Tram	12.4	38	19.6	28	459
9	HTM	Tram	13.4	48	16.8	29	479
11	HTM	Tram	7.7	26	17.8	18	453
12	HTM	Tram	10.6	40	15.9	24	461
15	HTM	Tram	7.1	20	21.3	13	592
16	HTM	Tram	17.4	58	18.0	39	458
17	HTM	Tram	12.6	41	18.4	26	504
19	HTM	Tram	11.0	30	22.0	16	733
26	GVB	Light rail	8.3	19	26.2	11	830
51*	GVB	Light rail	9.9	23	25.8	20	521
A*	RET	Light rail	5.8	12	29.0	8	829
B*	RET	Light rail	7.3	15	29.2	10	811
E*	RET	Light rail	20.4	27	45.3	13	1,700

Table 3.1: continued.

Line	Company	Type	L (km)	T (min)	v (km/h)	Stations	Stop dst. (m)
Hoekse lijn	RET	Light rail	23.0	25	55.2	9	2,875
3*	HTM	Light rail	24.2	39	37.2	21	1,210
4*	HTM	Light rail	18.6	29	38.5	15	1,329
60	U-OV	Light rail	12.2	27	27.1	15	871
61	U-OV	Light rail	16.6	36	27.7	19	922
Uithoflijn	U-OV	Light rail	8.0	17	28.2	9	1,000
50	GVB	Metro	20.2	35	34.6	20	1,063
51*	GVB	Metro	9.2	16	34.5	10	1,022
52	GVB	Metro	9.7	16	36.4	8	1,386
53	GVB	Metro	11.4	21	32.6	14	877
54	GVB	Metro	12.3	22	33.5	15	879
A*	RET	Metro	17.5	29	36.2	17	1,094
B*	RET	Metro	11.4	20	34.2	13	950
C	RET	Metro	29.9	45	39.9	26	1,196
D	RET	Metro	21.4	33	38.9	17	1,338
E*	RET	Metro	10.7	19	33.8	11	1,070

Figure 3.1 gives a scatter plot of the stop distance against the average speed. This scatter plot is based on the in table 3.1 given values and definitions. Is shows a strong correlation between stop distance and average speed, as expected.

It can furthermore be seen that tram and metro systems are quite homogeneous groups. All 34 tram lines have a stop distance between 300 and 800 meter, and have an average speed between 12 and 24 km/h. All 10 metro lines have a stop distance between 800 and 1400 meter, and an average speed between 32 and 40 km/h.

There is much more variation in the 11 light rail lines. Around half of the lines have an average speed between 26 and 30 km/h, and a stop distance between 800 and 1000 meter. These lines seem to be somewhere between tram and metro. But there are also some lines which are different: two light rail lines, both RandstadRail operated by HTM, are, in terms of stop distance and average speed, very similar to metro lines. Two more light rail lines, both from RET, have a stop distance and average speed, beyond that of metro. One light rail line has a stop distance similar to tram, but an average speed which is 6 tot 12 km/h higher than most tram lines.

It can be expected that for relatively homogeneous groups, in terms of stop distance and average speed, also the maintenance costs are relatively similar. Less variation in maintenance costs among the lines is thus expected for tram and metro than for light rail.

Network lengths

An overview of urban rail networks in the Netherlands is given in figure 3.2. The total route length of the tram networks is around 310 km. The lengths of the light rail and metro networks are much smaller, both having a total network length of around 80 to 90 km.

The total network length of urban lines is around 480 km. Network lengths of Amsterdam, The Hague, and Rotterdam are quite comparable, respectively around 140, 150, and 160 km. Utrecht has much less urban rail, only around 20 km.

GVB, Amsterdam, and RET, Rotterdam have tram, light rail, and metro lines. HTM, The Hague has a tram system and a light rail system, the latter named RandstadRail. U-OV, Utrecht only has a light rail system. The rail networks of these four companies and cities are discussed next in more detail, including the sources on which the previously discussed network lengths are based.

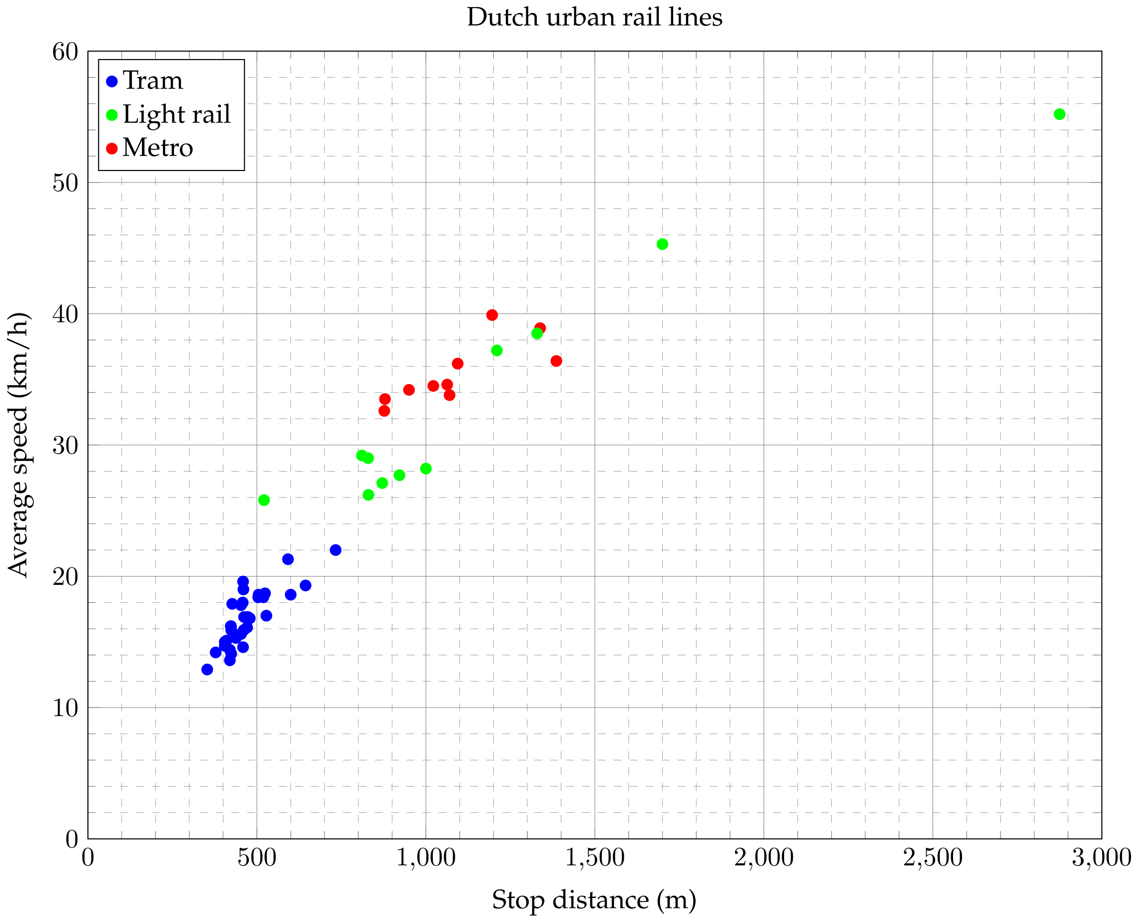

Figure 3.1: stop distance and average speed of Dutch urban rail lines, including tram, light rail, and metro.

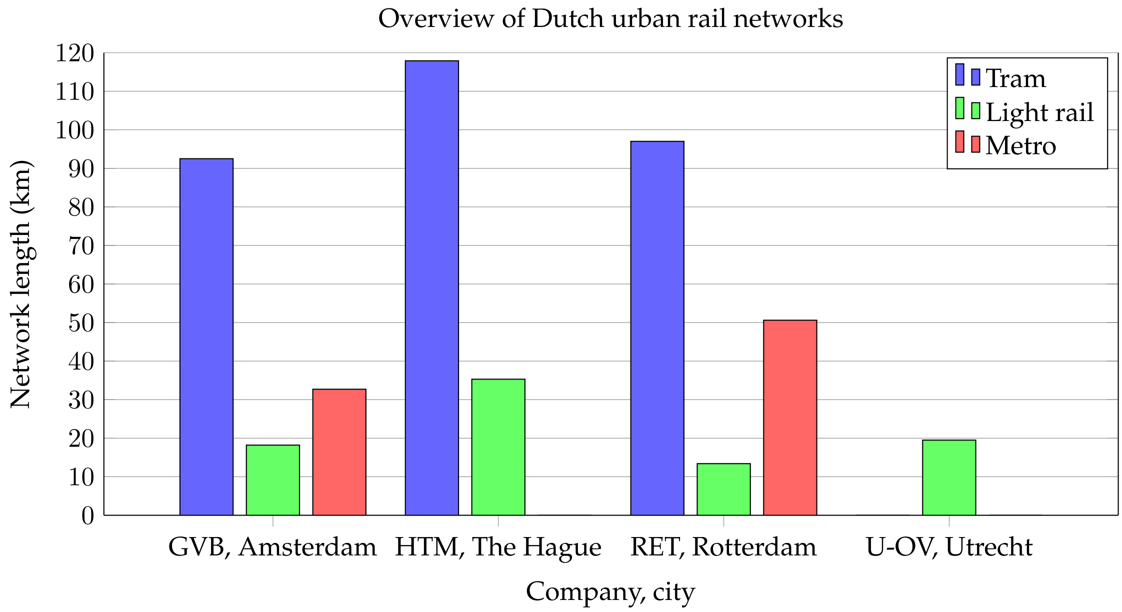

Figure 3.2: overview of network lengths of Dutch urban rail networks in 2017, given in route-km.

Network GVB, Amsterdam

The Amsterdam tram network consist of 201.5 km single track usable for operation, as given by GVB (2010). Assuming double track on the whole network, this results in a route length of 100.8 km for 14 lines. Line 26 is seen as a tram line by GVB (GVB, n.d.). Although it was previously defined as a light rail line, in further research it will be used as a tram line for this pragmatic reason. With a length of 8.3 km, it is only 8 percent of the total tram network, and it is therefore not expected to have a large influence on the results.

When excluding line 26, there is only one light rail line left: line 51 from Amsterdam Zuid to Amstelveen. This line has a route length of 9.9 km, as was shown in table 3.1.

The size of the metro network is calculated based on table 3.1 and some additional measurement in Google Maps. It has a total route length of 32.7 km. The Noord/Zuidlijn, with a route length of 9.7 km (Witteveen en Bos, n.d.), will increase total network length to 42.4 km in 2018. In some documents the light rail part of line 51 is included when calculating the costs for the metro network.

There is 3.5 km underground metro, increasing to 10.6 km after finishing the Noord/Zuidlijn. An overview of network lengths for the period 2011 till 2024 is given in table 3.2.

Table 3.2: overview network lengths tram, light rail, and metro of GVB, Amsterdam for the period 2011 till 2024. Network length is given in route-km.

Length in km	2011	2012	2013	2014	2015	2016	2017
Tram	100.8	100.8	100.8	100.8	100.8	100.8	100.8
Light rail	9.9	9.9	9.9	9.9	9.9	9.9	9.9
Metro	32.7	32.7	32.7	32.7	32.7	32.7	32.7

Length in km	2018	2019	2020	2021	2022	2023	2024
Tram	100.8	100.8	100.8	100.8	100.8	100.8	100.8
Light rail	9.9	9.9	9.9	9.9	9.9	9.9	9.9
Metro	42.4	42.4	42.4	42.4	42.4	42.4	42.4

Network HTM, The Hague

The tram network of HTM consists of 12 lines, with 129.4 km double track, of which 11.5 km are side tracks (HTM, 2015b). The network length, expressed in route-km, is then 117.9 km.

The light rail network, RandstadRail, consists of 3 lines, with a route length of 35.3 km, based on RET and HTM (2017). There is furthermore a few km of side track (HTM, 2015b).

The infrastructure of one line of the RandstadRail, metro line E, is maintained both by HTM and RET. The management border lies on the border of the municipalities of Pijnacker-Nootdorp and Lansingerland, somewhere between the stations Pijnacker Zuid and Berkel Westpolder (based on RET and HTM (2017) and Google Maps).

The network length is assumed constant over the period 2013 till 2026. The effect of possible extensions, namely extra maintenance costs, seems not included in the used documents, and therefore no increase in network length is assumed.

Network RET, Rotterdam

The Rotterdam tram network has 9 tram lines (RET, n.d.d), excluding line 12 which seems to be used only during competition days of Feyenoord (RET, n.d.c). Its network consists of 194 km single-track (Mott MacDonald, 2017a), which is, assuming double track over the whole network, 97 route-km.

For the light rail and metro network in Rotterdam multiple track plans, including distances were available: RET and HTM (2017), RET (2016d), and RET (2017f), respectively for RET line E, for RET line A, B, C, D, and E, and for the Hoekse lijn. Additional measurements are made with Google Maps, especially for calculating the amount of underground track.

There is 13.4 route-km light rail. The network size of the metro part, expressed in route-km, is 50.6 km. There is 18.8 km underground metro and 31.8 km above ground metro.

There was an increase in the metro network in 2010 due to the opening of the Statenweg tunnel (RET, 2011b). The light rail network will increase due to the opening of the Hoekse Lijn in 2018 and its extension in 2019 (RET, n.d.a). An overview of network lengths for RET are given in table 3.3.

Table 3.3: overview of the tram, light rail, and metro networks of RET, Rotterdam for the period 2007 till 2026. Network length is given in route-km.

Length in km	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Tram	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Light rail	16.3	16.3	16.3	13.4	13.4	13.4	13.4	13.4	13.4	13.4
Metro	47.6	47.6	47.6	50.6	50.6	50.6	50.6	50.6	50.6	50.6

Length in km	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Tram	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Light rail	13.4	36.4	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6
Metro	50.6	50.6	50.6	50.6	50.6	50.6	50.6	50.6	50.6	50.6

Network U-OV, Utrecht

The light rail network of Utrecht has two lines, with a total route length of 19.5 km (Provincie Utrecht, n.d.). This will increase to 27.5 km in 2018, with the start of the Uithoflijn (Uithoflijn, 2017). Network lengths for the period 2015 till 2020 are shown in table 3.4.

Table 3.4: overview network length light rail U-OV, Utrecht for the period 2015 till 2020. Network length is given in route-km.

Length in km	2015	2016	2017	2018	2019	2020
Light rail	19.5	19.5	19.5	27.5	27.5	27.5

3.2. Study area vehicles

First, an overview of Dutch urban rail vehicles will be given. Based on the previously made definitions, it is possible to define each vehicle as tram, light rail, or metro. When this is done, it is possible to calculate the fleet size of tram, light rail, and metro, sorted per company.

Overview Dutch urban rail vehicles

First an overview of vehicles is given in table 3.5. Most of these vehicles are currently used by GVB, RET, HTM, and U-OV. Next to these currently used vehicles, some vehicles were used until recently and some vehicles are to be introduced shortly.

For GVB, information about the vehicles is based on GVB (n.d.d) and GVB (n.d.c), for respectively the current tram types and the current metro types. For the 9G/10G tram, information is retrieved from Wikipedia (2017a), and for the M1/M2/M3 metro from Wikipedia (2017b).

For RET, information about the lengths and capacities of the vehicles is based on RET (n.d.f) and RET (n.d.e), for respectively the tram and the metro vehicles. Width of the vehicles are based on Wikipedia (2017d), Wikipedia (2017e), Wikipedia (2017g), and Wikipedia (2017f), for respectively Citadis I and II trams, MG2/1 metro vehicles, SG2/1 light rail vehicles, and RSG3/SG3/HSG3 light rail vehicles.

For HTM, information about the vehicles is based on Üstra (n.d.) for the TW6000, Wikipedia (2017c) for the GTL8-I and GTL8-II, Siemens (2014) for the Avenio, and Alstom (2006) for the RegioCitadis.

For U-OV, information about the vehicles is based on Wikipedia (2017h) for the SIG vehicles, and on CAF (n.d.a) and CAF (n.d.b) for respectively the Urbos 100 (5) and Urbos 100 (7).

Table 3.5: overview of urban rail vehicles in the Netherlands. It must be noted that some Combino's have a slightly lower capacity, due to a different configuration. Lengths and capacities are rounded to whole numbers, widths are rounded to two decimal places.

Vehicle	Company	Type of vehicle	Length (m)	Width (m)	Capacity	Capacity per 30 m
9G/10G	GVB	Tram	26	2.32	155	182
11G	GVB	Tram	26	2.35	150	174
12G	GVB	Tram	26	2.35	176	204
Combino	GVB	Tram	30	2.40	184	187
Citadis I	RET	Tram	31	2.40	178	171
Citadis II	RET	Tram	31	2.40	181	176
TW6000	HTM	Tram	28	2.40	150	159
GTL8 - I	HTM	Tram	29	2.35	189	198
GTL8 - II	HTM	Tram	29	2.35	188	194
Avenio	HTM	Tram	35	2.55	232	199
S1/S2	GVB	Light rail	30	2.65	233	233
S3	GVB	Light rail	30	2.65	250	250
SG2/1	RET	Light rail	31	2.66	217	213
RSG3/SG3/HSG3	RET	Light rail	43	2.66	271	190
RegioCitadis	HTM	Light rail	37	2.65	216	176
SIG	U-OV	Light rail	30	2.65	224	226
Urbos 100 (5)	U-OV	Light rail	33	2.65	216	197
Urbos 100 (7)	U-OV	Light rail	41	2.65	277	202
M1/M2/M3	GVB	Metro	37	3.01	296	238
M4	GVB	Metro	30	2.65	250	250
M5	GVB	Metro	116	3.00	960	248
MG2/1	RET	Metro	31	2.66	225	221

As can be seen in table 3.5, most tram vehicles have a width between 2.32 to 3.40 meter, except for the Avenio in The Hague, which has a width of 2.55 meter. The lengths of the vehicles vary between 26 to 35 meter. Capacity per 30-meter vehicle is around 180 persons. Light rail vehicles have a width of 2.65 or 2.66 meter and a length varying between 30 and 43 meter. Capacity per 30-meter vehicle is on average around 210 persons. Metro vehicles have a width of 2.65/2.66 meter in Rotterdam (RET), and 3.00/3.01 meter in Amsterdam (GVB). Their lengths vary between 30 and 116 meter. Capacity per 30-meter metro vehicle is around 240 persons. It must be noted that some vehicles can be coupled. The length of the longest light rail vehicle is 43 meter, were a coupled vehicle could for example have a length of around 75 meter (SpoorPro, 2017).

Number of vehicles per company

An overview of the number of urban rail vehicles in 2017 in the Netherlands is given in figure 3.3. It must be noted that GVB, HTM, and RET all have more than 250 30-meter equivalent rail vehicles, were U-OV only has a tenth of that.

A distinction is made between tram, light rail, and metro. HTM has tram and light rail vehicles and U-OV only light rail vehicles. GVB and RET have both tram, light rail, and metro vehicles.

GVB and HTM have a bit more tram vehicles than RET, both have over 170 30-meter equivalent vehicles, were RET has less than 120 30-meter equivalent vehicles. GVB has the largest metro fleet and RET the largest light rail fleet, followed by HTM.

The fleet sizes of these four companies are discussed next in more detail, including the sources on which the previously discussed fleet sizes are based.

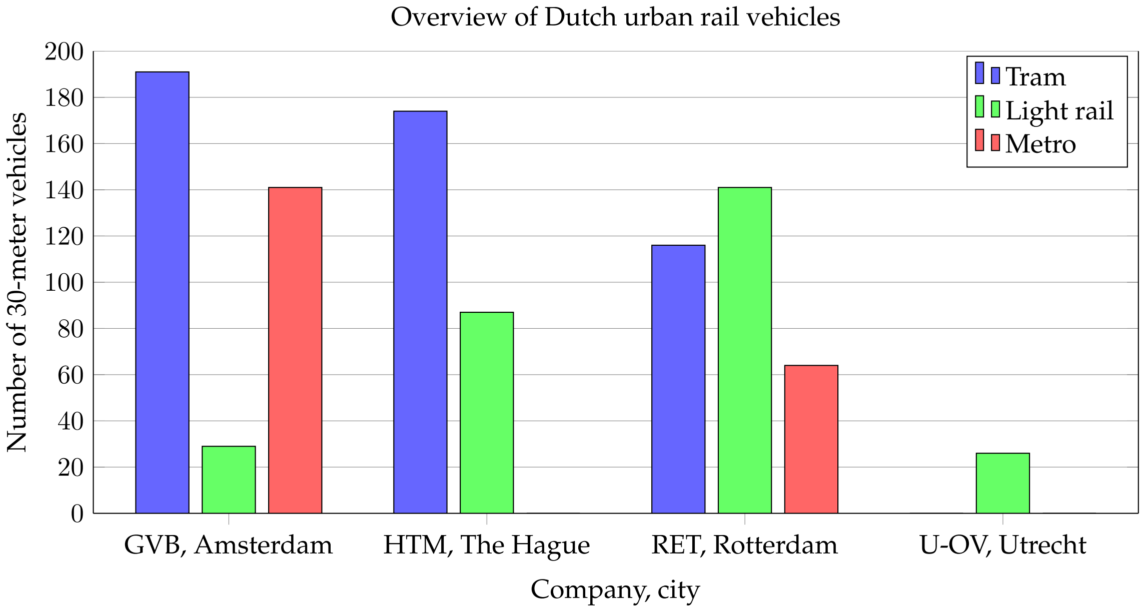

Figure 3.3: overview of fleet sizes for Dutch urban rail companies in 2017, given in number of 30-meter equivalent vehicles.

GVB, Amsterdam

An overview of the fleet size for GVB during the period 2013 till 2017 is given in table 3.6. The number of vehicles are based on Mott MacDonald (2017b), GVB (2017), and Wikipedia (2018). During this period there are three types of tram vehicles, two types of light rail vehicles, and three types of metro vehicles.

Table 3.6: overview of the number of 30-meter equivalent tram, light rail and metro vehicles for GVB, Amsterdam, for the period 2013 till 2017, rounded to whole numbers.

GVB	2013	2014	2015	2016	2017
Tram	202	202	197	191	191
Light rail	29	29	29	29	29
Metro	87	92	150	141	141

HTM, The Hague

An overview of the fleet size for HTM during the period 2005 till 2026 is given in figure 3.7. The given numbers are based on Mott MacDonald (2017b), HTM (2016d), HTM (2009), and HTM (2013). During this period there are five types of tram vehicles and one type of light rail vehicle.

Table 3.7: overview of the number of 30-meter equivalent tram and light rail vehicles for HTM, The Hague, for the period 2005 till 2026, rounded to whole numbers.

HTM	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Tram	148	148	147	147	147	147	138	138	124	124	147
Light rail	NA	NA	66	66	66	66	88	88	88	88	87

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Tram	153	174	155	134	134	134	134	134	152	152	152
Light rail	87	87	87	87	87	87	87	87	87	87	87

RET, Rotterdam

An overview of the fleet size for RET during the period 2016 till 2026 is given in figure 3.8. The vehicle numbers are based on RET (2016c). During this period there are two types of tram vehicles, four types of light rail vehicles, and one type of metro vehicle.

Table 3.8: overview of the number of 30-meter equivalent tram, light rail, and metro vehicles for RET, Rotterdam, for the period 2016 till 2026, rounded to whole numbers.

RET	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Tram	116	116	116	116	116	116	116	116	116	116	116
Light rail	132	141	141	141	141	141	141	141	141	141	141
Metro	64	64	64	64	64	64	64	64	64	64	64

U-OV, Utrecht

An overview of the fleet size for U-OV during the period 2015 till 2020 is given in figure 3.9. The number of vehicles are based on Provincie Utrecht (2016b), Provincie Utrecht (2017), Provincie Utrecht (2016a), and Uithoflijn (2017). During this period there are three types of light rail vehicles.

Table 3.9: overview of the number of 30-meter equivalent light rail vehicles for U-OV, Utrecht, for the period 2015 till 2020, rounded to whole numbers.

U-OV	2015	2016	2017	2018	2019	2020
Light rail	26	26	26	55	55	60

3.3. Ratio infrastructure and vehicles

To gain additional insight in the relation between infrastructure and vehicles, the ratio of the number of vehicles per km of infrastructure is calculated. Results are shown in figure 3.4.

This gives some very coarse results. Firstly, because results for the metro of Amsterdam and Rotterdam are calculated based on the numbers of vehicles and the infrastructure lengths of both light rail and metro. Secondly, because vehicles sometimes use another type of infrastructure, or because they use the infrastructure of another company. For example, light rail vehicles of HTM partially use the tram infrastructure, and light rail vehicles of RET also use some part of the HTM light rail infrastructure. Thirdly, because in some cases vehicles are already bought, but the infrastructure is not yet in use, for example for the Noord/Zuidlijn and the Hoekse Lijn.

The figure shows that metro has a larger number of vehicles per km of infrastructure than tram and light rail. This is not unexpected, as it is expected that metro has longer vehicles and higher frequencies. There is no consistent difference in the ratio of vehicles and infrastructure between light rail and tram.

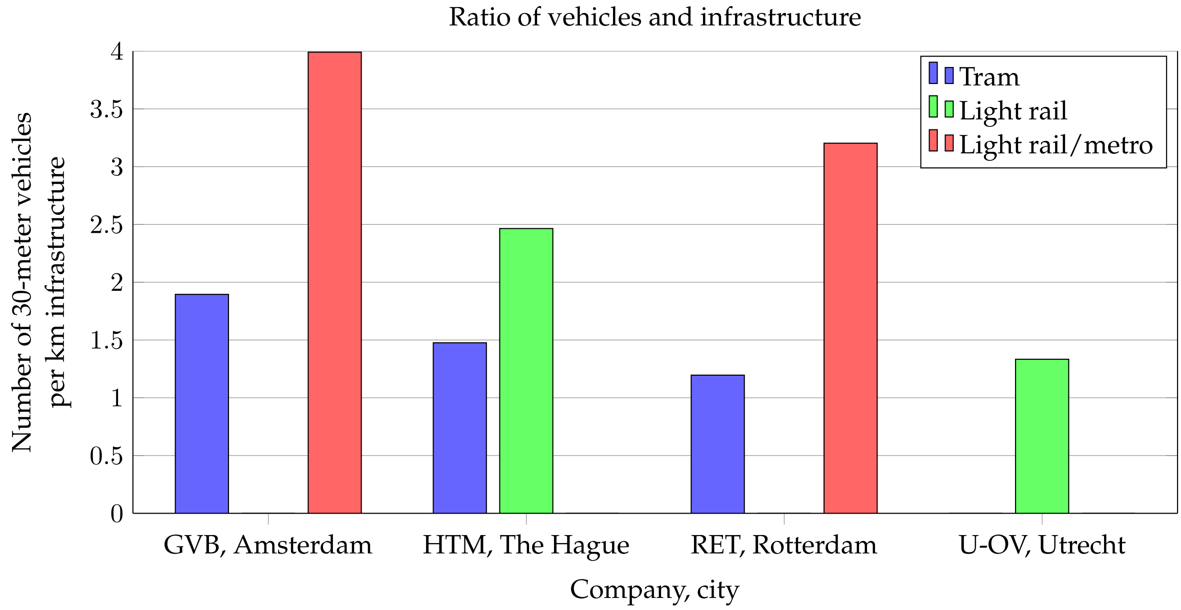

Figure 3.4: overview of the ratio of vehicles and infrastructure in 2017, given as the number of 30-meter equivalent vehicles per route-km.

3.4. Dataset maintenance costs

In the following paragraphs an overview of the available documents concerning maintenance costs for rail infrastructure and rail vehicles is given. This is mainly a collection of documents from Mott MacDonald, which is provided by the companies GVB, RET, and HTM. Next to that, some additional data is collected.

Overview documents

The data set from Mott MacDonald contains documents with financial information about the urban rail systems for the cities Amsterdam, The Hague, and Rotterdam. These documents consist mainly of annual plans, subsidy applications, multi-annual plans, sheets with capital expenses, and financial results. Additional information about maintenance costs is collected from interviews and online sources, for Amsterdam, The Hague, Rotterdam, and Utrecht. Table 3.10 gives an overview of the used sources, including the type of costs that can be obtained from these sources and the sample size of each document.

Sample size

As shown in table 3.10 the sample size varies between one and eleven. It must be noted that the sample size represents the actual sample size used in further analysis. For example for the multi-annual plan 2015-2050 (Amsterdam), due to the complexity of the data, only the total costs over the period 2019-2050 are analysed instead of analysing all the individual years. Therefore, the sample size is only one.

Some documents have multiple numbers for the sample size. This is the case if not for all categories an equal number of data points is available. For example, for the capital expenses (Rotterdam), there are replacement costs for one type of metro, for two types of trams, and for four types of light rail vehicles. Therefore, the sample size varies between one and four. Furthermore, starred (*) versions of the sample size represent documents with, at least partially, future estimates.

Table 3.10: overview of the used sources and the type of information they contain: a. DIVV (2011a), DIVV (2011b), Dienst metro (2012), Dienst metro (2014), Gemeente Amsterdam (2015b), and Gemeente Amsterdam (2016); b. BORI; c. Dienst Metro and GVB (2013); d. Gemeente Amsterdam (2015a); e. Dienst metro (2015); f. NoordZuidlijn (n.d.); g. GVB (n.d.a); h. GVB (2017); i. GVB (2012); j. GVB Activa B.V. (2017); k. Amsterdam (2017); l. HTM (2014), HTM (2016b), and HTM (2016c); m. HTM Techniek (2016b); n. HTM (2016d); o. HTM Techniek (2016a); p. HTM (2017); w. HTM (2015a) and HTM (2016a); r. HTM (n.d.a); s. OV-magazine (2014); t. RET (2008), RET (2009), RET (2010), RET (2011a), RET (2012), RET (2013), RET (2014), and RET (2015); u. RET (2016b); v. Uijtdewilligen (2017); w. RET (2016c); x. RET (2016e); y. Provincie Utrecht (2016b), Provincie Utrecht (2017), and Provincie Utrecht (2016a); z. BRU (2014) and BRU (2015). The sample size is included as well, numbers with a star (*) represent documents with (partially) future estimates.

Source (city)	Infrastructure	Vehicles	Management	Regular maintenance	Major maintenance	Life extension	Replacement	Sample size (n)
Subsidy applications 2011-2016 (Amsterdam)[a]	x		x	x	x			3-6
BORI 2014-2016 (Amsterdam)[b]	x		x	x	x			3*
BORI agreement 2014-2024 (Amsterdam)[c]	x		x	x	x			11*
Maintenance costs Amstelveenlijn (Amsterdam)[d]	x			x	x			1*
Multi-annual plan 2015-2050 (Amsterdam)[e]	x				x			1*
M&M Noord/Zuidlijn (Amsterdam)[f]	x		x	x				1*
Impact analysis metro project (Amsterdam)[g]		x		x				5*
Maintenance costs (Amsterdam)[h]		x	x	x	x			4
Capital costs vehicles (Amsterdam)[i]		x			x		x	1
Investment subsidy (Amsterdam)[j]		x					x	1
15G CAF trams (Amsterdam)[k]		x					x	1
Report M&M infrastructure 2013-2016 (The Hague)[l]	x		x	x				4
Strategic plan 2016-2026 (The Hague)[m]	x	x			x			10*
Bid 2016-2026 (The Hague)[n]	x	x	x	x	x			10*
AMP rail infrastructure 2017 (The Hague)[o]	x		x	x				4*
Annual results 2005-2015 (The Hague)[p]		x	x	x				3-5
Life extension and midlife revision GTL (The Hague)[q]		x			x	x		1
Financial overview HTM (The Hague)[r]		x					x	2
Avenio tram (The Hague)[s]		x					x	1
Annual plans infrastructure RET 2009-2016 (Rotterdam)[t]	x		x	x	x			5-9
Multi-annual maintenance plan (Rotterdam)[u]	x				x			1*
Interview MRDH (Rotterdam)[v]	x			x	x			1
SAMP, fleet management (Rotterdam)[w]		x	x	x	x			11*
Capital expenses (Rotterdam)[x]		x					x	1-4
Financial results and budget province of Utrecht (Utrecht)[y]	x	x	x	x				3*
Annual report BRU 2013/2014 (Utrecht)[z]	x	x			x	x		1

3.5. INTERVIEWS

In addition to the already available data, twelve interviews are held. The minutes of these interviews are given in appendix C. For these interviews, minutes are made on paper, and no sound recordings are made. The minutes of the interviews are submitted to the interviewed persons for possible feedback.

For these interviews six main groups can be distinguished: bus infrastructure, bus vehicles, rail infrastructure, rail vehicles, transport authorities, and a consultancy. First, it is introduced with whom interviews are held. Then, the goals of the interviews are given.

Four interviews are held with the focus on bus infrastructure. These interviews are held with Paul Koekkoek from the municipality of Enschede, with Hans Aldenkamp from bus operator Connexxion, location Arnhem, with Harmen Otto Smedes, Dennis de Kleer, and Henk Nieboer from the municipality of Almere, and with Hein den Hartog from the municipality of Arnhem. For bus vehicles only one interview is held, with Han van der Wal from bus operator Qbuzz, location Utrecht.

There are two interviews with the focus on rail infrastructure, the first one with Rick van Schie and Edwin van Loenen from the urban rail company HTM, The Hague. The second one is a combined interview, focussing on rail infrastructure as well as rail vehicles. This interview is held with Kees Aert and Hakan Zor from the urban rail company RET, Rotterdam, where Kees Aerts can answer questions regarding infrastructure, and Hakan Zor regarding vehicles. There are two more interviews regarding rail vehicles, one with Wolter Kok from HTM, The Hague, the other one with Vincent de Graaff from GVB, Amsterdam.

Then there are two interview with transport authorities. The first one is with Pim Uijtdewilligen from the transport authority of Rotterdam and The Hague, the MRDH. The second interview is with Lex Brantenaar from the transport authority of Amsterdam, the Vervoerregio Amsterdam. Finally, there is an interview with a consultancy: Koen Vervoort from Ecorys.

Goals of the interviews

In the next few paragraphs, the goals of these interviews are introduced. These are given per goal, including for which interviews they are relevant.

The first goal is to get an idea about the life cycle and the associated maintenance costs of both infrastructure and vehicles. This is especially relevant for bus infrastructure and bus vehicles, as estimations of maintenance costs will be based on these interviews. For rail infrastructure and vehicles, the interviews can be useful to discuss and verify the already estimated maintenance costs. Questions are asked to find out what types of maintenance activities are performed, what typical recurrence periods are, and what the related costs are.

The second goal is to get an idea about the factors that influence the maintenance costs. Open questions are asked, to find out what the interviewed persons think are important factors. Next to that, it is also asked what they think of the influence of obvious factors, such as the type of pavement and/or track, the frequency of vehicles driving on the infrastructure, and the type of maintenance strategy. This goal is relevant for the interviews with bus operators, rail operators, the municipalities, and the transport authorities.

The third goal is to find out to what extent management and maintenance costs are included in decision-making. This includes both decision-making on the building or renewal of infrastructure, as well as the purchase decision when buying new vehicles. It will be asked if maintenance costs are considered when building or renewing infrastructure or when purchasing new vehicles, and if it has influence on the actual decision-making. This is a relevant goal for all the interviews, but especially for the interview with the consultancy.

The fourth goal, coherent with the third one, is to find out at which stage cost-benefit analyses are used, and what its role and importance is, also in relation to decision-making. It will be asked on what detail level maintenance costs of vehicles and infrastructure are estimated and included, and if it is necessary to improve the estimations. This goal is relevant for the interview with the consultancy.

3.6. Cost-benefit analysis

A collection of CBAs is needed to verify the influence of the estimation of maintenance costs on the outcome of CBAs. These CBAs should of course be about urban public transport projects. Useful CBAs should furthermore include information about the number of vehicles and/or the length of the infrastructure. Next to this, also the maintenance costs should be traceable, they should for example not be hidden somewhere in the operational costs.

Based on an internet search a group of CBAs is found. Overviews of CBAs are found on two sites: Ecorys (n.d.) and Van Zutphen Economisch Advies (n.d.). Also, on Google the search terms "MKBA" (Dutch term comparable to CBA) in combination with "tram", "light rail", and "metro", are used. Another report with CBAs is given by a supervisor.

Furthermore, seven light rail projects are given on Wikipedia (2017i): "Uithoflijn", "Regiotram Groningen", "HOV-as Arnhem-Nijmegen", "RijnGouwelijn", "Zuidtangent", "tram Zwolle-Kampen", and "tram Maastricht-Hasselt". These projects are also googled in combination with the search term "MKBA".

This results in ten reports with CBAs for urban public transport projects, as shown in table 3.11. Of these ten reports, only five are selected for further research. The other reports lack the necessary information.

Table 3.11: Overview of documents with one or more CBAs. Sources: a. Ecorys (2009), b. Railinfra Solutions (2012), c. Ecorys (2012b), d. Ecorys (2012a), e. Ecorys (2012c), f. Ecorys (2011), g. Stadsregio Amsterdam (2014), h. Gemeente Amsterdam (2017), i. Provincie Zuid-Holland (2012), and j. Goudappel Coffeng (2010).

Document	Included in research
Regional public transport projects[a]	x
Amstelveenlijn[b]	x
HOV Hollands Midden[c]	
Amsterdam-Almere-Markermeer[d]	
Tram Vlaanderen-Maastricht[e]	x
Uithoflijn[f]	x
Uithoornlijn[g]	
Extension metro Amsterdam[h]	x
HOV Zuid-Holland Noord[i]	
Zuidtangent[j]	

In all of these five reports, one or more CBAs are included. In some reports multiple projects are analysed, in other reports multiple variants of the same line is analysed. There is furthermore one report with only one project and variant. These five reports include seventeen CBAs. These seventeen CBAs are shown in table 3.12.

For some of the variants the route-length is given in the reports. That is the case for the variants from Railinfra Solutions (2012), Ecorys (2012c) and Gemeente Amsterdam (2017). For variants from Ecorys (2011) the length is adopted from table 3.1. For variants from Ecorys (2009) the report performs a sensitivity analysis using a given amount of maintenance costs per km, which can be used to calculate the route-length. For variant 5 from Railinfra Solutions (2012) and variants 13, 14, 15, and 17 from Gemeente Amsterdam (2017) there are some underground sections.

Only for the variants from Gemeente Amsterdam (2017) the maintenance costs of vehicles are included in the maintenance costs, and not integrated in for example the operational costs. For Railinfra Solutions (2012) only the vehicle replacement costs are included as a separate cost item, the vehicle maintenance costs are not. For the variants from Railinfra Solutions (2012) the number of vehicles and vehicle lengths are given in the report. For the variants from Gemeente Amsterdam (2017) the exact number of vehicles is not given, but the frequencies are. Assuming a speed of 36 km/h (average of 32 and 40, see chapter 3.1), and an roughly estimated additional amount of 20 percent, for turning and spare vehicles, results in the number of vehicles as given in table 3.12. Vehicle lengths for the variants from Railinfra Solutions (2012) are given in the report. For variants from Gemeente Amsterdam (2017) the vehicle lengths are adopted from the most recent metro type in Amsterdam, which is shown in table 3.5.

It must be noted that the variants from Railinfra Solutions (2012) include both positive and negative route-lengths and/or number of vehicles. This means that next to an increase in infrastructure and/or vehicles of one mode, there is also a decrease in the the infrastructure and/or vehicles of another mode.

Table 3.12: Overview of included CBAs, including route-length, number of vehicles, and vehicle length. Sources: 1-4. Ecorys (2009), 5-8. Railinfra Solutions (2012), 9. Ecorys (2012c), 10-12. Ecorys (2011), 13-17. Gemeente Amsterdam (2017).

Variant	Type	Route-length (km)	Number of vehicles	Vehicle length (m)
1. Alphen a/d Rijn-Schiphol	Bus, asphalt	17	NA	NA
2. Bus lane A6/A1	Bus, asphalt	16	NA	NA
3. Schiphol Oost	Bus, asphalt	12	NA	NA
4. Utrecht-Overvecht	Bus, asphalt	5	NA	NA
5. Amstelveenlijn Metro	Metro	10	11	116
	Light rail	-4.7	0	0
	Tram	0	-13	30
6. Amstelveenlijn HTV1	Light rail	6.8	19	45
	Tram	0	-23	30
7. Amstelveenlijn HTV1+	Light rail	6.8	17	45
	Tram	0	-23	30
8. Amstelveenlijn HTV3	Light rail	5.3	10	45
	Tram	0	-13	30
9. Vlaanderen-Maastricht	Light rail	5	NA	NA
10. Uithoflijn bus	Bus, asphalt	8	NA	NA
11. Uithoflijn bus+	Bus, asphalt	8	NA	NA
12. Uithoflijn tram	Light rail	8	NA	NA
13. Westlijn	Metro	16	17	116
14. Oost/Westlijn	Metro	19	20	116
15. Noord/Zuidlijn-Schiphol (1)	Metro	9	7	116
16. Noord/Zuidlijn-Schiphol (2)	Metro	11	9	116
17. Kleine ring	Metro	4	4	116

The applied time horizon for the variants from Railinfra Solutions (2012) is 109 years. For the other reports the time horizon is either given or assumed to be 100 years.

The discount rate is given as 4.5 percent for the variants from Gemeente Amsterdam (2017) and for the variants from the other reports either given or assumed to be 5.5 percent.

The construction periods in Ecorys (2009) are respectively 5, 3, 4, and 3 years for variants 1 to 4. The construction period in Railinfra Solutions (2012) is assumed to be the time from the start of the time horizon till the end of the construction period: 9 years for variant 5 and 7 years for variant 6 to 8. The construction period in Ecorys (2012c) is 6 years. Construction periods in Ecorys (2011) are respectively 5, 9, and 6 years for variants 10 to 12. The construction periods for the variants from Gemeente Amsterdam (2017) are 5 years.

4. METHODS

This chapter describes the methods used in this research. Started is with an explanation of the data processing of the maintenance costs. This is followed by explaining the model used to calculated the maintenance costs of an urban public transport system. This model can be applied on cost-benefit analyses (CBAs), which is discussed in the last part of this chapter.

4.1. DATA PROCESSING

The next paragraphs will describe the general procedure of the data processing of the maintenance costs. The data processing is performed in six steps, as shown next.

1. Calculating costs

The first step is to calculate the costs. Costs are divided in infrastructure and vehicle costs, and furthermore divided in management costs, regular maintenance costs, major maintenance costs, life extension, and replacement costs. For rail infrastructure, costs are divided in costs for track, costs for stops and stations, and other costs. Lastly, a distinction is made between the various types of infrastructure and the various types of vehicles.

In general very basic calculation steps are needed, for example summation of multiple costs, or separating costs based on a calculated ratio. Based on some documents, or group of similar documents, a time series of costs can be made.

2. Applying inflation correction

The source documents are made in various years, and also based on varying price levels. To correct for this, an inflation correction should be applied. In that way, costs from different years and price levels can be compared correctly.

This correction will be based on the OV-index (public transport index), with the year 2017 as the base year. Costs from earlier years will be multiplied with a multiplication factor based on the OV-index. This index is based on a combination of the wage level and the IMOC (DOVA, 2017). The IMOC is an index based on the average increase in prices for the sum of the purchase of service and materials, of depreciations, and of sales (CPB, 2017). The OV-index can be calculates as a weighted average of these two indexes, with a 65 percent weight for wage levels, and a 35 percent weight for IMOC, following DOVA (2017). The OV-index is given in table 4.1.

The multiplication factor is based on this yearly OV-index. When costs from a given year are multiplied with the corresponding multiplication factor, costs can be expressed equivalent to costs in the base year 2017.

3. Calculate costs per unit

A second step is needed to compare costs correctly: they need need to be expressed per unit. For infrastructure, this unit is the length in route-km. This length is defined as the route-length of the network, excluding side tracks, and independent of the number of tracks (single track, double track, etcetera) of a certain route. For rail infrastructure, these costs per route-km are then simply calculated by dividing the maintenance costs by the network or line length. For bus infrastructure, this is either done in a similar way, or calculated based on the maintenance costs per square meter.

For vehicles, one unit is defined as a vehicle with a length of 30 meter. Two 45-meter tram vehicles are for example equivalent to three 30-meter long vehicles, and five 12 meter buses are equal to two 30-meter long vehicles. For rail vehicles, the costs per vehicle are calculated by simply dividing the maintenance or replacement costs by the number of unit length (30-meter) vehicles. For buses, maintenance costs are calculated based on the costs per kilometre multiplied by the annual travel distance, adjusted to 30-meter vehicles. Replacement costs for buses are based on costs per vehicle

Table 4.1: overview of the wage level, IMOC, OV-index, and multiplication factor for the period 1999 till 2017. The wage level is based on CBS (2010) for the period 2000 till 2006 and on Centraal Planbureau (2017) for the period 2007 till 2017. The IMOC index is based on CBS (2017) for the period 2000 till 2006 and on Centraal Planbureau (2017) for the period 2007 till 2017. The OV-index is calculated based on a weighted average, following DOVA (2017).

Year	Wage level (%)	IMOC (%)	OV-index (%)	Multiplication factor
1999	NA	NA	NA	1.521
2000	5.30	4.40	5.00	1.449
2001	5.40	2.50	4.40	1.388
2002	5.50	3.20	4.70	1.326
2003	4.40	1.80	3.50	1.281
2004	3.50	-0.10	2.20	1.253
2005	1.50	1.60	1.50	1.234
2006	2.60	1.40	2.20	1.208
2007	3.50	1.50	2.80	1.175
2008	3.60	3.20	3.50	1.136
2009	3.00	0.40	2.10	1.113
2010	0.10	2.00	0.80	1.104
2011	1.70	0.90	1.40	1.089
2012	2.90	2.20	2.70	1.060
2013	1.70	1.40	1.60	1.044
2014	0.80	1.00	0.90	1.035
2015	0.20	-0.90	-0.20	1.037
2016	1.60	1.10	1.40	1.022
2017	2.60	1.50	2.20	1.000

and adjusted to 30-meter vehicles.

For rail infrastructure and vehicles, time series of the network lengths and the number of vehicles are needed. If in some documents other assumptions are made regarding the number of vehicles or the network length, this can be taken into account as well.

4. Time series of costs

Some of the documents now have results from multiple years. Per year, results are in the same format, they are corrected for inflation, and are calculated per km or vehicle. Information from multiple years can then be used to calculate both average values and the standard error of the mean (SEM). The SEM is equal to the standard deviation of the population divided by the square root of the sample size (n) (Encyclopædia britannica, 2017). As the standard deviation of the population is unknown, the standard deviation from the sample size is used instead.

For the replacement costs of vehicles, the sample size is based on the number of vehicle types per mode. Averages over multiple type of vehicles are calculated by dividing the total costs by the total number of 30-meter vehicles. When there are multiple types of vehicles per mode, the SEM is calculated as well.

If results are only based on future estimates, only the average value is calculated. It is likely that future estimations for multiple years lead to a biased value of the SEM, for example when future estimates have a much lower variation than realised costs.

5. Overview of costs

As a next step, information from multiple sources can be combined in overviews per company or city. Again, this is possible as costs are now in the same format, corrected for inflation, and calculated per km or vehicle. Information can furthermore be combined, if for example one source provides information on management and regular maintenance costs, where another provides information on major maintenance costs.

The SEM of the total costs is only calculated when for all sub costs, for example management, regular maintenance, and major maintenance, also a SEM is calculated. There are for example some cases were the SEM is available for management and regular maintenance, but not for major maintenance. It is expected that there is more variation, and therefore a higher SEM, for major maintenance, due to the lower frequency of maintenance activities. Therefore, an estimation of the SEM excluding information for major maintenance, will likely be underestimated.

6. Final overview

Finally, information from multiple companies and cities can be combined and compared. This results in an overview with infrastructure and vehicle costs for multiple types of transport systems, and for multiple companies and cities. Similarities and differences can be discussed. Based on this overview final estimations of infrastructure and vehicle costs can be made.

4.2. Model

The next part of this chapter describes the model which can be used to calculated maintenance costs for a public transport system. This model is used for estimating maintenance costs in CBAs. Necessary input for this model are estimations of maintenance costs of infrastructure and vehicles, expressed in costs per km or costs per 30-meter vehicle.

Vehicle costs

First the maintenance costs of the vehicles MC_{veh} are calculated. The maintenance costs are a combination of a vehicle length factor L^*, the annual management and maintenance costs of a vehicle $MC_{mm,veh}$, and the vehicle replacement costs RC_{veh}, as given in equation 4.1. The vehicle maintenance costs are in euro per vehicle and depend on the time t in years and the type of vehicle i.

The vehicle length factor L^* is used to compensate for the length of a vehicle, as shown in equation 4.2. For example for a tram vehicle with a length L_{veh} of 45 m, and a unit length L_{unit} of 30 m, this factor is 1.5. Therefore the maintenance costs for this vehicle are 1.5 times the costs of a vehicle which has unit length.

The annual management and maintenance costs of a vehicle $MC_{mm,veh}$ are calculated in equation 4.3. After construction of the system, which takes a period of T_{const} years, the maintenance costs are equal to the unit costs $UP_{m,veh}$, and only depending on the type of vehicle i. During construction the maintenance costs are zero.

The vehicle replacement costs RC_{veh} are calculated as given in equation 4.4. In this equation $UP_{r,veh}$ is the unit costs of replacing a vehicle of type i, T_{veh} is the life span of a vehicle, T_{const} is the construction period of the system in years, and k is a positive integer. The equation simply states that the replacement costs of a vehicle are equal to the unit price in the years that a vehicle should be replaced, and is zero in the other years.

$$MC_{veh}(i,t) = L^*(i) \cdot [MC_{mm,veh}(i,t) + RC_{veh}(i,t)] \tag{4.1}$$

$$\textit{with} \quad L^*(i) = L_{veh}/L_{unit}(i) \tag{4.2}$$

$$\textit{and} \quad MC_{mm,veh}(i,t) = \begin{cases} UP_{m,veh}(i) & \textit{if} \quad t \geq T_{const} \\ 0 & \textit{otherwise} \end{cases} \tag{4.3}$$

$$\textit{and} \quad RC_{veh}(i,t) = \begin{cases} UP_{r,veh}(i) & \textit{if} \quad t = k \cdot T_{veh}(i) + T_{const} \quad (k = 1,2,3,...) \\ 0 & \textit{otherwise} \end{cases} \tag{4.4}$$

Infrastructure costs

Next, the maintenance costs of the infrastructure MC_{infra} are calculated, as shown in equation 4.5. This equation is simply a summation of the management and regular maintenance costs $MC_{mr,infra}$ and the major maintenance cost $MC_{mj,infra}$. The maintenance costs of the infrastructure are in euro per route-km, depending on the type of infrastructure j, and the time t given in years.

The management and regular maintenance costs are calculated in equation 4.6, and depend on the unit price of the infrastructure UP_{infra}, a factor x_{mj}, and the construction period T_{const}. The factor x_{mj} states the amount of the maintenance costs that are related to major maintenance. The costs not related to major maintenance are then the management and regular maintenance costs. During construction the maintenance costs are zero, after that they have a constant value.

The major maintenance costs $MC_{mj,infra}$ are calculated in equation 4.7. The maintenance costs depend on a factor x_{mj}, a function f_{mj}, and the unit price UP_{infra}. The function f_{mj}, which depends on the time t, is a distribution of the major maintenance costs. That could for example mean that major maintenance takes places every 25 years, or that some maintenance takes place after each 10 and 20 years, and a larger part of the maintenance every 30 years. Again T_{const} compensates for the duration of the construction period.

$$MC_{infra}(j,t) = MC_{mr,infra}(j,t) + MC_{mj,infra}(j,t) \tag{4.5}$$

$$\text{with} \quad MC_{mr,infra}(j,t) = \begin{cases} [1 - x_{mj}(j)] \cdot UP_{infra}(j) & \text{if} \quad t \geq T_{const} \\ 0 & \text{otherwise} \end{cases} \tag{4.6}$$

$$\text{and} \quad MC_{mj,infra}(j,t) = x_{mj}(j) \cdot f_{mj}(t + T_{const}, j) \cdot UP_{infra}(j) \tag{4.7}$$

Total costs

After calculation of both vehicle and infrastructure maintenance costs, the total costs can be calculated. This is shown in equation 4.8. The number of vehicles N_{veh} are multiplied with the maintenance costs of the vehicles MC_{veh}, which were calculated in equation 4.1. The length of the track L_{track}, in km, is multiplied with the maintenance costs of the infrastructure MC_{infra} as was calculated in equation 4.5. Both costs are then added, to get the total maintenance costs in euro, depending on the time t in years, the type of vehicle i, and the type of infrastructure j.

$$MC(i,j,t) = N_{veh} \cdot MC_{veh}(i,t) + L_{track} \cdot MC_{infra}(j,t) \tag{4.8}$$

Net present value

Finally, the net present value NPV_{MC} of the maintenance costs can be calculated, as shown in equation 4.9, which is similar to the general equation of the net present value as used by Excel (Microsoft, n.d.). For every year the maintenance costs $MC(i,j,t)$ are divided by a factor depending on the discount rate r and the year t, to retrieve the present value of the maintenance costs at a given price level. Then a summation is made over the maintenance costs for every year till year T, which is the time horizon in years. The net present value is given as costs in euro.

$$NPV_{MC}(i,j) = \sum_{t=0}^{T} \frac{MC(i,j,t)}{(1+r)^t} \tag{4.9}$$

4.3. Cost-benefit analysis

The outcomes of existing CBAs will be evaluated. This will be done by inserting new estimates for the maintenance costs and compare that with the old results. This will be done using an implementation of the previously discussed model in Excel. Other costs, for example the investment costs, and benefits, are not changed. Other influencing factors, for example the time horizon, the construction period, and the discount rate, are not changed either. Because it is not always explicitly stated what assumptions are used in the original reports, it can not be ruled out that there are some differences between the assumption used in the original reports and the assumption used in this research.

First, the maintenance costs, the total costs, and the total benefits are extracted from the CBAs. These costs and benefits are then adapted to the price level 2017. The costs and benefits are compared, using a benefit/costs-ratio (b/c-ratio).

The model is used to give a new estimation of the maintenance costs. This new estimation of the maintenance costs will be compared to the original maintenance costs.

Thirdly, these maintenance costs are included in the CBAs. The benefits will stay the same. However, by changing the maintenance costs, the total costs will also change. Now a new b/c-ratio can be calculated. This new outcome is compared to the old b/c-ratio.

A few assumptions are needed to evaluate the CBAs. First, major maintenance for asphalt bus lanes is assumed to have cycles of 30 years. This is based on the renewal period of the underlayer of the asphalt pavement which has a life span equal to 20 to 30, and preferential 40 years, see appendix A. For the upper layer a renewal period of 10 years is assumed, also see appendix A. As replacement of the under and upper layer have comparable costs (appendix A), the costs in one life cycle of 30 years is as following: 25 percent of the costs after 10 years, 25 percent of the costs after 20 years, and 50 percent of the costs after 30 years.

Renewal of a concrete bus lane is needed every 20 to 30 years, as given in appendix A. All major maintenance costs are assumed at the end of this cycle, for which an average value of 25 years is taken.

Renewal of rail infra is assumed to have an average cycle of 30 years, with 25 percent of the costs after 10 years, 25 percent of the costs after 20 years, and 50 percent of the costs after 30 years, see appendix A.

According to the interviews replacement of rail vehicles is needed every 25 or 30 year. A life span of 30 years is assumed for use in the CBAs.

5. RESULTS

In this chapter the results of this research will be presented. First an overview of the infrastructure costs of five types of infrastructure is presented. This is followed by an overview of the vehicle costs of eight types of vehicles. Then an overview of the main results of the interviews is given. The last section describes the results from the cost-benefit analyses (CBAs).

5.1. Infrastructure costs

In the next section an overview of the main results regarding maintenance costs of the infrastructure are given. The presented maintenance costs are in more detail calculated in appendix A.

Table 5.1 shows the maintenance costs for five types of infrastructure, including standard deviations and the distribution of costs over management, regular maintenance, and major maintenance. The table shows that there is a large gap between the cheapest and the most expensive type of infrastructure. The most expensive bus system has a factor fifteen lower maintenance costs than the cheapest rail system. There is not so much difference in costs between tram and light rail, but there is a large gap between tram and light on the one hand and metro on the other: metro has more or less a factor three larger maintenance costs than tram and light rail.

The table furthermore shows that major maintenance costs for rail systems account for around half of the total costs. For bus systems, it is hard to make a reliable distribution of regular and major maintenance costs.

It must be noted that the sample size varies between one and four. This only represent the number of companies which are included, although per company more detailed information can be available.

Table 5.1: overview of maintenance costs, including standard deviations, for five transport systems, with costs in euro per km per year. Furthermore, the distribution of costs over management, regular maintenance, and major maintenance is given, rounded to the nearest five percent. All costs are price level 2017. Maintenance costs and standard deviations for bus are rounded on 1,000 euro, for tram and light rail on 10,000 euro, and for metro on 100,000 euro. The sample size is given as well, representing the number of companies or municipalities from which information is used. For bus infrastructure, with a sample size with a star (*), not for all costs an equal number of sources were available: for maintenance of the asphalt lane itself 1 source, for maintenance of concrete bus lanes themselves three sources, for management costs two sources, and for other maintenance costs one source.

	Bus, asphalt	Bus, concrete	Tram	Light rail	Metro
Maintenance costs in euro/km/year	24,000	17,000	370,000	450,000	1,300,000
management (%)	10%	10%	10%	10%	10%
regular maintenance (%)	90%	90%	30%	45%	35%
major maintenance (%)			55%	45%	55%
Standard deviation in euro/km/year	NA	NA	20,000	80,000	100,000
Sample size	1*	3*	3	4	2

Maintenance costs per company

There are some differences in the maintenance costs among the companies, which is shown in figure 5.1. There is in general not so much difference in the total maintenance costs, but more variation in the distribution of the costs over management, regular maintenance, and major maintenance. It is not clear to what extent this is due to an actual difference in costs, and to what extent due to differences in the definitions of these costs.

The figure shows that there is not so much difference in total maintenance costs among the various tram companies. Having only a standard error of the mean (SEM) for one company, no statistical significant statements can be made.

There is a clear difference in maintenance costs of more than 100,000 euro per km per year between light rail companies D and E, and companies F and G. A possible explanation is that light rail for companies F and G is combined with metro, were that is not the case for companies D and E.

For metro, the difference in total maintenance costs is less than 100,000 euro per km per year. A possible explanation is the difference in management costs of around 100,000 euro. As stated before, this difference could also be just a matter of definition. In that case, no clear explanation for the difference in costs can be given.

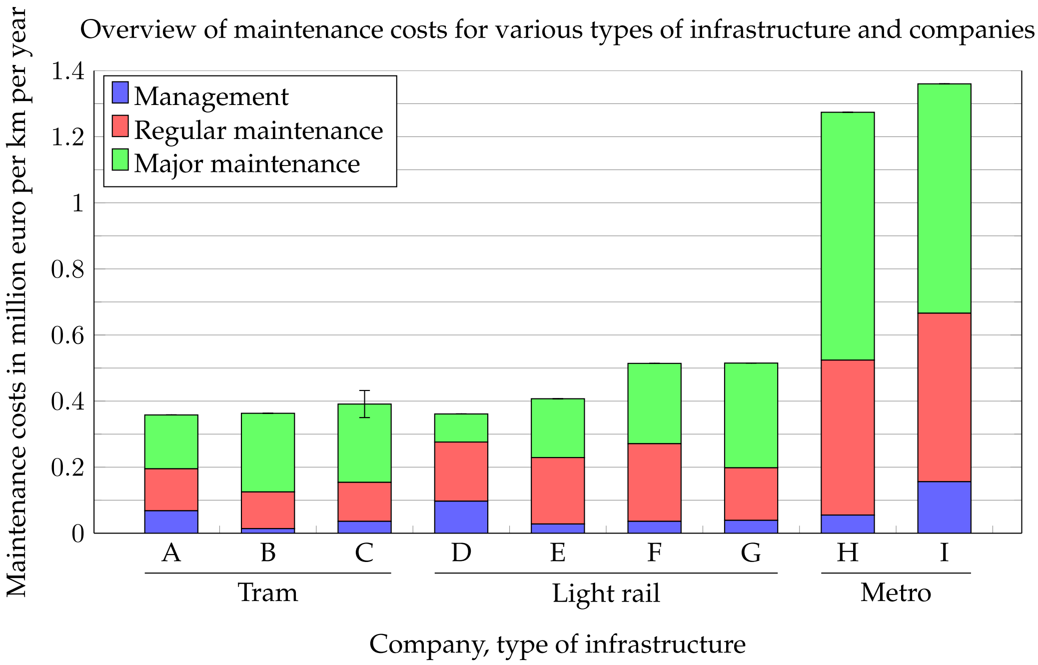

Figure 5.1: overview of maintenance costs in million euro per route-km per year for various types of infrastructure and companies, price level 2017. Companies are made anonymous. Results are first ordered based on the type of infrastructure and then on the total maintenance costs per company. For company C an error bar is included, with a 95 percent confidence interval, using a t-distribution, based on the SEM and sample size as given in Appendix A.

Aboveground and underground track

There are notable differences in costs between underground and aboveground track, as in more detail given in appendix A. For one company, aboveground major maintenance costs of metro are 20 percent lower than average, and major maintenance costs for underground metro are 40 percent higher than average. For another company costs are 10 percent lower for aboveground metro, and 80 percent higher for underground metro. It must be noted that underground stations have mostly busier stations and more frequent used track. Furthermore, some aboveground metro tracks can be seen as a type of light rail.

The differences in costs were only found for major maintenance costs, but it seems not very unlikely to have total maintenance costs 10 to 20 percent lower for aboveground metro. One line, with dominantly underground track, is estimated to have around 70 percent higher than average costs for that company. It therefore seems possible to have a fully underground line with costs up to 70 to 80 percent higher than average. It was also noted in the interviews that there are additional systems in underground sections and larger underground stations. These factors could, at least partially, explain these large difference in costs.

Distribution of costs
For only one company enough data was available to make a good distribution of costs over track, stops/stations, and other costs, although for tram the costs for stops were unknown. Other companies had for example only a distribution of costs for major maintenance and not for regular maintenance, or had a distribution over stations and other costs for regular maintenance and over track and other costs for major maintenance.

The distribution of these costs for tram, light rail, and metro are shown in figure 5.2. For tram, around 67 percent of the costs were related to maintenance of track. It was not clear how much was spend to maintenance of stops. Other costs account for 33 percent of the costs.

For light rail, a bit less, but still 51 percent of the costs were related to maintenance of track. Only 4 percent of the costs were spend to maintenance of stations. It is likely that costs spend on maintenance on stops for trams is even less due to smaller stops, and therefore is negligible. Other costs account for 45 percent of the costs.

For metro, 27 percent of the maintenance costs are spend on track, 31 percent on stations, and 42 percent are related to other costs.

Thus, with increasing complexity of the system, relative spending of maintenance costs on track is decreasing. Maintenance costs for stops and stations are however increasing. There is no clear trend for the other costs.

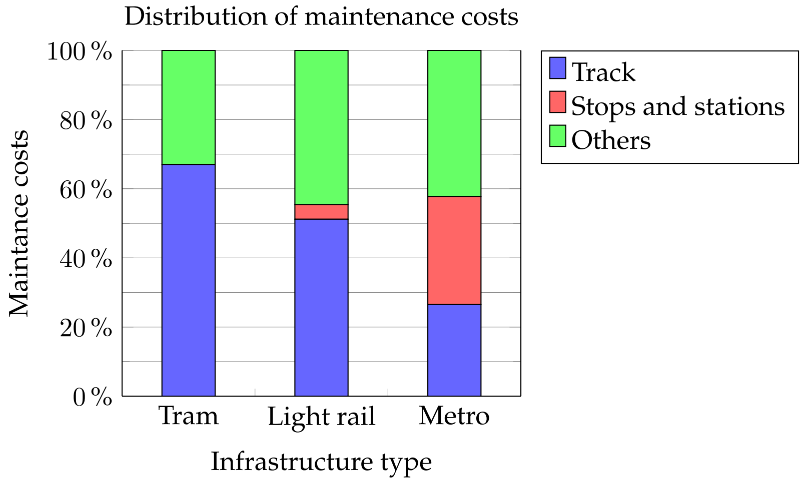

Figure 5.2: overview of the distribution of maintenance costs over track, stops and stations, and others, given as a percentage of the total costs, for tram, light rail, and metro.

5.2. Vehicle costs

In the next part of this chapter the vehicle costs are given. The results are adapted from the results given in appendix B. An overview of the maintenance and replacement costs is given in table 5.2.

It must be noted that there are relatively small differences in both maintenance and replacement costs of standard, articulated, and bi-articulated diesel buses. An exception is the replacement of the bi-articulated diesel bus, which has considerable higher costs than standard and articulated buses. The electric bus has almost double replacement costs with respect to a standard diesel bus, but is also cheaper to maintain. The gas bus has both higher replacement and maintenance cost with respect to the standard diesel bus.

There is furthermore a clear difference in maintenance costs between bus and rail vehicles. There is also a clear difference in replacement costs between bus and rail vehicles, although the relative difference in replacement costs is in general smaller than the relative difference in maintenance costs.

Light rail and metro vehicles are a bit more expensive to replace than tram vehicles. Maintenance costs however decrease from tram, to light rail, to metro.

Regular maintenance costs for all rail vehicles is around half of the costs, with management and major maintenance both accounting for a quarter each. For buses, most costs are made for maintenance and less for management.

Table 5.2: overview of maintenance and replacement costs for eight type of vehicles, with maintenance costs in euro per 30-meter vehicle per year, and replacement costs in euro per 30-meter vehicle. Maintenance costs are distributed in management and maintenance costs for buses, and in management, regular maintenance, and major maintenance costs for rail vehicles. All costs are price level 2017. The sample size is given as well, representing the number of companies from which information is used. Is must be noted that the results for light rail (sample size given with a star (*)) are based on only three of the four companies. Replacement costs of light rail vehicles is based on two companies. Maintenance costs are rounded of to 1,000 for buses and to 10,000 for rail vehicles. Replacement costs are rounded of to 100,000 for rail vehicles and the electric bus, and to 10,000 for the other buses.

	Standard bus, diesel	Bus, diesel, articulated	Bus, diesel, bi-articulated
Maintenance costs in euro/vehicle/year	33,000	30,000	27,000
management (%)	10%	10%	10%
maintenance (%)	90%	90%	90%
Replacement costs in euro/vehicle	730,000	720,000	970,000
Sample size	1	1	1

	Standard bus, electric	Standard bus, gas
Maintenance costs in euro/vehicle/year	21,000	41,000
management (%)	10%	10%
maintenance (%)	90%	90%
Replacement costs in euro/vehicle	1,400,000	850,000
Sample size	1	1

	Tram	Light rail	Metro
Maintenance costs in euro/vehicle/year	160,000	140,000	120,000
standard deviation in euro/vehicle/year	20,000	40,000	<10,000
management (%)	30%	30%	25%
regular maintenance (%)	45%	45%	50%
major maintenance (%)	20%	25%	25%
Replacement costs in euro/vehicle	2,300,000	3,400,000	2,800,000
standard deviation in euro/vehicle	<100,000	300,000	200,000
Sample size	3	4*	2

Explaining factors

Some of the differences in costs among the various types of vehicles can be explained. Firstly, the infrastructure can have an important influence on the maintenance costs of vehicles. It is likely that rail vehicles driving on a network with many straight lines, and wide curves, have lower maintenance costs than vehicles driving on a network with tight curves. It was mentioned in one of the interviews that tighter curves with a hard type of track, could lead to more wear of the wheels. This could explain why metro vehicles have in general lower maintenance costs than trams.

Secondly, metro vehicles have in general chipcard systems at the stations, were tram vehicles have in general chipcard systems inside the vehicles. It is therefore expected that metro infrastructure is more expensive to maintain, but that a metro vehicle is cheaper to maintain.

Thirdly, there are enormous differences in maintenance costs among buses with different types of engines. As shown in table 5.2, electric engines are cheaper to maintain than diesel engines, were gas engines are the most expensive. This is for rail vehicles a less important factor, as all Dutch urban rail vehicles are already electric.

Maintenance costs per company

There are some differences in the maintenance costs among the rail companies, which is clearly shown in figure 5.3. It must be noted that in some cases no distinction was made between management and regular maintenance costs, and that therefore an estimation was made based on the results from the other companies. For company F, no estimation for major maintenance costs is given. More details can be found in appendix B.

What can be seen is that there are large differences in costs among the companies for all three types of maintenance costs: management, regular maintenance, and major maintenance. The largest variation in total maintenance costs, measured as the difference between the cheapest and most expensive company, is found for light rail, with a difference of 61 percent. The difference between the cheapest and most expensive company is smaller for tram, with a difference of 28 percent, and smallest for metro, with a difference of only 4 percent.

Maintenance costs are in general lowest for metro, then for light rail, and then for tram. This is however not the case when comparing individual companies. Some of the tram vehicles have for example lower maintenance costs than some of the light rail vehicles.

No statistical significant statements per type of infrastructure can be made, as per type of infrastructure only for one company the SEM over the total costs can be calculated.

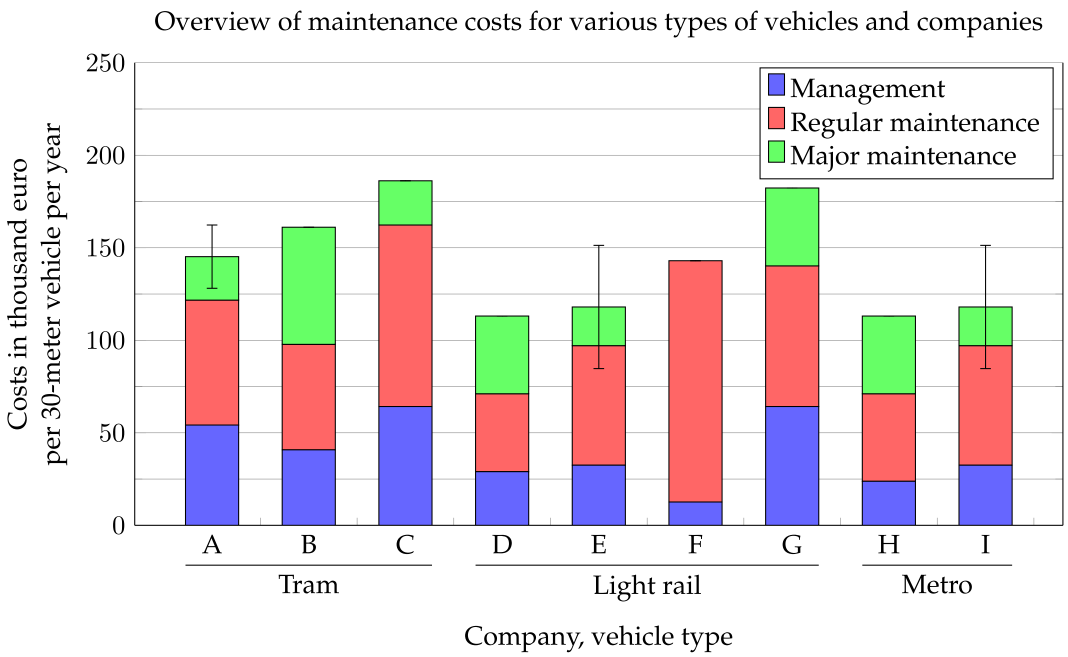

Figure 5.3: overview of maintenance costs in thousand euro per 30-meter vehicle per year, for various types of vehicles and companies, price level 2017. Error bars are included, using a 95 percent confidence interval with a t-distribution. Companies are made anonymous. For some of the displayed companies, no distinction was made between management and regular maintenance costs, so an estimation is based on the results from the other companies. Results are first ordered based on the type of vehicle and then on the total maintenance costs per company.

Replacement costs per company

There are some differences in replacement costs among the rail companies. Figure 5.4 shows the replacement costs of tram, light rail, and metro vehicles. It can be seen that there is little difference in replacement costs among the various tram companies. There is more difference between the two light rail companies and between the two metro companies, both have a difference of around 13 percent between the most expensive and the cheapest company.

No statistical significant statements can be made, due to small sample sizes and because there is a SEM for only three companies.

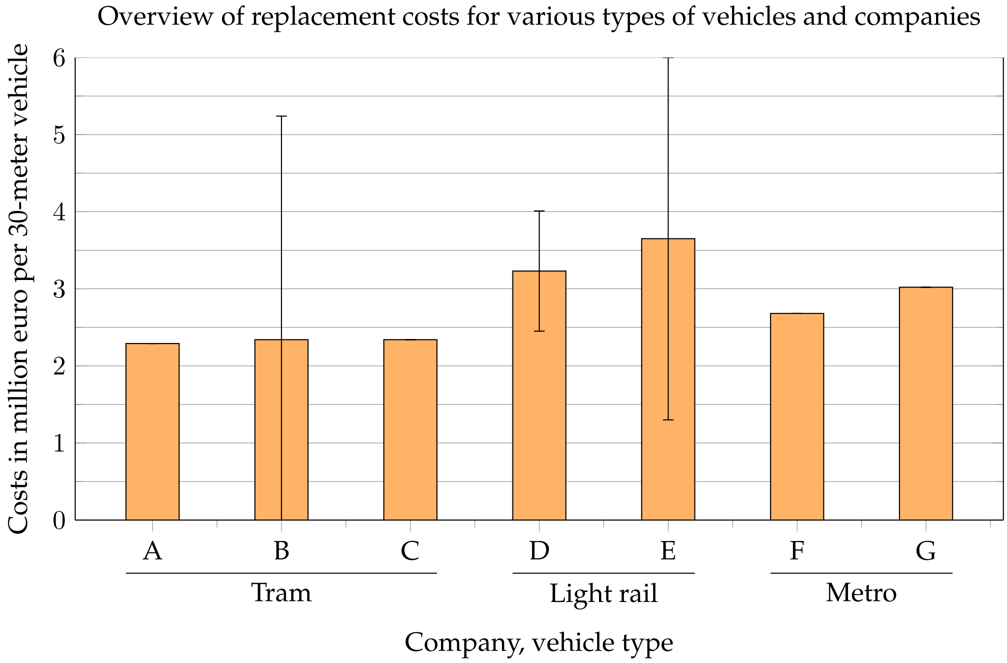

Figure 5.4: overview of replacement costs in million euro per 30-meter vehicle, for various types of vehicles and companies, price level 2017. Error bars are made using an 95 percent confidence interval, with a t-distribution. Companies are made anonymous. Results are first ordered based on the type of vehicle and then on the replacement costs per company.

5.3. Interviews

In the next part of this chapter a summary of the interviews will be given. The results are given in order of the four goals for the interviews, as presented in chapter 3.5.

Maintenance costs

The first goal of the interviews is to get an idea about the life cycle and the associated maintenance costs of both infrastructure and vehicles. This resulted in estimations of maintenance costs for bus infrastructure, as given in appendix A, and in estimations of vehicle maintenance and replacement costs of buses, as given in appendix B.

Furthermore, two municipalities state that maintenance of a bus road is comparable to a normal road. However, a bus road is used by relatively heavy vehicles with relatively low frequencies. All three municipalities indicate the effect of rutting on bus lanes. One municipality indicate that they use thicker asphalt layers for bus lanes. All three municipalities use concrete layers for some part of the bus infrastructure.

All three municipalities agree that buses driving on normal roads do not lead to significant extra maintenance costs. One municipality gives as a reason that buses have a relatively low frequency and weight in comparison with trucks. Buses could however lead to extra maintenance if they drive on roads not meant for heavy traffic. It is furthermore stated that a more critical look is taken at the quality of roads which are used by buses. One municipality states that this could lead to performing maintenance on a road a few years earlier. Another municipality however states that no extra costs are expected, as buses are a relatively small part of the total amount of traffic.

It was difficult to verify results for rail infrastructure and rail vehicles. Interviewed persons found it hard to compare results with their knowledge. This was among others due to the given format: a price per kilometre or a price per 30-meter vehicle. Furthermore, it was not always clear for them what costs were included. If interviewed persons made a statement about it, they thought estimates mostly rather high than low.

Factors influencing maintenance costs

The second goal is to find out which factors have an influence on the maintenance costs. First, the factors having influence on both infrastructure and vehicle maintenance costs are given. Then the factors influencing the infrastructure maintenance costs are given, followed by the factors having influence on the vehicle maintenance costs.

General factors

There are some factors which can have influence on the maintenance costs of both infrastructure and vehicles. These factors include the interactions between infrastructure and vehicles, laws and regulations, and the maintenance strategy:

- It was suggested in one of the interviews that maintaining infrastructure and vehicles separately can lead to higher costs, than when looking at the total costs of a system. In one of the interviews an example of this is given: a hard type of track in combination with tighter curves, leads to faster wear of the vehicle wheels. However, harder tracks also have a longer life span, thus slower wear of the infrastructure;
- There is an effect due to environmental pressure and (new) laws and regulations. In one interview it was stated that the amount of regulations does not increase, however constants change of these regulations involves extra costs. It was furthermore stated that intensive use of public space can explain 25 percent of the maintenance costs for the rail infrastructure.
  An example is the effect of vibration nuisance of rail, which can increase with heavier vehicles. It is possible to reduce that, for example with more intensive maintenance of wheels. That can also increase the maintenance costs. Another example is for maintenance of bus infrastructure: the use of traffic controllers could add up to 50 percent of the costs. Furthermore, fire safety systems can be responsible for around 5 percent of the maintenance costs for rail infrastructure;
- The maintenance strategy also influences maintenance costs. One municipality states that delaying of maintenance could lead to much larger costs, were another municipality however states that the extra costs related to delayed maintenance are low. In one of the interviews it was stated that professionalisation of asset management systems and renewal of the organisation can decrease maintenance costs with 5 tot 10 percent in the coming 10 to 15 years. Furthermore, insourcing of public transport is a political choice, but has influence on the amount of overhead. The overhead is around 20 percent, where it could be around 15 percent for another company;

Infrastructure

The following factors are mentioned as having influence on maintenance (costs) of the infrastructure: the type of track or pavement, underground metro, the type of vehicles driving on the infrastructure, the frequency of vehicles, availability, as well as multiple other factors. According to one of the interviews, roughly two third of the maintenance costs of infrastructure can be explained by wear, the other one third by external factors, as interaction with the environment, and laws and regulations. The factors are given next:

- There is some influence of the type of track or lane on the maintenance costs. For rail, it is stated that grass track has higher costs than ballast track. Replacement costs of paved track are tenfold of that of ballast track. In another interview, variation in maintenance activities is discussed between various types of track, although it is not stated what the effect is on the maintenance costs. Other track characteristics can have influence as well, for example the number of curves, radius of the curves, number of level crossing, amount of adjustment infra, and the type of switches. For buses, concrete pavements needs less maintenance than asphalt. However, maintenance itself could take longer, due to longer curing periods;

- In an interview it is stated that underground metro is more complex, leading to higher maintenance costs, for example due to safety systems, but also due to elevators and escalators. This could lead to extra costs ranging between 10 and 100 percent. In another interview it is stated that there is little maintenance at a tunnel. It is also stated underground stations are in general larger than aboveground stations;
- Use of multiple types of rail vehicles leads to extra costs, which is stated to be a more important factor than the frequency of these vehicles. That is the case because every vehicle has its own characteristics, where the infrastructure can be optimised much better for only one type of vehicle. For buses, it is stated that these become heavier and have smaller turning circles, leading to a heavier load on the road;
- There is a relation between frequency and maintenance. For asphalt bus lanes with a frequency of 8 times an hour, replacement once every 15 to 20 years is much, were at busier sections, replacement is needed once every 10 years. For rail, the frequency of vehicles also has an effect, although it is stated that an effect can not be modelled or tested with experiments, as there are many influencing factors. In another interview it is stated that replacement frequency ranches from once every 40 years for a tram line with straight track, to replacement once every 5 years for a crossing at the central station;
- For bus infrastructure, the availability of a bus lane is also an influencing factor, as it is undesirable to have a lane closed for a longer period than necessary. That could lead to an increase in costs of 20 to 40 percent. It is not stated if availability also leads to higher costs for rail infrastructure;
- There are some more influencing factors for bus and/or rail infrastructure: the weather, use of sand, lubrication of wheels, type of subsoil, track positioning, use of grooved rail, and sand coming from the dunes;

Vehicles
Next, there are some factors which can influence the maintenance (costs) of vehicles:

- One rail company states that a new vehicle type is expected to have a better performance, but that it is insufficiently utilised. It is a challenge to keep this vehicle reliable due to its complexity. It is stated that the fail safe system could lead to phantom notifications, for which maintenance should be performed. It is not stated what the overall effect is on the maintenance costs;
- In another interview it is stated that maintenance of vehicles depends on the number of bogies, as the intermediate part is just metal;
- It is hard to say what the influence is of the vehicle length. The use of (redundant) systems could make shorter vehicles relatively more expensive;
- Further variations in costs can be due to chip card systems, ticket machines, more luxurious vehicles, air conditioning, and the number of doors, although it is not in all cases clear if this leads to extra maintenance costs and/or to higher purchase costs of a vehicle;

Decision-making
The third goal is to find out to what extent maintenance costs are included in decision-making. In general, maintenance cost are taken into account when purchasing new vehicles. Concerning the infrastructure, the importance of maintenance costs seem to be larger for bus infrastructure than for rail infrastructure. Next an overview of the influence of maintenance is given, first for infrastructure, then for vehicles.

For bus infrastructure, one municipality states that maintenance costs are reviewed in the planning stage. Costs are reviewed by comparing the costs to a standard amount. Another municipality states that use is made of life cycle calculations.

In one interview with a rail operator, it is stated that there is limited budget for new infrastructural plans. Maintenance costs are not taken in to account during the decision-making, but it will be examined what maintenance costs are expected. In another interview, it is stated that maintenance costs are taken into account, and that the company targets on lower maintenance costs.

In one interview with a transport authority it is stated that management and maintenance cost play almost no role in a investment decision for new urban rail lines. Transport volume, investment costs, operational costs, sustainability, and prestige, are in contrast factors which are taken into account. There are however some projects for which maintenance and replacement costs are estimated. In another interview it is stated that it is a good firsts step to have maintenance costs in mind when taking a decision. It is however not necessary to have already a set budget. It is stated that management and maintenance should be part of the decision. That could lead to lower life cycle costs. A possible explanation that maintenance costs are not taken into account in decision-making, is that construction and maintenance are the responsibilities of two different companies or departments. Secondly, it could serve a political goal, namely getting a project realised first.

For bus vehicles, maintenance costs are taken into account with the purchase decision. The purchase price of the bus is thereby a small part of the life cycle costs.

One interviewed rail company states that the purchase of vehicles is a careful process, but that it is still questionable if vehicles are optimal maintainable. They furthermore state that demands of stakeholders are important, but there is also a shift to making decisions based on what is good for the company itself. Another company states that for buying new vehicles, in principal it is looked at the total costs of ownership (TCO). It is tried to maximise the outcome given there is a maximum amount of money available. Management and maintenance has a fair share of only a few percent in the decision. There is however a lot of attention for management and maintenance costs by suppliers.

According to an interview with a transport authority, the TCO of vehicles does play a role in the purchase decision. Supplier also have attention for the TCO. There is however little space for customization of vehicles. In the other interview it is stated that maintainability was a tender criterion, although the most important was the purchase price.

Cost-benefit analysis

The fourth goal is to find out more about CBAs, its role, and its importance. The interviewed consultant stated that CBAs are used if the national Dutch government takes the lead, or if it subsidises projects. For provincial and municipal projects CBAs are not mandatory. However, for example in the province of Limburg, and for larger projects, CBAs are used. Normally, CBAs are made in the study or exploratory phase. For decision-making multiple alternatives are included in the CBA. For public transport these alternatives are mostly the use of different timetables, different trajectories, or different modes. Decision-making is political, CBAs are in general not decisive. They are however used to support opinions.

Management, maintenance, and replacement costs are included in a CBA. Information from other reports, for example a life cycle costs analysis of the project, are used. It is a rule of thumb that annual maintenance costs for public transport projects are 2 or 3 percent, sometimes 4 percent, of the investments costs. Often only this type of key figures are used, instead of a life cycle costs analysis. The interviewed person has the feeling that management and maintenance costs are underestimated. When life cycle costs estimations are made, this likely results in better estimations.

5.4. Cost-benefit analysis

The next paragraphs give an overview of the evaluated CBAs. First an overview of the current outcomes of the CBAs is given. Next, new estimations for the maintenance costs are made, with also new outcomes for these CBAs.

Current results CBAs

The current results of the CBAs are given first. An overview of the maintenance costs, total costs, total benefits, and the b/c ratio is given in table 5.3. Total costs and total benefits were provided in the reports. The maintenance costs are in some instances provided, and are in some cases calculated based on assumptions given in the reports. The benefit/cost-ratio (b/c-ratio) is calculated based on the total benefits and the total costs.

The table shows that maintenance costs are varying between 6 million euro to over 1 billion euro, with an average value of 229 million euro. Maintenance costs are on average 22 percent of the total costs, and are between 10 and 40 percent in around three quarters of the cases.

Total costs vary between 55 million and 6.4 billion euro, with an average value of 1.3 billion euro. Costs for metro projects are higher, varying between 0.9 and 6.4 billion euro, than costs for bus and light rail projects, which vary between 55 and 314 million euro. Total benefits of the projects are on average lower, between 32 million and 1.7 billion euro, with an average of 441 million euro.

The b/c-ratio is larger than 1 in slightly less than half of the cases and lower than 1 for the other cases. The average ratio is 0.81, varying between 0.17 and 1.60. Metro projects have an average ratio of 0.34, light rail an average ratio of 0.85, and bus an average ratio of 1.24.

Table 5.3: overview of maintenance costs, total costs, total benefits, all in million euro, price level 2017, and the b/c-ratio of CBAs.

Variant	Type	Maintenance costs (million euro)	Total costs (million euro)	Benefits (million euro)	b/c-ratio
1. A. a/d Rijn-Schiphol	Bus	24	55	71	1.29
2. Bus lane A6/A1	Bus	45	139	143	1.03
3. Schiphol Oost	Bus	24	64	72	1.11
4. Utrecht-Overvecht	Bus	41	80	99	1.24
5. Amstelveenlijn Metro	Metro	280	941	598	0.64
6. Amstelveenlijn HTV1	Light rail	51	282	256	0.91
7. Amstelveenlijn HTV1+	Light rail	46	290	348	1.20
8. Amstelveenlijn HTV3	Light rail	41	258	119	0.46
9. Vlaanderen-Maastricht	Light rail	14	75	32	0.42
10. Uithoflijn bus	Bus	8	108	172	1.60
11. Uithoflijn bus+	Bus	6	294	351	1.19
12. Uithoflijn tram	Light rail	32	314	389	1.24
13. Westlijn	Metro	1,107	6,274	1,084	0.17
14. Oost/Westlijn	Metro	863	6,425	1,697	0.26
15. NZ-lijn-Schiphol (1)	Metro	637	3,639	723	0.20
16. NZ-lijn-Schiphol (2)	Metro	385	1,989	768	0.39
17. Kleine ring	Metro	292	1,524	578	0.38

Evaluation of CBAs

Next, new estimations of maintenance costs are made, and these are substituted in the CBAs. These new estimations are based on the index number of the maintenance costs, as estimated in this research. The new maintenance costs and the new b/c-ratios are shown in table 5.4.

There is an increase in maintenance costs for light rail projects 9 and 12. The increase is respectively 85 percent and 29 percent. The maintenance costs decrease for all the other variants, including the three light rail projects and all bus and metro projects. The decrease in costs is between 15 and 97 percent, on average 55 percent.

The light rail projects have a change in the b/c-ratio ranging from an decrease of 0.05 to an increase of 0.03, on average 0.00. Metro projects show an increase between 0.01 and 0.13, on average 0.04. Bus projects show a much larger increase, between 0.02 and 1.20, with an average of 0.49. It must be noted that in none of the cases the b/c-ratio change from below 1 to above 1, or vice verse.

Table 5.4: overview of a new estimate of the maintenance costs in million euro, price level 2017, a new b/c-ratio, the percentual change in maintenance costs, and the absolute change in the b/c-ratio, for seventeen CBAs.

Variant	Type	Maintenance costs (million euro)	b/c-ratio	Change maintenance costs (%)	Change b/c-ratio
1. A. a/d Rijn-Schiphol	Bus	4	1.99	-82%	0.70
2. Bus lane A6/A1	Bus	5	1.46	-90%	0.43
3. Schiphol Oost	Bus	3	1.64	-86%	0.53
4. Utrecht-Overvecht	Bus	1	2.44	-97%	1.20
5. Amstelveenlijn Metro	Metro	120	0.77	-57%	0.13
6. Amstelveenlijn HTV1	Light rail	41	0.94	-21%	0.03
7. Amstelveenlijn HTV1+	Light rail	39	1.23	-15%	0.03
8. Amstelveenlijn HTV3	Light rail	30	0.48	-27%	0.02
9. Vlaanderen-Maastricht	Light rail	26	0.37	85%	-0.05
10. Uithoflijn bus	Bus	2	1.68	-73%	0.08
11. Uithoflijn bus+	Bus	2	1.21	-73%	0.02
12. Uithoflijn tram	Light rail	41	1.20	29%	-0.04
13. Westlijn	Metro	522	0.19	-53%	0.02
14. Oost/Westlijn	Metro	618	0.27	-28%	0.01
15. NZ-lijn-Schiphol (1)	Metro	264	0.22	-59%	0.02
16. NZ-lijn-Schiphol (2)	Metro	328	0.40	-15%	0.01
17. Kleine ring	Metro	128	0.43	-56%	0.05

6. DISCUSSION AND CONCLUSION

In this chapter the main conclusions of this research are presented and discussed. First, a conclusion and discussion is given per research question. These research questions concern the importance of maintenance costs on decision-making, the level and composition of maintenance costs, the factors influencing maintenance costs, and the evaluation of cost-benefit analyses (CBAs). This is followed by the recommendations, which includes suggestions for future research.

Importance of maintenance costs on decision-making

It can be concluded that in general maintenance costs are taken into account in decision-making concerning the purchase of vehicles. There is varying attention for maintenance costs concerning infrastructure, where the importance of maintenance costs seem to be larger for bus infrastructure than for rail infrastructure.

There is quite some attention to the maintenance costs when purchasing vehicles. At least some companies and suppliers look at the life cycle costs. This does not necessarily mean maintenance is a very important factor, as it could have a share of only a few percent in the actual decision-making.

There is furthermore wide varying attention to maintenance costs in decision-making of new infrastructure. This ranges from no attention for maintenance costs, to just estimating the maintenance costs, reviewing the costs by comparing the costs to a standard amount, and including the costs in a life cycle calculation or a CBA. A CBA is however not decisive in decision-making, but is used to support opinions.

The previously given conclusions were based on twelve interviews, distributed over six different groups, which seems enough to draw some first conclusions. It helps supporting the other parts of this research: if maintenance costs were of no importance, the other results would also be less valuable.

However, only one or a few persons per group were interviewed, with mostly only a part of the interview concerning this topic. This makes it inappropriate to draw very firm conclusions. If this topic would be the main topic of research, it would be necessary to have a larger group of people interviewed. Furthermore, another important stakeholder in this process, the politicians, should be interviewed as well.

Level and composition of maintenance costs

Maintenance costs of five types of infrastructure and eight types of vehicles were estimated. It is not surprising that maintenance costs of both rail infrastructure and rail vehicles are higher than maintenance costs of bus infrastructure and bus vehicles. Furthermore, metro infrastructure has considerably higher maintenance costs than tram and light rail infrastructure, but metro vehicles are in contrast slightly cheaper to maintain than tram and light rail vehicles.

It was observed that major maintenance costs are a very important part of the maintenance costs of the rail infrastructure, with a share of around half of the costs. For rail vehicles, regular maintenance has the largest share, also accounting for around half of the costs. However, it must be noted that the composition of costs, consisting of management, regular maintenance, and major maintenance, is widely varying among the companies.

It was furthermore shown that, for rail infrastructure, the proportion of costs related to track decreased from almost seventy percent for tram, to around fifty percent for light rail, to less than thirty percent for metro. A limited part of the costs for tram and light rail are related to stops and stations, where for metro this is a bit more than thirty percent of the costs.

Estimated maintenance costs are compared with results from CROW-KpVV (2015). Costs can not be compared directly, therefore in appendix D some assumptions are given and calculations are made to make a comparison of costs possible. These processed costs are used further on.

CROW-KpVV (2015) has replacement costs of a 30-meter tram vehicle of 2.8 million euro, which is around 20 percent higher than results from this research. Maintenance costs for bus infrastructure from this research of 17.000 and 24.000 euro per route-km per year, are within the range of 3,000 to 250,000 euro per route-km per year given by CROW-KpVV (2015). For tram infrastructure, results from this report of 370.000 euro per route-km per year, are slightly higher than the 240,000 to 360,000 euro per km per year from CROW-KpVV (2015). For metro, the difference is larger, with this research estimating costs on 1,3000,000 euro per route-km per year, were CROW-KpVV (2015) gives costs between 680,000 and 900,000 euro per route-km per year.

Some differences in maintenance costs exist, but these are in general not very large. Furthermore, there are some possible explanations for these differences. Firstly, it is not explicitly stated that management costs are included in CROW-KpVV (2015), which could explain part of the differences in costs. Secondly, this research expresses costs in euro per route-km, where CROW-KpVV (2015) expresses costs in euro per km lane for bus, and in euro per km single track for rail. It is assumed that a route-km is more or less equal to two times single track. However, this is not necessarily the case, because of side tracks, or routes with one, three, or four tracks.

Next, two topics are discussed which have influence on the results and their reliability. Firstly, light rail is considered as one type of system in this research, thereby excluding the tram. This in contrast to Railforum (2010) were light rail was subdivided in tram, tramtrain, traintram, trammetro, and metrotram systems. Possible variations in costs between the various light rail types is not reflected in the final estimation of the maintenance costs. This makes results for light rail less applicable to one of the mentioned subcategories. On the other hand, when all the mentioned subcategories would have been included in this research separately, the data would have been fragmented over these categories. That was not a useful method for this research, as already limited data for light rail were available. It is however shown that there are variations in maintenance costs between the various light rail companies, thereby suggesting that there is also variation among the various subcategories of light rail. Thus, with more detailed data available, it would be useful to research multiple subcategories of light rail independently.

Secondly, only one company for maintenance costs of bus vehicles is included. This makes results of course less reliable. For bus infrastructure, data from three municipalities were included, although not all three municipalities had data on both asphalt and concrete bus lanes, on management costs, and on other maintenance costs. Furthermore, none of the four large Dutch cities were included, and for example a well known bus rapid transit line as the Zuidtangent was not included. It is possible that in these cases maintenance costs are larger, but it is hard to estimate to what extent.

Explanations for variation in maintenance costs

Deviations in maintenance and replacement costs among modes, among companies, and among municipalities were observed. Next, three factors which can influence maintenance costs are given.

Firstly, it was found that maintenance costs for aboveground metro can be around ten to twenty percent lower than the estimated average, were costs for underground metro can be up to eighty percent higher than the the estimated average. It is likely that a part of this difference in costs can be related to additional systems in underground sections and larger underground stations. Secondly, there was variation in costs between the various light rail companies. It is expected that light rail which is combined with metro has higher maintenance costs than light rail which is not. Thirdly, metro vehicles are cheaper to maintain than light rail and tram vehicles. This can be due to the metro infrastructure which has in general straighter lines, with wider curves, than tram infrastructure. This could also be due to the chipcard systems which are in general on stations for the metro system, were tram vehicles have in general chipcard systems on the vehicle itself.

There are more factors which can influence maintenance costs, but which are not clearly reflected in the data. Main factors for infrastructure are the characteristics of rail track or bus lane, the frequency of vehicles, and the number of different types of vehicles for rail infrastructure. For vehicles, it is likely that there is among others some influence of the length and the age of a vehicle. There are also factors having influence on both infrastructure and vehicles. One factor concerns the environmental pressure and laws and regulations. Others factors are the maintenance strategy, the amount of overhead of a company, and professionalisation of the asset management system. There is furthermore some potential for reducing maintenance costs by looking at a transport system as a whole, instead of looking at vehicles and infrastructure separately.

It must be noted that results were mostly based on aggregated data per company or city. This makes it difficult to relate factors influencing maintenance costs to the data, as it is likely that there are multiple factors which are different among the companies or cities. In an ideal research of course only one factor should change, to quantify the effect of that factor. This was in general not possible with the data at hand and would probably also require another method of research. Where this research largely used already available data, additional and probably more detailed data should be collected to study factors in more detail.

There are thus many factors that have an influence on the maintenance costs, but it is hard to give a clear quantitative relation between these factors and the maintenance costs. It is therefore also hard to estimate to what extent reduction in maintenance costs is feasible.

Evaluation of cost-benefit analyses

This research found some influence of using index numbers of maintenance costs on the outcome of CBAs. It was shown that the total maintenance costs in the evaluated situations deviate from the original results, with results ranging from a decrease of 97 percent to an increase of 85 percent. Most projects seem to over estimate maintenance costs and only two of the seventeen projects seem to underestimate maintenance costs.

The original b/c-ratios, which represents the outcome of the CBAs, of all projects vary between 0.17 and 1.60. For bus, light rail, and metro projects average results are respectively 1.24, 0.85, and 0.34. A report by CPB and KiM (2009) contains an overview of CBAs of 25 public transport projects, including a lot of heavy rail projects. The b/c-ratios range from 0.0 to 6.8. A bit more variation is thus observed in CPB and KiM (2009) than in this research. When excluding the three highest and lowest ratios, results range from 0.2 to 1.6, which is quite similar to the results from this research.

The change in maintenance costs, when using index numbers instead of the original results, has also an effect on the b/c-ratio. The change in b/c-ratio for light rail and metro projects is relatively small, ranging from a decrease of 0.05 to and increase of 0.13. For bus projects a change of up to 1.20 was observed. However, in none of the cases there was a change in b/c-ratio from below 1 to above 1, or vice verse.

The change in b/c-ratio seems large enough, even for light rail and metro projects, to potentially change the ranking order of multiple projects or multiple variants of a single projects.

Cantarelli et al. (2012) estimated cost overrun of Dutch rail projects to be on average 11 percent. Assuming that construction costs are quite a large part of the total costs, it seems that the error in the construction costs is at least as large as the error in maintenance costs of light rail and metro projects.

Underestimation of maintenance costs can be linked to the general underestimation of construction costs, as shown by (Flyvbjerg et al., 2003). However, in this research most projects seem to overestimate the maintenance costs. The number of CBAs included in this research, seventeen, seems reasonable. However, these CBAs are derived from only five reports. It is therefore not unlikely that this small sample size has influence on the unexpected outcome that in general maintenance costs seem to be overestimated.

Furthermore, estimations of the average maintenance costs of infrastructure and vehicles were used in the CBAs. No adjustments to the estimations of these costs were made based on the factors which can explain variation in maintenance costs. That could be a very promising approach, as maintenance costs could then be estimated in more detail, probably leading to better results. However, there should be additional information about the situation of the new to build line in the first place.

This could for example be the type, or types, of track to be used. Secondly, the effect of these factors need to be quantified. However, for only a few factors information is available to make a good estimation. Based on the data of this research, most factors can not yet reliably be quantified.

Recommendations

It is recommended to let management and maintenance costs play a fair role in decision-making. This does not necessarily mean that maintenance costs have to play a large role, but it does mean that these costs should not be omitted due to for example political reasons.

A possible way of giving management and maintenance costs a fair share, is by using a CBA, in which these costs are normally included. It is advised to keep the CBA understandable and verifiable. This means that, in the case of management and maintenance costs, not only the final net present value of these costs is given, but also the main underlying assumptions and values. These are for example the number of vehicles, the length of the infrastructure, and the estimated maintenance costs per vehicle and per km of infrastructure. In that way, it is possible to verify the results.

This research provides some practical guidance regarding the estimation of maintenance costs. This includes an overview of maintenance costs of both infrastructure and vehicles, as well as a model, which in combination can be used to estimate maintenance costs for a new urban public transport connection. This can be used to verify results from an existing CBA, or any other document which includes estimations of maintenance costs. It can also be used for making a first estimation of the maintenance costs of a project.

It is not advised to use the in this research estimated maintenance costs without further thinking. These estimated values are averages, were maintenance costs for a specific case are likely to deviate from this. This is supported by the fact that are many factors which can influence maintenance costs.

There are furthermore some possibilities for future research. One possibility is to research the effect of factors on the maintenance costs in more depth, for example the type of track, or the frequency of vehicles. This would preferably lead to quantitative estimates of the effects of these factors on the maintenance costs. It is likely that research should then take place on a much lower scale, for example that of the type of vehicles and individual lines or even part of lines.

Another possibility is the verifications of management and maintenance costs of CBAs in more detail. This can be done by researching actual observed management and maintenance costs of finished projects, which were formerly included in a CBA. A comparison can be made of the actual observations, the estimated maintenance costs in the CBA, and the estimated maintenance costs based on the index numbers from this research.

It was already suggested in one of the interviews that the research should focus on the costs of a system as a whole, instead of looking at vehicles and infrastructure separately. It is interesting to research this further, to find out if, and to what extent, maintenance costs can be reduced by looking at a system as whole, in comparison to looking at the parts separately.

APPENDIX A. INFRASTRUCTURE COSTS

The information from this appendix is not displayed, because of confidentiality. Possible referenced sources from this appendix are displayed in the reference list.

APPENDIX B. VEHICLE COSTS

The information from this appendix is not displayed, because of confidentiality. Possible referenced sources from this appendix are displayed in the reference list.

APPENDIX C. INTERVIEWS

The information from this appendix is not displayed, because of confidentiality. Possible referenced sources from this appendix are displayed in the reference list.

APPENDIX D. MAINTENANCE COSTS IN THE LITERATURE

A report by CROW-KpVV (2015) includes maintenance and replacement costs of vehicles and infrastructure. Bus, tram, and metro are included, but light rail is not.

For vehicles, CROW-KpVV (2015) has management costs given per vehicle per year, and maintenance costs given per km, making it hard to compare the results with the results from this report. Furthermore, the replacement costs of vehicles are converted to a price per square meter. This makes it also hard to make a fair comparison of replacement costs with the results from this report. There is however one example of a 30-meter tram, which costs 2.7 million euro, price level 2015. This is converted to price level 2017, by using a multiplication factor of 1.037, as given in table 4.1. The replacement costs of a tram is than equal to around 2.8 million euro per 30-meter vehicle, price level 2017.

CROW-KpVV (2015) also contains information about maintenance costs for infrastructure. In that report, annual maintenance costs for bus infrastructure are given as being 1 to 2 percent of the investments costs. The investments costs range between 300,000 and 12 million euro per km buslane. These costs can be converted to be 3,000 to 250,000 euro per route-km per year for bus infrastructure, price level 2017, again using a multiplication factor of 1.037.

For rail infrastructure, annual maintenance costs are given as 115,000 to 175,000 euro per km single track per year for tram, and 330,000 to 435,000 euro per km single track for metro, price level 2015 (CROW-KpVV, 2015). It must be noted that CROW-KpVV (2015) makes a distinction between maintenance and replacement costs, with maintenance costs given in cost per km per year and replacement costs in costs per km. Both costs however have the same order of magnitude, as was also observed in this research, and it is therefore expected that replacement costs are also costs per year. Furthermore, the costs of single track are doubled, giving the expected costs for double track. It is then assumed that a kilometre of double track is more or less equal to a route-km, as used in this research. Converting costs to price level 2017 and to route-km, results in costs of 240,000 to 360,000 euro per route-km per year for tram, and 680,000 to 900,000 euro per route-km per year for metro.

REFERENCES

Voertuigkosten 2013-2016, 2017. Excel document.

Hoekse lijn planning. http://hoekselijn.mrdh.nl/planning, n.d.a. Accessed: 11 December 2017.

9292. 9292 reist met je mee. https://9292.nl/, n.d. Accessed: 2 November 2017.

Alstom. Regio citadis, de moderne lagevloertam ...als regiotram voor randstadrail in nederland, 2006.

Vervoerregio Amsterdam. Kadernota 2018, 2017.

Jan Anne Annema. The use of cba in decision-making on mega-projects: empirical evidence. In Hugo Priemus and Bert van Wee, editors, *International Handbook on Mega-Projects*, chapter 13. Edward Elgar, 2013.

Müfide Banar and Alp Özdemir. An evaluation of railway passenger transport in turkey using life cycle assessment and life cycle cost methods. *Transportation Research Part D: Transport and Environment*, 41:88 – 105, 2015. ISSN 1361-9209. doi: https://doi.org/10.1016/j.trd.2015.09.017.

BORI. Bori verantwoording 2015 v2016-12-31, 2016.

BRU. Jaarstukken 2013, 2014.

BRU. Jaarstukken 2014 van bestuur regio utrecht, 2015.

CAF. Utrecht uithoflijn tramway, 27 low-floor trams, type urbos 100 for the new uithoflijn utrecht, the netherlands, n.d.a.

CAF. Regio utrecht tram, urbos 100 trams voor de tramlijn utrecht - nieuwegein/ijsselstein, n.d.b.

C.C. Cantarelli, B. Flyvbjerg, and S.L. Buhl. Geographical variation in project cost performance: the netherlands versus worldwide. *Journal of Transport Geography*, 24:324 – 331, 2012. ISSN 0966-6923. doi: https://doi.org/10.1016/j.jtrangeo.2012.03.014. Special Section on Theoretical Perspectives on Climate Change Mitigation in Transport.

CBS. Nationale rekeningen 2009; arbeidsrekeningen, 1969-2009. http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=7511nr&D1=37&D2=0&D3=31-37&HDR=G1,T&STB=G2&VW=T, 2010. Accessed: 20 November 2017.

CBS. Overheid; overheidsproductie en -consumptie. http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=82568ned&D1=88&D2=5-11&HDR=G1&STB=T&VW=T, 2017. Accessed: 20 November 2017.

Centraal Planbureau. *Centraal Economisch Plan 2017*. Sdu Uitgevers, 2017.

CPB. Toelichting bij kerngegevenstabel. https://www.cpb.nl/artikel/toelichting-bij-kerngegevenstabel, 2017. Accessed: 26 February 2018.

CPB and KiM. Het belang van openbaar vervoer; de maatschappelijke effecten op een rij, 2009.

CROW-KpVV. Kostenkengetallen regionaal openbaar vervoer 2015, 2015.

CVOV. Kostenkengetallen openbaar vervoer, 2005.

Hein Den Hartog, 11 October 2017. Interview.

Dienst metro. Subsidieaanvraag beheer en onderhoud railinfrastructuur 2013 en 2014, 2012.

Dienst metro. Subsidieaanvraag bori 2014, 2014.

Dienst metro. Mpv metro 2015-2050, 2015.

Dienst Metro and GVB. Hoofdlijnen tot wijziging van overeenkomst Beheer & onderhoud railinfrastructuur 2013/14 en opstellen overeenkomst beheer & onderhoud railinfrastructuur 2015-2024, 2013.

DIVV. Subsidieaanvraag 2011 beheer en onderhoud railinfrastructuur en aflossing voorfinanciering personeelsvoorziening gvb, 2011a.

DIVV. Subsidieaanvraag voor beheer en onderhoud railinfrastructuur 2012-2013, 2011b.

DOVA. Indexen voor dummy's, 2017.

Ecorys. Kkba's regionale ov-projecten actieprogramma ov, 2009.

Ecorys. Mkba uithoflijn; rapportage uitkomsten, 2011.

Ecorys. Mkba rijk-regioprogramma amsterdam-almere-markermeer, 2012a.

Ecorys. Quick-scan mkba hov-netwerk hollands midden, 2012b.

Ecorys. Mkba tramlijn vlaanderen-maastricht; kosten en baten voor nederland, 2012c.

Ecorys. Mkba - transport & mobiliteit. `http://www.ecorys.nl/casestudy/mkba-transport-mobiliteit-MIRT-OEI-leidraad`, n.d. Accessed: 24 January 2018.

Jonas Eliasson and Mattias Lundberg. Do cost–benefit analyses influence transport investment decisions? experiences from the swedish transport investment plan 2010–21. *Transport Reviews*, 32 (1):29–48, 2012. doi: 10.1080/01441647.2011.582541.

Encyclopædia britannica. Estimation of a population mean. `https://www.britannica.com/science/statistics/Estimation-of-a-population-mean#ref367453`, 2017. Accessed: 23 March 2018.

Bent Flyvbjerg, Mette K. Skamris holm, and Søren L. Buhl. How common and how large are cost overruns in transport infrastructure projects? *Transport Reviews*, 23(1):71–88, 2003. doi: 10.1080/01441640309904.

Bent Flyvbjerg, Mette K. Skamris Holm, and Søren L. Buhl. How (in)accurate are demand forecasts in public works projects?: The case of transportation. *Journal of the American Planning Association*, 71(2):131–146, 2005. doi: 10.1080/01944360508976688.

Gemeente Amsterdam. Onderhoudskosten amstelveenlijn en aanpak optimalisatie bouw-beheer kosten, 2015a.

Gemeente Amsterdam. Subsidieaanvraag bori 2015 (beheer en onderhoud rail infrastructuur), 2015b.

Gemeente Amsterdam. Subsidieaanvraag bori 2016 (beheer en onderhoud rail infrastructuur), 2016.

Gemeente Amsterdam. Uitbreiding metronet amstedram aanvullende verkenningen 2017, 2017.

Gemeente Amsterdam. Achtergrondinformatie voor docenten werkstukken spreekbeurten. `https://www.amsterdam.nl/publish/pages/515633/achtergrondinformatie_voor_docenten_werkstukken_spreekbeurten_2.pdf`, n.d. Accessed: 2 November 2017.

Goudappel Coffeng. Toekomstperspectief zuidtangent, 2010.

GVB. Notitie onderbouwing toename financiële omvang meerjaren vervanging programma tram 2012-2017, 2010.

GVB. Gvb kaplsten materieel doorkijk 2024, 2012. Excel document.

GVB. Lines ≫ tram 26. https://maps.gvb.nl/en/lijnen/26, n.d. Accessed: 12 April 2018.

GVB. Impact van projecten metro op de exploitatiekosten concessie 2012-2017, n.d.a.

GVB. Saldo. https://www.gvb.nl/saldo, n.d.b. Accessed: 2 November 2017.

GVB. Metro. https://www.gvb.nl/vervoer/metro, n.d.c. Accessed: 4 December 2017.

GVB. Tram. https://www.gvb.nl/vervoer/tram, n.d.d. Accessed: 1 December 2017.

GVB and CAF. Urbos 100 tram voor gvb amsterdam, n.d.

GVB Activa B.V. Investeringssubsidies activa b.v., 2017. Excel document.

Hoekse Lijn. Veelgestelde vragen. http://hoekselijn.mrdh.nl/veelgestelde-vragen-overzicht, n.d. Accessed: 2 November 2017.

HTM. Jaarverslag 2007, 2009.

HTM. Jaarverslag 2012, 2013.

HTM. Concept rapportage beheer en onderhoud infra 2013, 2014.

HTM. Financiële verantwoording lvo – midlife, 2015a.

HTM. Beheer en onderhoud assets railinfrastructuur jaarplan 2016, 2015b.

HTM. Opleverdocument lvo/ml, 2016a.

HTM. Beheer en onderhoud infrastructuur rapportage q4 2014, 2016b.

HTM. Beheer en onderhoud infrastructuur rapportage q4 2015, 2016c.

HTM. 2016-06-02 formulier c en d bieding gereclassificeerd (na afstemming mrdh) definitief, 2016d. Excel document.

HTM. Tabel2 fy2005-2015 en capaciteitskosten en km kosten, 2017.

HTM. Mrdh_p-#3880-v6-htm_rail_opzet_overzicht_beschikkingen_2010-2016, n.d.a. Excel document.

HTM. Reizen met de ov-chipkaart. https://www.htm.nl/vervoerbewijzen/ov-chipkaart/reizen-met-de-ov-chipkaart/, n.d.b. Accessed: 2 November 2017.

HTM Techniek. Asset management plan railinfrastructuur 2017, 2016a.

HTM Techniek. Strategisch plan techniek bedrijfsmiddelen railsysteem mrdh regio haaglanden 2016-2026, 2016b.

Paul Koekkoek, 10 October 2017. Interview.

Carl Koopmans. Kosten en baten van het centraal planbureau: verleden, heden en toekomst, 2010.

Carl Koopmans and Piet Rietveld. Long-term impacts of mega-projects: the discount rate. In Hugo Priemus and Bert van Wee, editors, *International Handbook on Mega-Projects*, chapter 14. Edward Elgar, 2013.

Parviz A. Koushki, Saleh Yaseen, and Laila I. Ali. Evaluation of bus transit maintenance and operation costs in kuwait. *Transport Reviews*, 19(4):305–314, 1999. doi: 10.1080/014416499295411.

Microsoft. Npv function. `https://support.office.com/en-us/article/npv-function-8672cb67-2576-4d07-b67b-ac28acf2a568`, n.d. Accessed: 10 April 2018.

Mott MacDonald. Audit bov-kosten lokaalspoor vervoerregio's, 2017a.

Mott MacDonald. Bov netwerk en vloot inventarisatie v07, 2017b. Excel document.

NoordZuidlijn. Beheer & Onderhoud NoordZuidlijn, n.d.

OV-magazine. `https://www.ovmagazine.nl/2014/06/nieuwe-tram-voor-den-haag-komt-deze-maand-1740/`, 2014. Accessed: 14 December 2017.

Provincie Utrecht. Begroting 2017. `http://provutrecht.begroting-2017.nl/p702/traminfrastructuur`, 2016a. Accessed: 27 November 2017.

Provincie Utrecht. Jaarrekening 2015. `http://provincie-utrecht.jaarverslag-2015.nl/p469/onderhoud-kapitaalgoederen`, 2016b. Accessed: 27 November 2017.

Provincie Utrecht. Jaarrekening 2016. `http://provincie-utrecht.jaarverslag-2016.nl/p1382/tramsysteem`, 2017. Accessed: 27 November 2017.

Provincie Utrecht. Sneltram sinds 1983. `http://www.regiotramutrecht.nl/tram/sneltram-sinds-1983/`, n.d. Accessed: 27 November 2017.

Provincie Zuid-Holland. Hov-net zuid-holland noord, 2012.

Railforum. Light rail?! vertel mij wat!, 2010.

Railinfra Solutions. Ombouw amstelveenlijn; maatschappelijke kosten-batenanalyse, 2012.

RET. Jaarplan instandhouding infrastructuur 2009, 2008.

RET. Jaarplan infrastructuur 2010, 2009.

RET. Jaarplan instanhouding infrastructuur 2011, 2010.

RET. Jaarplan instandhouding infrastructuur 2012, 2011a.

RET. Jaarverslag 2010, 2011b.

RET. Jaarplan instandhouding infrastructuur 2013, 2012.

RET. Jaarplan instandhouding infrastructuur 2014, 2013.

RET. Jaarplan instandhouding infrastructuur 2015, 2014.

RET. Jaarplan instandhouding infrastructuur 2016, 2015.

RET. Asset management plan vlootmanagement 2017 - 2018, 2016a.

RET. Meerjaren investeringsplan railinfrastructuur 2017-2026, 2016b.

RET. Strategisch asset management plan ret vlootmanagement 2016 – 2026, 2016c.

RET. Sporenplan metro erasmuslijn en calandlijn, 2016d.

RET. 160224 kaplasten rail 2016 - 2021 mrdh, 2016e. Excel document.

RET. 2017 mjp ret, 2017a.

RET. 2018 mjp ret, 2017b.

RET. 2019 mjp ret, 2017c.

RET. 2020 mjp ret, 2017d.

RET. 2021 mjp ret, 2017e.

RET. Sporenplan metro hoekselijn, 2017f.

RET. Producten & tarieven. https://www.ret.nl/home/reisproducten/producten-tarieven.html, n.d.b. Accessed: 2 November 2017.

RET. Tram 12. https://www.ret.nl/home/reizen/dienstregeling/tram-12.html, n.d.c. Accessed: 11 December 2017.

RET. Dienstregeling. https://www.ret.nl/home/reizen/dienstregeling.html, n.d.d. Accessed: 11 December 2017.

RET. Metromaterieel. http://corporate.ret.nl/over-ret/materieel/metromaterieel.html, n.d.e. Accessed: 4 December 2017.

RET. Trammaterieel. http://corporate.ret.nl/over-ret/materieel/trammaterieel.html, n.d.f. Accessed: 4 December 2017.

RET and HTM. Sporenplan metro hofpleinlijn en zoetermeerlijn, 2017.

G. Romijn and G. Renes. Algemene leidraad voor maatschappelijke kosten-batenanalyse, 2013.

Siemens. Avenio tram – the hague, netherlands, 2014.

Harmen Otto Smedes, Dennis De Kleer, and Henk Nieboer, 4 October 2017. Interview.

SpoorPro. Utrecht krijgt 75 meter lange stadstram. https://www.spoorpro.nl/lightrail/2017/01/20/utrecht-krijgt-langste-stadstram-van-europa/, 2017. Accessed: 12 April 2018.

Stadsregio Amsterdam. Sporen naar uithoorn verkenningenstudie doortrekking amstelveenlijn naar uithoorn, 2014.

Üstra. Tw 6000. https://www.uestra.de/unternehmen/betrieb-technik/stadtbahn/tw-6000/, n.d. Accessed: 4 December 2017.

Alejandro Tirachini, David A. Hensher, and Sergio R. Jara-Díaz. Comparing operator and users costs of light rail, heavy rail and bus rapid transit over a radial public transport network. *Research in Transportation Economics*, 29(1):231 – 242, 2010. ISSN 0739-8859. doi: http://dx.doi.org/10.1016/j.retrec.2010.07.029. Reforming Public Transport throughout the World.

Trans Link Systems B.V. Instap- en basistarief. https://www.ov-chipkaart.nl/zo-werkt-reizen/tarieven/instap-en-basistarief.htm, n.d. Accessed: 2 November 2017.

U-OV.

U-OV. Tarieven ov-chipkaart. https://u-ov.info/mijn-reis-betalen/ov-chipkaart/tarieven-ov-chipkaart/, n.d. Accessed: 7 December 2017.

Pim Uijtdewilligen, 18 August 2017. Interview.

Uithoflijn. Trammaterieel. Source:http://www.uithoflijn.nl/trammaterieel/, 2017. Accessed: 4 December 2017.

Uithoflijn. Facts and figures, 2017.

University of Twente. Templates & downloads. https://www.utwente.nl/organisatie/huisstijl/templates-downloads/, n.d. Accessed: 10 April 2018.

Rob Van der Bijl and Niels Van Oort. *Light rail explained*. EMTA, 2014.

Han Van der Wal, 5 Ocotober 2017. Interview.

Bert Van Wee and Piet Rietveld. Cba: ex ante evaluation of mega-projects. In Hugo Priemus and Bert van Wee, editors, *International Handbook on Mega-Projects*, chapter 12. Edward Elgar, 2013.

Van Zutphen Economisch Advies. Kosten-batenanalyses openbaar vervoer. http://www.vanzutpheneconomischadvies.nl/index.php/mkba-database#Kosten-batenanalyses_openbaar_vervoer, n.d. Accessed: 24 January 2018.

Wikipedia. Amsterdamse gelede trams 9g en 10g. https://nl.wikipedia.org/wiki/Amsterdamse_gelede_trams_9G_en_10G, 2017a. Accessed: 1 December 2017.

Wikipedia. Metromaterieel m1/m2/m3. https://nl.wikipedia.org/wiki/Metromaterieel_M1/M2/M3, 2017b. Accessed: 4 December 2017.

Wikipedia. Gelede tram lang. https://nl.wikipedia.org/wiki/Gelede_Tram_Lang, 2017c. Accessed: 4 December 2017.

Wikipedia. Rotterdamse citadis. https://nl.wikipedia.org/wiki/Rotterdamse_Citadis, 2017d. Accessed: 4 December 2017.

Wikipedia. Metrotype b (5300-serie). https://nl.wikipedia.org/wiki/Metrotype_B_(5300-serie), 2017e. Accessed: 4 December 2017.

Wikipedia. Metrotype r. https://nl.wikipedia.org/wiki/Metrotype_R, 2017f. Accessed: 4 December 2017.

Wikipedia. Metrotype s (5400-serie). https://nl.wikipedia.org/wiki/Metrotype_S_(5400-serie), 2017g. Accessed: 4 December 2017.

Wikipedia. Zwitserse trams in utrecht. https://nl.wikipedia.org/wiki/Zwitserse_trams_in_Utrecht, 2017h. Accessed: 4 December 2017.

Wikipedia. Lightrail. https://nl.wikipedia.org/wiki/Lightrail, 2017i. Accessed: 24 January 2018.

Wikipedia. Metro/sneltramlijn 51. https://nl.wikipedia.org/wiki/Metro/sneltramlijn_51, 2018. Accessed: 12 April 2018.

Wikipedia. Metro-/sneltrammaterieel m4/s3. https://nl.wikipedia.org/wiki/Metro-/sneltrammaterieel_M4/S3, 2018. Accessed: 28 March 2018.

Witteveen en Bos. Noord/zuidlijn. http://www.witteveenbos.nl/nl/informatie-noordzuidlijn, n.d. Accessed: 27 November 2017.