A design methodology for mobility management strategies during infrastructure renovation projects

The case of the renovation of The Maastunnel in Rotterdam.

Master's thesis: Final Report

Date: 17-12-2015

Student: Ruben Daniel de Ruiter

Student number: 1503405

MSc Transport, Infrastructure and Logistics

Gemeente Rotterdam

TU Delft

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Author:

Ruben Daniel de Ruiter (1503405)

MSc Transport, Infrastructure and Logistics

Delft University of Technology

Ruben.deruiter@hotmail.com

Thesis committee members:

Prof. dr. ir. Bert van Wee (TU Delft, TPM)

Dr.ir Jan Anne Annema (TU Delft, TPM)

Dr. ir. Adam Pel (TU Delft, CITG)

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Preface

This report focusses on the design of mobility management strategies for infrastructure renovation projects in urban areas. The characteristics of temporary mobility management in an urban context to mitigate problems caused by temporary changes in the transportation system are analysed. The results of this analysis are combined in a design methodology. The amount of these projects will most likely increase in the near future, emphasizing the relevance of such a design methodology. A systematic way of dealing with these problems can help cities by keeping the transportation city functioning during large infrastructure renovation assignments.

The design methodology is tested on the case of The Maastunnel in Rotterdam. When writing this thesis, this was an existing problem and perfect case for evaluating the methodology. This thesis is derived in collaboration with The Municipality of Rotterdam. With this thesis, I finish the Master of Science: Transport, Infrastructure and Logistics at the Delft University of Technology.

The process of writing this thesis was an interesting life experience. I would like to thank several people for their contributions to this experience. First of all I like to thank The Municipality of Rotterdam, for giving me the opportunity to produce my thesis in their amazing office: The Rotterdam, in Rotterdam. Special thanks to Peter Hut, Kristiaan Leurs & Tijs Overbeek, for their mental support and making my days at The Municipality of Rotterdam a lot more fun. I also would like to thank, the people at The Municipality who helped me during my research for their contributions, and people from other organizations who contributed.

From TU Delft, I would like to thank Jan Anne Annema & Adam Pel for the constructive and critical comments and guidance, and especially for their positivity during the entire process. It really helped me reach the finish line. I would also like to thank Professor Van Wee for his critical reviews during the official meetings. And finally, I would like to thank all my family members and friends who supported me!

Summary:

Introduction

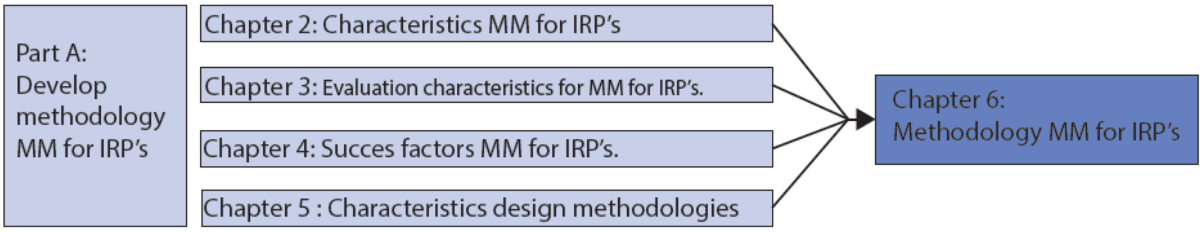
In dense cities with complex transportation systems, the implementation of supply side related transport measures during the renovation of infrastructure segments can be very difficult or even impossible. If this is the case, looking at the demand side of the transportation system to mitigate temporary problems is inevitable. For these infrastructure renovation projects (IRP's) in urban areas, the use of mobility management (MM) to mitigate temporary problems seems to be promising.

The relative young discipline of mobility management has not been subject to a comprehensive analysis in the context of infrastructure renovation projects. With increasing complexity of travel patterns and social and economic structures in and around cities, the importance of this type of policy instrument to mitigate temporary problems during renovation projects will increase. This thesis explains the specific characteristics of mobility management strategies for infrastructure renovation projects (IRP's) and the aspects influencing the level of success of mobility management strategies in the context of these type of projects. The results of this analysis will be incorporated in:

A design methodology for mobility management strategies for infrastructure renovation projects.

Research methodology

The methodology used to accomplish this research goals is based on several aspects. A literature study is conducted to specify the relevant aspects and characteristics influencing the level of success of a mobility management strategy for infrastructure renovation projects. First the specific characteristics of MM measures in the context of IRP's in researched. This is followed by an analysis of the relevant evaluation criteria for this type of assignments. After this, the factors and characteristics influencing the level of success are determined. Finally different design approaches are investigated, to define the necessary sequence of steps and deliverables for a MM strategy for IRP's.



Summery figure 1 Research objectives

Based on this literature study a design methodology is developed. This design methodology is evaluated using an expert panel of The Municipality of Rotterdam and with a case study. The expert panel exists of different experts in the fields of transport, project management and urban economics. The case study entails the renovation of The Maastunnel in Rotterdam. This case study is in particular relevant, because the renovation will lead to significant network problems in Rotterdam with associated economic and social effects.

Main findings

The need for a proper functioning transportation system, combined with the primary goal, of MM strategies for IRP's to mitigate congestion during the renovation project, increases the importance of the effectiveness of measures. Measures with a temporary effect, short implementation and short incubation time are needed. This need for a high effectiveness of the MM strategy can demand more extreme measures: push measures. Push measures in general have a high level of effectiveness, but realise low levels of public support.

A good communication strategy, creating problem awareness is necessary to limit the decrease of public support. Stakeholder participation is important during the entire design process to increase the level of public support and the level of effectiveness. The efficiency is given as indication of the overall effects of the measures. The transportation system exist to service the economic and social urban systems. If the overall impacts on these systems are negative, measures are not efficient. To increase public support, compensating pull measures can be added to the MM strategy. These measures will have a lower effectiveness in reducing private car use, but can help creating public support and achieving the secondary goals regarding access equity, noise and air pollution and road safety. In the end the MM strategy needs to fulfil the goals and be political feasibility. For this political feasibility a weighted judgement of the effectiveness, efficiency and public support needs to be conducted.

Design methodology

This obtained knowledge in this thesis is combined. This results in a design methodology for mobility management strategies for infrastructure renovation projects (Summery figure 2). Chapter 6 elaborates further on this design methodology. The different stages are executed using an iterative process to come up with a design that fulfils the demands. The process can be divided in three phases. During the first phase, the problem is analysed and the design deliverables are determined. During the second phase, the main mobility management measures are examined, and evaluated against the goals. Based on the results of phase 2, one or several alternatives are chosen and additional measures are defined to finalize the MM strategy. A complementary communication and marketing strategy is developed to increase the level of success of the MM strategy.

Evaluation design methodology

The design methodology is a first design. The combination of phases and stages is chosen, to illustrate the essential process and deliverables. Testing the design methodology will help improving it, filtering unnecessary information and adding possible important aspects.

The main problems experienced during the case study are related to the static regional transport model (Omnitrans model). The model variant used by The Municipality is based on OD pairs per mode per time period. This eliminates a lot of valuable information about the trip choice process. Information regarding changes in the decision to perform the trip, where to perform the trip, when to perform the trip and with what kind of transport mode to perform the trip, caused by the MM measures/strategy is lost.

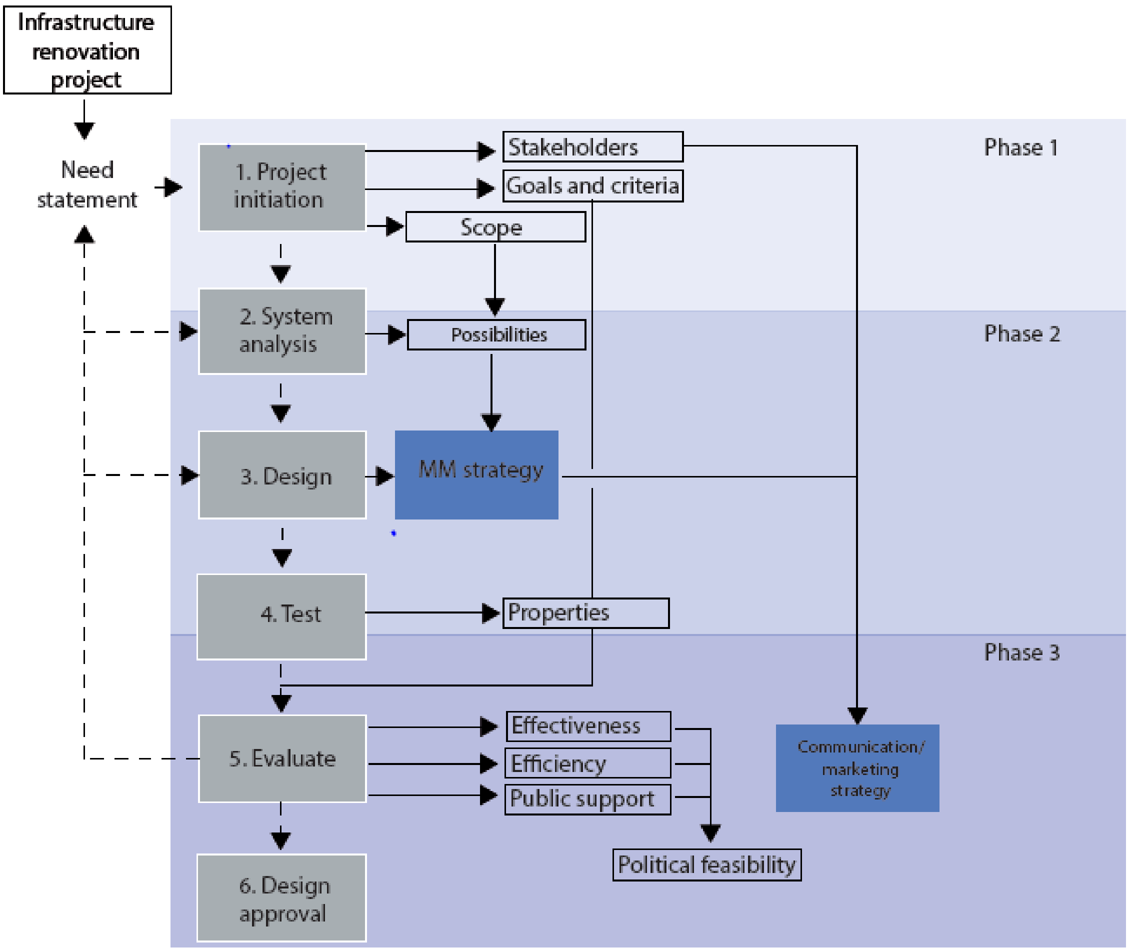
Because of the limitations, different parts of the evaluation could not be performed properly. A more detailed stakeholder analysis combined with involving essential stakeholders will provide more information about the level of social support.

A dynamic transport model will provide more information regarding travel behaviour and traffic flow in the transportation system. This will enable the evaluation of the secondary goals and the different impacts. If the different impacts can be quantified, a proper evaluation of the efficiency can be conducted. The different impacts can be monetized to create a cost benefit analysis. Combined with the more detailed stakeholders analysis this will create understanding of the implications of MM strategies for a city.

Determining the political feasibility will become better underpinned if stakeholder analysis and the modelling testing are adjusted, resulting in better political decision making.

More research is needed regarding the weight of the effectiveness, efficiency and public support and the related characteristics. This way the design methodology can really become a comprehensive design approach including a wide range of goals, impacts and implication for the specific urban context.

The design methodology does provide an extensive design and evaluation process. It is, however, a time consuming exercise and the right knowledge and tools must be available. If the complexity of the problem is less significant, a comprehensive approach like this is not needed. Where the relevance of the project and city is smaller, it is suggested to focus on the effectivity of measures. A proper functioning transportation system is essential for a city. This will provide the necessary infrastructure for the social and economic urban systems. Due to the temporary characteristic of renovation projects, other negative impacts will not be permanent, which decreases the weight of them.



Summery figure 2 design methodology (grey boxes are stages, blue boxes are direct deliverables for the MM strategy, and boxes with black edges are deliverables during the design process.)

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1. Introduction:

1.1. Thesis motivation

This Master's thesis is written with the purpose to analyse the possibilities and characteristics of mobility management (MM) applied during infrastructure renovation projects (IRP's). The relative young discipline of mobility management has not been subject to a comprehensive analysis in the context of infrastructure renovation projects. With increasing complexity of travel patterns and social and economic structures in and around cities, the importance of this type of policy instrument to mitigate temporary problems during renovation projects will increase. This thesis explains the specific characteristics of mobility management strategies for infrastructure renovation projects (IRP's) and the aspects influencing the level of success of mobility management strategies in the context of these type of projects. The results of this analysis will be incorporated in:

A design methodology for mobility management strategies for infrastructure renovation projects.

This design methodology is evaluated using a case study and an expert panel. The goal of the expert panel is to evaluate the methodology from a professional perspective. The case of The Maastunnel in Rotterdam will be used. This case is particularly relevant, because the renovation of this link has a significant impact on the transport network and the social and economic structures of Rotterdam. The highly densified and complex structure of the city and the important position of Rotterdam on a national and international level, demands a MM strategy to cope with the network problems during the renovation to protect the economic and social systems.

This chapter will further elaborate on the purpose of this thesis. First the background of mobility management and the relation with urbanized areas is set out in section 1.2. This is followed by a problem analysis (section 1.3), resulting in a problem statement, which is translated into two research goals with related objectives (section 1.4). Section 1.5 illustrates the essential demarcations of this thesis. Section 1.6 shows the contribution of this thesis to the different fields of science and practice. This chapter is concluded with the methodology, applied to accomplish the research goals (section 1.7).

1.2. Mobility management in the urban context

Background of mobility management

'Mobility management (MM) is any action or set of actions aimed at influencing people's travel behaviour in such a way that alternative mobility options are presented and/or congestion is reduced (Meyer, 1997).' It can refer to a broad variety of strategies aimed at distributing demand more efficiently over all available modes, times and routes on a specific transportation system (Fijalkowski, McCoy, & Lyons, 2013). This type of transportation policy, in The U.S. called travel demand management (TDM), was introduced in the United States during the beginning of the 70's. The rapid growth in private car use during this period, resulted in heavily congested roads in urban areas. Investing in new and existing infrastructure to enlarge capacity in order to fulfil market demands was sufficient at the beginning.

However, policy makers were forced to come up with alternative ways to manage the increasing demand on roads, when space in urban areas became scarce or even unavailable. Focussing on the demand side rather than on the capacity side, by managing the travel demand, emerged as alternative way to cope with the increasing pressure on the transportation system (Saleh & Sammer, 2009).

Similar policies were used before in Europe (Bradshaw, 1998), but these policies were not categorized as a specific type of policy instrument. Nowadays, this so called strategy of 'Travel Demand 'Travel Demand Management' or 'Mobility Management' has become an essential tool in current and future policy making to match capacity and demand in urban areas.

Importance of transportation systems in urban areas.

Where mobility of people leads to economic growth and increased (social) welfare, it is essential for governments to secure and develop the quality of the transportation system (Easterley & Rebelo, 1993; Rodrique, Comtois, & Slack, 2013). Also for urban and regional governments securing a proper functioning transportation system is essential from a social and economic perspective. Policy makers need to come up with ways to maintain the quality of the urban and regional transportation system. With the increased density and complexity in urban areas, determining proper solutions to cope with increasing transport demand becomes more difficult every day.

In many cities the pressure on urban transportation systems is still increasing. This already results in a mismatch between demand and supply during certain periods (mostly during peak hours). The transport network, existing of links and nodes, forms an interrelated system, supplying transport demand (Chaker, Moulin, & Theriault, 2010). Many links and nodes of the network are essential for the functioning of the transportation system. If one or several links and/or nodes are not accessible, this can impact the entire system.

An example of a link temporarily not accessible is the M4 in London. Because of a traffic accident in 2012, the temporary closing of the M4, resulted in a completely congested West London (Watling, 2012). Another example of a temporarily inaccessible link, is The Maastunnel in Rotterdam. In 2015, caused by an incident with a truck, the forced closing of the tunnel for a couple of hours created a gridlock in the entire city centre (RTV Rijnmond, 2015).

Potential mobility management for infrastructure renovation projects.

Although the incidents of the two examples in London and Rotterdam cannot be foreseen and road users are not supplied with in-advance-information, which is the case when maintenance is planned, they do show how the transportation system in highly densified areas can easily be disrupted. Occasionally, maintenance of road infrastructure in urban areas is necessary. If the part of the transport network, subject to renovation, is important for the urban transportation system, this can potentially lead to major problems. If a link or node is 'eliminated' from the system, the system can collapse. This indicates that maintenance at important links and nodes demands a well-thought strategy to guarantee the functioning of the transportation system during this maintenance period. In certain cases infrastructure network elements can be closed up to several years, impacting the transportation system dramatically for a substantial amount of time. The time between identifying the need for renovation and the start of the project can differ considerably. In case of calamities, this time can be reduced significantly, raising the need for policy measures to be implemented and effective within a very short time span. This is where mobility management can play an important role for infrastructure renovation projects in urban areas to mitigate temporary problems.

1.3. Problem analysis

Focus of literature on long term mobility strategies.

Current practice and research mainly focusses on mobility management for long term mobility strategies. Several studies focus on the entire process from design stages up to the implementation stages (Ferguson, 1990; Litman, Potential Transportation Demand Management Strategies, 1999; Gris Orange Consultant, 2012). Other studies focus on specific characteristics. For example, research has been done focussing on the success factors influencing mobility measures (Garling & Schuitema, 2007), the acceptability of MM (Eriksson, Garvill, & Nordlund, 2006), and the effectiveness of different measures (Rosenbloom, 1978; Henstra, Akkersdijk, pol, Pieper, & Voerman, 2005).

Examples of short term mitigation projects: Focus on highway segments and lack of integrated approach.

There are renovation projects using MM to mitigate short term problems. In The Netherlands MM strategies have been developed for several projects, e.g. the A12 - Zoetermeer in 2006, the A12 - Gouda between 2008 and 2009, A16 - between Rotterdam and Breda in 2008, and others (Bliemer , Dicke-Ogenia, & Ettema, Rewarding for Avoiding the Peak Period: A Synthesis of Four Studies in The Netherlands, 2009). Several analysis exist, taking cost effectiveness of measures into account. Mainly the effects of peak-avoidance-rewarding for private car users to reduce the demand during peak periods on the network is researched, e.g. (Bliemer , Dicke-Ogenia, & Ettema, Rewarding for Avoiding the Peak Period: A Synthesis of Four Studies in The Netherlands, 2009). For The Moerdijk Bridge near Rotterdam the cost effectiveness of peak-avoidance rewarding, park and ride facilities, and special information panels for car users is evaluated (Rienstra & Rienstra, 2009). Also the cost effectiveness of peak-avoidance rewarding for The Waal Bridge and a project in Utrecht are analysed (Ministerie van infrastructuur en milieu, 2011). All these projects evolve around highway segments of the national transportation system. These links of the transportation network are important for the accessibility of cities, but they are not situated inside highly urbanised areas, directly influencing urban economic and social systems.

Limitations comparative design methodologies

Different design methods exist for transport related problems. Two in particular are very interesting.

The handbook for sustainable traffic management mentions several actions regarding the design of a transport policy strategy (Rijkswaterstaat, 2003). Though this handbook is develop for sustainable traffic management, the main methodology seems applicable for mobility management. This method entails two main problems: It does not elaborate on the characteristics of different existing MM measures. And, it does not specifically elaborate on the impacts in an urban context. The focus of this method is on developing effective transport policy. A comprehensive analysis of the effects is not considered.

The Toekan method is a design method to mitigate short term problems for IRP's using MM (Rijkswaterstaat, 2010b). It purely focusses on the design of MM strategies based on cost effectiveness. This methods does not consider the wide range of different impacts, which are essential for the functioning of large cities.

1.4. Problem definition and research goal

Findings problem analysis.

Three main findings follow from the problem analysis:

1. Most mobility management literature focusses on long term mobility strategies.
2. There are no examples of IRP's inside large cities, where the related social and economic urban complexity, are included in a mobility management strategy as leading policy instrument. The examples found and discussed in literature of MM strategies applied to mitigate short term network problems are mainly part of highway systems.
3. Literature about MM strategies for short term mitigation problems does not stress the importance of a comprehensive interrelated approach, elaborating on the different characteristics of this complex type of policy assignments. Design methodologies focus on developing (cost) effective strategies, neglecting the wide range of impacts, important for the functioning of large cities.

Problem definition.

The conclusions of the problem analysis lead to the following problem statement:

'No comprehensive design methodology exists for MM strategies, creating overview of the essential characteristics and impacts of IRP's inside the context of urban areas '

Research goals.

To tackle the problem as defined the problem statement, two research goals are formulated:

'Determine the relevant aspects, needed to successfully implement MM strategies to mitigate network problems during infrastructure renovation projects in urbanised areas.'

Following from this:

'Combine these aspects into a design methodology including the relevant aspects of MM strategies for IRP's and illustrating the relevant steps in the design process.'

Objectives

This design approach needs to be applicable in different contexts, when essential elements of the road infrastructure in complex urban contexts are subject to renovation. In order to accomplish the goals, several objectives are derived (table 1). These objectives are either related to the content or the process of the design method.

Table 1 Research objectives.

Objectives:		Process (P) or Content (C)	Chapter
1.	Determine the specific characteristics of MM measures in the context of IRP's.	C	2
2.	Determine the evaluation characteristics for MM strategies for IRP's.	C	3
3.	Determine which factors and characteristics influence the success of mobility management measures.	C	4
4.	Determine the sequence of necessary steps to develop a MM strategy.	P	5
5.	Develop a methodology on how to approach the design process of MM strategies of IRP's in urban regions.	P + C	6

1.5. Research demarcations

This section demarcates the boundaries of this research. First the project characteristics of relevant projects are defined. After this, the definition of MM for IRP's is given and the types of measures defined in this research as mobility management are explained. Chapter 2 elaborates further on the definition and type of measures. The results are set out in this section to clarify the research scope.

Type of projects

Essential in this thesis is the type of project, the methodology is developed for. Research focusses on infrastructure renovation projects in urban areas

- The first important element is the definition of *urban areas.* This design methodology aims to evaluate a broad variety of impacts: transport related, economic and social impacts. Several of these impacts are only of interest in urban areas, where economic and social activity is at a high level and the transportation system is essential in facilitating this activity.
- The second important element is the aspect: *renovation.* The methodology aims to guide the design process during renovation projects. Only projects creating a temporary change in the transportation system are part of research.
- The final important element in this definition: *Infrastructure*. Links or nodes with a proven decisive position in the transportation system have got the necessary relevance to be subject for the development of mobility management strategies. The links or nodes, should contribute significantly to the social and or economic functioning of the city. Often this will be higher level network links or nodes, but also lower level network elements can demand the design of a comprehensive MM strategy.

Definition mobility management for IRP's

The definition as given in section 2.1 for mobility management measures/strategies for infrastructure renovation projects is as follows.

*'Mobility management for IRP's refers to a broad variety of quickly implementable strategies aimed at **temporary** influencing people's travel behaviour to **directly** distribute demand more efficiently **to protect** the transportation system.*

Essential for the type of measures is that they temporary influence travel behaviour to adjust the demand side of the transportation system to protect the functioning of the transportation system. Measures focus on short term mitigation and need to have a short incubation time.

Types of mobility management measures

There are different types of solutions to match demand to supply in urban areas. Seven solution types can be distinguished, see table 2 (Rijkswaterstaat, 2010a).

- Solution type 2, 3 and 4 are part of the scope of this research. These solutions are considered to be part of mobility management during the development of a design methodology. They fit the definition of section 1.7.2.
- Solution type 5, 6 and 7 influence the supply side.
- Solution type 1 is part of mobility management, but not suited for IRP's (see section 2.1). Therefore MM measures defined as spatial developments are considered as possible mobility management measures in this research.

Table 2 Solution types to match demand and supply defined as MM for IRP's (Rijkswaterstaat, 2010a).

	Solutions	Type	Demand/supply
1.	~~Spatial development~~	~~Mobility management; *Land use related*~~	**Demand**
2.	**Pricing policies**	**Mobility management; *Transport related***	
3.	**Mobility management (non-pricing or PT related)**		
4.	**Improvements in PT service networks and operations**		
5.	~~Traffic control~~	~~Traffic control~~	~~Supply~~
6.	~~Improving existing infrastructure~~	~~Supply related solutions~~	
7.	~~New Infrastructure~~		

1.6. Contribution research

The result of this thesis can be beneficial for different stakeholders related to research and practice.

Theoretical research contribution

First of all, from a transport policy research perspective it aims to provide an overview of the relevant elements regarding the design of a mobility management in the context of infrastructure renovation projects. The specific characteristics of this type of transport policy in its specific context are researched, with the aim to generate understanding of the type of assignment. Based on this analysis recommendations will be done for science, regarding the aspects which demand further research.

Practical research contribution

For policy makers, the results of this thesis, will help approach the design of a MM strategy in a more structured way. From the beginning till the end, the necessary steps are sequentially described, analysing the possibilities and related consequences of mobility management. This should help by defining the best possible MM strategy in a more efficient way. This can be seen as the link between science and practice.

For future renovation projects the case can serve as example on how to approach the design of a MM strategy in an interrelated way. This can be useful from a practical perspective. What are the implication of the case approach? And it can be useful from a theoretical perspective. What can be learned regarding policy making and evaluation?

Practical contribution

For (local/regional) governments the developed methodology can be used as a decision support instrument to support policy interventions during IRP's. It provides overview of the different impacts, their weight, the relation with stakeholders and the cost-benefit ratio of MM measures.

The case study can help the municipality of Rotterdam by determining the important impacts of the renovation of The Maastunnel. The results can be used to construct a MM strategy for the renovation project. For the city of Rotterdam this can lead to the mitigation of problems caused by the renovation project, enabling normal functioning transport, social and economic systems in the city.

1.7. Methodology

To fulfil the main goal of this thesis, to derive a design methodology for MM strategies during IRP's in urban areas, several research methods are used. Research is based on two main parts: Part A and Part B (figure 1).

- Part A focusses on achieving the research goals and objectives related to the design of the methodology, defined in section 1.4. This will be done using a literature study. By combining the existing knowledge regarding mobility management, infrastructure renovation projects, design approaches and evaluation characteristics, a design methodology for MM strategies for IRP's is derived.
- Part B focusses on evaluating the developed design methodology.
  - Part B contains a case study to evaluate aspects of the developed methodology. The renovation of the Maastunnel in Rotterdam is used as case.
  - A focus group session is organised to discuss the MM design strategy. The members of the project team of The Maastunnel renovation project are used as expert panel.

The design methodology of part A is used to approach the case study of Part B, The Maastunnel. The output of Part B will be used to adjust and improve the results of part A where necessary.

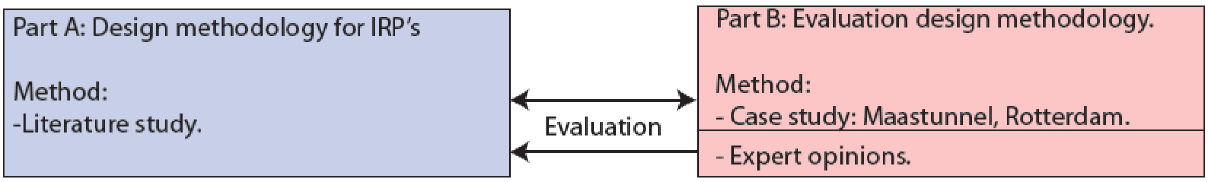

Figure 1 Relation between part A & B of this Masters' thesis.

1.7.1. Part A (Literature study)

Chapter 2-5 are part of a literature study to establish a methodology on how to design MM strategies for IRP's in urban regions (chapter 6). Chapter 2-4 analyse the content. These chapters analyse what should be included in the different steps of the process. Chapter 5 explores the process design of this methodology and the different essential design steps and deliverables. Chapter 6 concludes part A, with a design methodology for MM strategies for IRP's, combining the results of chapter 2-5.

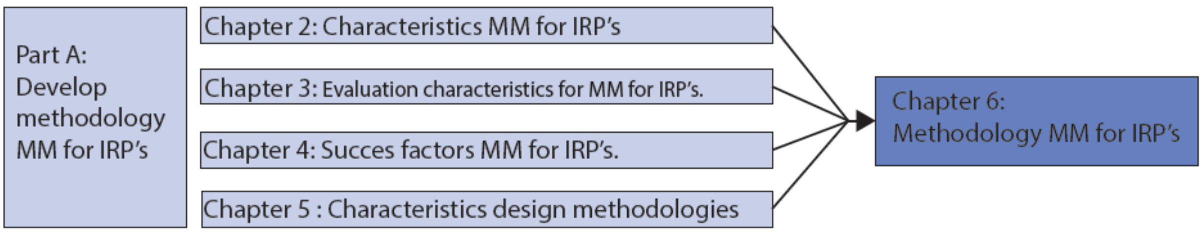

Figure 2 Chapters of part A, Development of a design methodology for MM strategies in IRP's.

- Chapter 2 analyses the characteristics of mobility management measures and strategies in relation with infrastructure renovation projects.
- Chapter 3 analyses the important evaluation characteristics when designing a MM strategy for IRP's.
- Chapter 4 analyses the success factors of mobility management and the characteristics determining these success factors.
- In chapter 5, existing design methods are analysed to determine the essential design characteristics of policy instruments.

- In chapter 6 is a design methodology for MM strategies for IRP's is developed.

1.7.2. Part B (case study and expert opinions)

Part B is used to test and evaluate the design methodology for MM strategies for IRP's developed in part A. A case study and an expert panel are used to perform this evaluation.

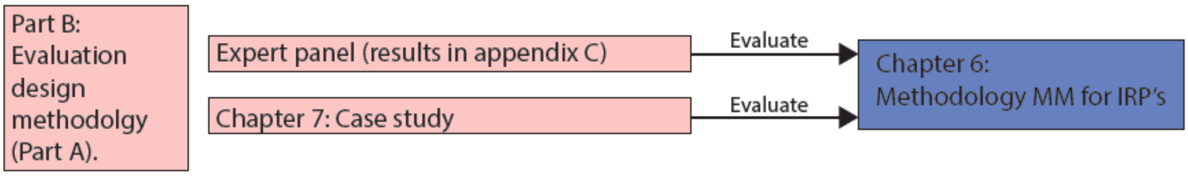

Figure 3 Chapters of part B, case study Maastunnel and expert opinions.

Case study

Chapter 7 contains the case study. The renovation of The Maastunnel in Rotterdam is used as case, because the renovation of this link will have a significant impact on the transportation network of Rotterdam and the social and economic structures. The different stages and phases of the design methodology are run through to analyse the sequence and completeness of the process. The deliverables are tested on relevance and completeness.

Case study research is a research strategy that can be defined as: *'An empirical inquiry that investigates a phenomenon within its real-life context.* (Yin, 2014).' *"Case studies are analyses of persons, events, decisions, periods, projects, policies, institutions, or other systems that are studied holistically by one or more methods. The case that is the subject of the inquiry will be an instance of a class of phenomena that provides an analytical frame — an object — within which the study is conducted and which the case illuminates and explicates* (Thomas, 2011)."

As mentioned by Thomas (2011), the case, provides an analytical frame, to further analyse specific aspects of a research. In this case, the functioning and applicability of the developed design methodology. The design methodology developed in this thesis, should be able to be successfully applied in a real-life context (Yin, 2014), where a MM strategy is demanded to mitigate network problems. This relation between theory (developed methodology) and practice (real life context: The renovation of The Maastunnel) is researched with the case study.

Expert panel

The expert panel is used to evaluate the methodology from a professional perspective. *'Expert Judgment is qualitative review, opinion, and advice from experts on the subject being evaluated, based on objective criteria. Expert judgment is a fast-to-apply, well-known, widely accepted, and versatile evaluation method that can be used to answer a variety of questions throughout the program performance cycle, as well as in other applications.'* (Ruegg, 2007).

The characteristics of quickly getting a widely accepted versatile opinion on the subject, the design methodology, improves the value and credibility of the research.

The focus group session is held on June 24, 2015. Different experts of The Maastunnel renovation project were part of the panel. The participating experts are summarized in table 3.

Table 3 Members expert panel.

Function:	Attendee:	Employer:
Project and process manager	Hein Pierhagen	Municipality of Rotterdam
Mobility management policy advisor	Gert-Jan Polhuijs	Municipality of Rotterdam/ De verkeers onderneming
Urban/economic policy advisor	Klaas Bart van den Berg	Municipality of Rotterdam
Transport policy advisor	Kristiaan Ieurs	Municipality of Rotterdam
Traffic planner/designer	Dennis Scherpenberg	Municipality of Rotterdam
Traffic managment advisor	Robert Kooijman	Municipality of Rotterdam

Different elements are discussed during the focus group session. The goal was to get input about the quality of the different aspects of the design methodology for MM strategies for IRP's and the relation with practice. The conclusions of the different chapters 2-6 are presented and discussed. The following elements are discussed during the session:

- Specific project characteristics of infrastructure renovation projects and the relation with mobility management (chapter 2).
- The possibilities of different kind of mobility management measures (chapter 2).
- The characteristics and success factors influencing the success of mobility management (chapter 4).
- The evaluation criteria (chapter 3).
- The combination of these aspects in a design methodology (chapter 6).

The main findings are incorporated in the design methodology. The results are summarised in annex C.

2. Mobility management for infrastructure renovation projects

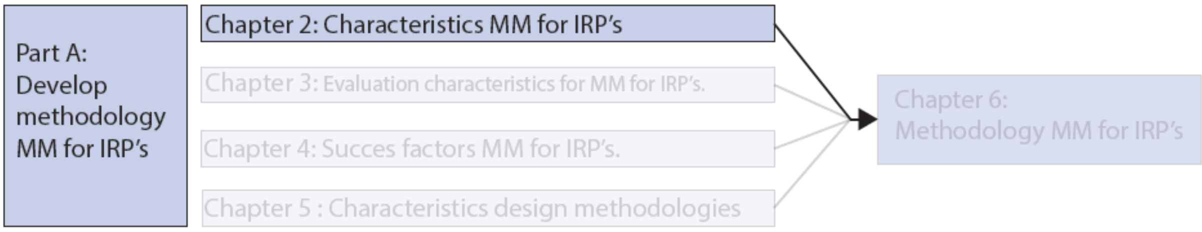

Figure 4 Position chapter 2 in literature review.

This chapter analysis the concept of mobility management. First a definition of MM strategies for infrastructure renovation projects is given. Based on this definition, the types of measures considered as mobility management are defined (section 2.1). Mobility management aims to change travel behaviour. The relation between the different choices made related to travel behaviour are analysed in section 2.2. The trip choice model explains the different decision steps made to derive travel behaviour. Then, the goals of MM strategies for IRP's are distinguished from general goals for MM strategies and criteria are defined to evaluate the goals set for a specific project during the process. Section 2.3 categorises the MM measures applicable for IRP's according to the steps in the trip choice process, the type of policy instrument and whether measures are considered to be push or pull measures. Finally, section 2.4 elaborates on literature studies and project reviews of the effects of MM measures. This results in a short list of potentially effective MM measures for IRP's. Section 2.5 describes the conclusions of this chapter.

2.1. Definition Mobility Management for infrastructure renovation projects

First different definitions of mobility management are analysed to determine the best possible definition for mobility management used in this thesis. After this, the specific characteristics of infrastructure renovation projects will be analysed to distinguish MM for IRP's.

Definition mobility management.

Different definitions for mobility management have been given in literature. All authors emphasis the essence of this type of transport policy to change travel behaviour, e.g. (Taylor, Nozick, & Meyburg, 1997; Litman, Potential Transportation Demand Management Strategies, 1999; Eriksson, Garvill, & Nordlund, 2006). Originally, the goal was to reduce private car use in order to solve congestion on overcrowded roads (Meyer, 1999). Nowadays, MM is used for different reasons, always with the purpose to increase the efficiency of the transportation system and/or the quality of the environment in some way (Broaddus, Litman, & Menon, 2009). Looking at the different definitions found in literature, two definitions in particular combine all essential characteristics:

1. 'Mobility management is any action or set of actions aimed at influencing people's travel behaviour in such a way that alternative mobility options are presented and/or congestion is reduced (Meyer, 1997).'
2. It can refer to a broad variety of strategies aimed at distributing demand more efficiently over all available modes, times and routes on a specific transportation system (Fijalkowski, McCoy, & Lyons, 2013).

These two definitions are not perfect. With regard to Meyer's definition:

- Not every mobility management strategy 'presents alternative mobility options'. Some strategies increase or decrease the attractiveness of existing mobility options, without presenting alternatives, for example: pricing policies. Pricing policies do not provide alternative mobility options. Pricing policies increase or decrease the cost component of existing mobility options, resulting in a higher or lower attractiveness for specific modes, routes or departure time.
- The goal of mobility management is not always 'to reduce congestion'. An example of another goal is improving air quality (Hatzopoulou, Hao, & Miller, 2011)
- The aspect of influencing people's travel behaviour is essential. The essence of MM is to change travel behaviour. Every policy measure categorised as mobility management thrives to affect the transportation system by changing travel behaviour.

With regard to the definition of Fijalkowski, McCoy, & Lyons (2013):

- The use of 'distributing demand' is important to differentiate MM measures from other type of transport measures. MM aims to influence the demand side of the transportation system. Measures influencing the supply side are never part of mobility management measures or strategies.
- The use of 'more efficiently' is also vital. MM can serve several goals. In the end every goal is related to the purpose to increase the efficiency of the transportation system in a certain way, either by increasing the accessibility, the liveability or equity (see table 18, section 3.3).
- 'Over all available modes, times and routes' is not defined incorrect. But it is not complete. MM measures or strategies can impact anywhere in the trip choice decision mechanism. Both destination choice (referring to where to perform the activity) and trip choice (referring to whether to make a trip or not) should be included.

Combining the essential characteristics of mobility management, results in the following definition:

‘Mobility management refers to a broad variety of strategies aimed at influencing people’s travel behaviour to distribute demand more efficiently within the transportation.’

Position Mobility management in the field of transport policy: scope and characteristics.

The definition above differentiates mobility management from other type of transport policies. Table 4 illustrates the different types of existing transport measures (Rijkswaterstaat, Handreiking MIRT Verkenning, 2010a). The different type of transport policies can be divided in measures influencing travel demand (solution 1-4) and measures influencing the travel supply (solution 5-7).

This typology of transport measures specifically distinguishes ‘mobility management’ as a separate type of transport policy, different from spatial developments, pricing policies and PT improvements. This category contains measures like teleworking/shopping and awareness campaigns. In this thesis, all policy instruments influencing the demand side of the transportation system, are considered to be part of mobility management strategies. A classification of different categories of mobility management is given in section 2.3.2, to provide more structure and a better overview of the different available alternatives.

Mobility management can be divided in land use related measures and transport related measures Land use related measures influence the accessibility of the land use system. The spatial distribution, quality and amount of opportunities for different activities/trip purposes are influenced with this type of policy instrument. Transport related measures influence the quality, prices and level of service of the transportation system (Geurs & Van Wee, 2004).

Table 4 Solutions to match demand and supply of the transportation system (Rijkswaterstaat, Handreiking MIRT Verkenning, 2010a).

	Transport policy solutions types	Land use related or transport related.	Influencing demand side or supply side
1.	Spatial development	Mobility management *Land use related*	Demand
2.	Pricing policies	Mobility management *Transport related*	
3.	Mobility management (non-pricing or PT related)		
4.	Improvements in PT service networks and operations		
5.	Traffic control		Supply
6.	Improving existing infrastructure		
7.	New Infrastructure		

Specific demands MM strategies for IRP’s.

Certain characteristics influence the scope of mobility management strategies for infrastructure renovation projects. There are two type of MM strategies according to Meyer (1999). One type aims to change behaviour structurally. These ‘long term strategies’ are part of urban, regional or national spatial development programs. In these projects it is essential to develop a sustainable strategy supported by society to achieve a structural change in travel behaviour. The other type of MM strategies aims to mitigate short term problems. These ‘short term mitigation strategies’ perfectly fit the characteristics of infrastructure renovation projects. Four main characteristics can be related to these short term mitigation strategies for IRP’s (table 5).

Table 5 Specific demands MM strategies for IRP's.

	Demands
1.	Temporary effect
2.	Short implementation time
3.	Short Incubation time
4.	High level of effectiveness

First of all, the level of impact of MM strategies for IRP's needs to be high. In contrary to long term MM strategies, where policy makers look at opportunities and future threats and weaknesses, the need for short term mitigation demands immediate results caused by a direct threat. This justifies the right to implement 'heavier' measures, which guarantee the functioning of the transportation system on the short run, causing potentially more social resistance.

Not all renovation projects are pre-planned. Unforeseen damage or change in law and regulation can demand the need for MM strategies, applicable within a short time span.

This lead to the third demand, a short incubation time. After MM strategies are implemented, the effect on the transport network need to be visible as soon as possible, to mitigate network problems caused by the renovation project.

Finally, the effects of MM strategies for IPR's do not need to be structural. Merely a temporary effect is demanded. Infrastructure renovation projects cause a temporary decrease of the capacity of the transport network, leading to a mismatch between demand and supply. When the renovation works are completed, the original capacity level is restored, and the need for a lower demand in the transportation system due to the IRP is not existing anymore.

Definition MM strategy for IRP's

The specific demands for MM strategies for IRP's change the scope of these MM strategies. The main goal is to mitigate short term network problems, affecting the accessibility, economy and social structures of cities. Incorporating these demands in the general definition for mobility management defined in section 2.1, results in the following definition for mobility management strategies applied during infrastructure renovation projects:

*'Mobility management for IRP's refers to a broad variety of quickly implementable strategies aimed at **temporary** influencing people's travel behaviour to **directly** distribute demand more efficiently **to protect** the transportation system.*

The temporary characteristic combined with the demand for a relative quick incubation and implementation time of MM strategies for IRP's demands 'transport related' mobility measures (solution 2-4, table 4). The incubation time of 'land use related' MM measures will be insufficient for IRP's. It can take up to decades before the effects of land use measures are visible. This eliminates the effectiveness. A second argument versus land use related measures, is the time before the benefits are visible. Selecting MM strategies, which can be defended by directly observable benefits for economic and social urban structures, can be decisive in the political decision making process. From the transport policies enumerated in table 4, three solution types are suitable for MM strategies for IRP's (table 6). These three transport related types of MM measures, all contain measures which fulfil the specific demands for MM strategies for IRP's.

Table 6 Transport solutions considered as policy instruments within the scope of MM strategies for IRP's (Rijkswaterstaat, 2010a)

	Solutions	Land use/transport
2.	Pricing policies	Transport related mobility management measures.
3.	Mobility management (non-pricing or PT related)	
4.	Improvements in PT service networks and operations	

2.2. Trip choice process

The definition of MM for IRP's emphasizes the fact that these kind of measures aim to influence travel behaviour. Travel behaviour is caused by the need to perform activities, resulting in trips. This section will analyse the trip choice process, explaining how travel behaviour is derived.

There are four stages during the trip choice process (Bogers, 2009).

- First there is the activity choice. The process starts when a potential traveller decides to perform an activity and decides where this activity will be performed.
- After this, there is the mode choice. During this stage, the traveller decides what kind of mode he or she will use.
- This is followed by choosing the time period. The period of day and the time of departure are chosen during this stage.
- Finally, a route is selected to arrive at the chosen location to perform the activity.

This process is not per definition sequential. Steps can be performed simultaneously or in a different order (Wong, Wu, Yang, & Lam, 2004). Also, later decisions can influence previous decisions. In transport modelling these four decision stages of Bogers (2009) are related to five modelling steps from the transportation planning model (figure 5). To simulate the activity choice, a trip generation and trip distribution step is performed. For the mode choice, a trip mode choice model is used. For the departure time, another step is included in the model (McNally, 2008). And finally the route choice assigns the trips to the network. The arrow from route choice back to trip generation in figure 5, indicating a restart of the trip choice process, shows that every step in the decision process can influence the other steps of the process. An individual can, for example, determine not to perform the preferred activity, or to perform the activity at a different location, based on route choice information.

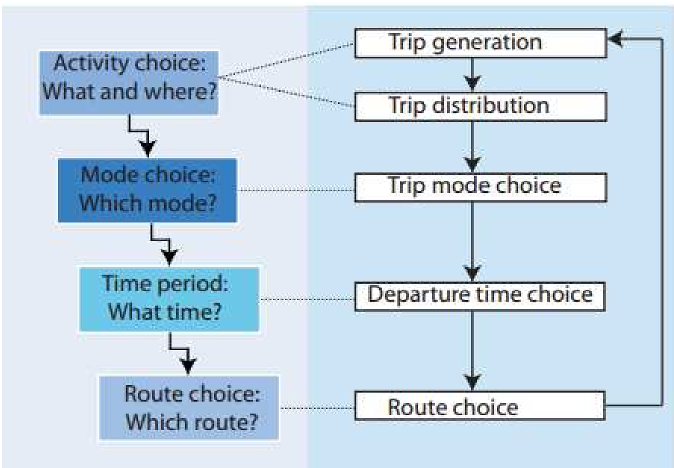

Figure 5 Four stages trip choice model (Bogers, 2009) and related five step model.

These decisions can be linked to three markets (figure 6).The decisions to perform an activity and where to perform an activity are made on the travel market. Also an initial decision is made on when to perform the activity; which (part of the) day. The travel market is formed by the needs of society to perform activities: the demand side. And by the land use patterns, determining where activities can be performed: the supply side. The accessibility of the travel market is formed by two components (Kwan, Murray, O'Kelly, & Tiefelsdorf, 2003): A spatial component: where are the locations for the different activities? And a temporal component: When are the activities available/accessible? The result of this market is the demand for transportation.

After the activity and location choice are made, the mode choice comes up. This is facilitated by the transport market. This market balances persons (demand) with transport modes/vehicles and services (supply). To perform activities people need to travel, and therefore they need modes of transportation and in some cases transport services (for example for the use and operations of public transportation). Influenced by the transport services the time period choice is made, this relates to the departure time choice.

For the functioning of the transport market, there is the need for infrastructure. This is organised at the traffic market. This market matches the demand of vehicles with the supply of infrastructure. On this market the decisions regarding route choice are made. The traffic market also influences the departure time choice. The traffic market determines the quality of the transport network, which influences the travel time. The travel time is of influence on the departure time choice, because people want to perform certain activities at certain moments.

These three markets together facilitate the demand and supply of the transportation system. With the demand of society to perform activities on one side, starting the trip choice process, and the supply of transportation by the transport and traffic market on the other side, answering to the demands of derived on the travel market. Mobility management, as defined in section 2.1, mainly impacts the transport market. Regarding MM measures influencing the travel market, only measures aimed at eliminating trips are part of the scope. Other measures influencing this market, and the trip generation and trip distribution, are land use measures, which are excluded from the scope. Also MM measures influencing the traffic market exist, but these are scarce. Mainly measures that aim to reward or provide penalties for the use of certain links, influence the departure time and route choice.

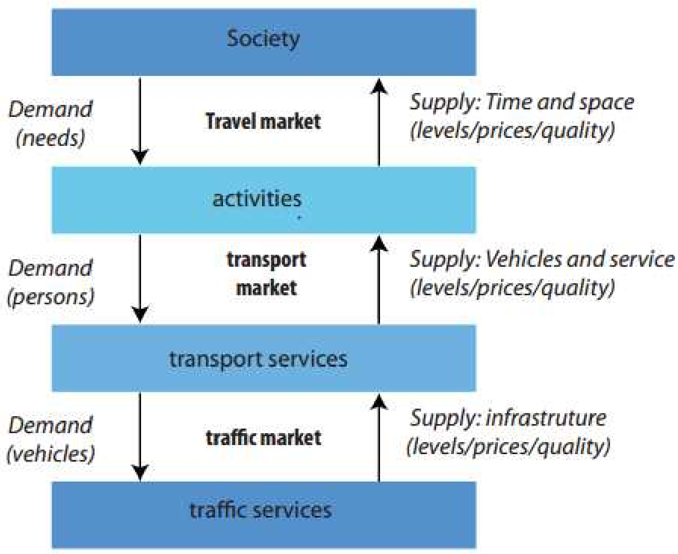

Figure 6 Layer model of the transportation system, including the travel market, based on Van de Riet & Egeter (1998) and Schoemaker, Koolstra, & Bovy (1999).

2.3. Mobility Management measures for infrastructure renovation projects.

This section analysis the different types of mobility management and their impacts. First, ways to categorise mobility management are analysed. Categorizing the measures helps by understanding the similarities and differences between the different measures and it creates overview of the process of selecting the best measures. After the categorisation method is defined, the MM measures with a high potential to solve problems during IRP's are extracted and sorted according to the different categories.

2.3.1. Categorisation methods

First the different categorisation methods found in literature are analysed and compared. This analysis is used to determine the most suitable way of categorising MM measures, with the purpose to provide insight in the differences and similarities of the different possible measures.

Different authors have defined categorisation methods to structure the large number of existing mobility management measures (Annex A). These measures can be structured according to three principals.

1. The first method is based on the decision stage during the trip choice process.
    a. For the step mode choice a sub-categorisation by mode is established.
2. The second typology is based on type of policy instrument.
3. The third method makes a distinction between push and pull measures.

Categorisation by step in the decision in the trip choice model.

The first method is the method of Ferguson (1990). This method is based on where measures impact the decision making process of the users in the transportation system (as discussed in section 2.2). Ferguson (1990) mentions all five categories (table 7) and links them to the four/five step transportation model. Meyer (1999), Garling & Schuitema (2007), Tanaboriboon (1992) and Rosenbloom (1978) all mention similar categories. Rosenbloom (1978) does not mention trip distribution. Therefore, this categorisation method is not complete. And the categories of Meyer (1999), Garling & Schuitema (2007), and Tanaboriboon (1992) are not adequately named. Leaving several MM measures uncategorised.

Table 7 categorisation by stage in 4/5 step model based on Ferguson (1990)

	Stage in 4/5 step model
1	Trip generation
2	Trip distribution
3	Mode choice
4	Departure time choice
5	Route selection

The different measures for mode choice can be subdivided according to the type of mode. Car, bicycle pedestrian and public transport.

Categorisation by type of policy instrument

Besides the categorisation by decision in the trip choice model, Rosenbloom (1978) uses a categorisation by type of policy instrument. This method is also used by Taylor, Nozick, & Meyburg (1997). This method is based on how measures impact the users of the transportation system. It divides measures by the type of governmental instrument. Combining the essential characteristics of these two methods resutls in five different categories (table 8).

Table 8 Types of MM measures sorted according to policy instrument

	MM measures: type of policy instrument
1.	Information/ communication
2.	Social
3.	economic
4.	legal
5.	physical

Rosenbloom (1978) does not cover the category 'information/communication'. But it is an essential category for succesfull MM strategies. This is emphasised by Garling and Schuitema (2007). It is the base of awareness. The method of Taylor, Nozick, & Meyburg (1997) does not include 'social measures'. This type of measures is from a govermental perspective very interesting. As no direct policy interference is necessary. Goverments can serve merely as facilitator, creating awareness of the problem and indicating how people can contribute themselves (An example of a measure is the staggered work week, which aims to spread demand more even over time). The category 'socio-economic' of Rosenbloom exist of the categories: 'economic' and 'legal meaures' of Taylor, Nozick, & Meyburg (1997). These types of measures change the relative attractiveness of certain mobility options. Economic measures respect the freedom of choice, where legal measures do not. Rosenblooms 'socio-technical' measures refer only to teleworking/shopping or the performance of other types of activities at home. In essence this type of measure can be considered as social measures too, if no direct policy intervention is needed. Otherwise, if financial in- or decentives are provided, this mobility management measure can be categorised as economic measure. Finally, the categories 'technical' of Rosenbloom and 'physical' of Taylor et al. are relative similair. Both refer to network services or network quality. The essence of this type of measures is to generate a change in the absolute attractiveness of certain mobility options.

Categorisation by pull/push measures

Push measures aim to reduce the attractiveness of car use, while pull measures aim to improve the relative attractiveness of alternative ways to fulfil the trip purpose causing the need to travel (Steg & Vlek, 1997). This distinction is important as research shows that push measure on average influence travel demand to a larger extent, but can cause greater social resistance (Espino, De Ortuzar, & Roman, 2007). Loukopoulos (2005) underlines this, by stating that transport policy instruments have got an increased level of effectiveness, but encounter higher levels of public resistance when measures become more coercive.

2.3.2. Categorisation methods for MM strategies for IRP's.

The two categorisation typologies by policy instrument and stage in the 4/5 step model deducted from literature can be combined in a two dimensional scheme (table 9), classifying MM measures both by type of policy instrument and by decision stage of the trip choice process.

The classification by decision stage in the trip choice process is a useful categorisation method for MM strategies for infrastructure renovation projects. The potential effectiveness of measures regarding improving the efficiency of the transportation system/ solving congestion is researched by comparing possible measures with the characteristics influencing the effectiveness of the measures for the specific case. The categorisation by steps in the four/five step model matches the trip choice decision model (Section 2.2), which is essential in understanding how travel behaviour can be influenced and useful when testing the measures in transport models. Using this methodology creates a clear overview of the opportunities of MM within the transportation system of the specific infrastructure renovation project. There are also measures benefiting MM in general. This category is called general improvements.

The classification by type of policy instrument explains how governments can influence the transportation system. Measures which demand less governmental influence are preferred. The type of policy instrument strongly influences the public acceptability (Schlag & Schade, Public Acceptability of Traffic Demand Management in Europe, 2000). For example, road pricing is generally seen as a highly effective instrument to reduce congestion and related problems. The low public acceptability is, however one of the biggest problems for the implementation of these type of measures (Haoa, Sunb, & Lu, 2013). Other measures have a positive effect on the public acceptability of MM strategies. For example, as said before communication and information supply (Garling & Schuitema, 2007). Understanding this relation between effectiveness and the public opinion is crucial when developing a MM strategy. Communication and marketing strategies increase the effectiveness of MM strategies, but should be combined with other policy instruments (Loukopoulos, Jakobsson, Garling, Schneider, & Fujii, 2003).

Finally, the different measures will be divided in push and pull measures (Garling & Schuitema, 2007). Where push measures attain higher effectiveness rates, but in general lower levels of public acceptance, categorizing measures according to pull and push measures helps by preliminary indicating the level of effectiveness and the public opinion towards different alternatives. Push measures will be shown in bold and underscored to illustrate the difference between push and pull measures.

Table 9 Categorisation method MM strategies for IRP's.

	info/ communication	social	economic	legal	physical
trip generation	Pull measures 1				
Trip distribution			**<u>Push measures 1</u>**		
mode choice					
departure time choice					
route selection					
general improvemetns					

2.3.3. Possible measures for IRP's

Different studies report about available measures and strategies when implementing mobility management. Annex 0 shows a long list of these measures. Annex B already explains why certain measures are not applicable for MM strategies for IRP's. The potentially effective measures are divided according to the categorisation framework based on, push or pull measure, policy instrument and decision in the trip choice model (table 10), where the mode choice measures are specified per mode. Some measures are included in different categories, because these measures can be used to influence different steps of the trip choice model. An example of this is the measure 'pricing policies'. Pricing policies can be used to make travelling on specific times less attractive (departure time choice). It can be used to make travelling on specific links less attractive (route choice). And it can be used to make travelling by car in general less attractive (mode choice).

Measures purely aimed at providing information are categorised as info/communication. A traveller information system specifically tries to influence mode choice. The other measures categorised as info/communication try to influence the overall trip choice process. MM measures which do not demand government involvement, besides information and communication are categorised as social measures. Measures directly providing incentives or decentives are categorised as economic measures. Measures changes travel behaviour changed with restrictions are categorised as legal measures and finally, measures changing the quality of the transportation system are categorised as technical/physical measures. For every type of policy instrument different measures exist influencing different steps of the trip choice process. The decision measures influence in the trip choice decision process determine where measures are located on the Y-axe of table 10.

Decision in the trip choice process		Policy instrument: info/ communication	social	economic	legal	technical/ physical
general improvemetns		• Info campaign • MM marketing • Tourist transport management				
trip generation			• Teleshopping • Teleworking	• **Road pricing** • 'Stay home subsidies' (for example: subsidies for home based work environments (computers))	• **Drive restriction (for example: even/uneven number plate rule)**	
Trip distribution			• Use alternative facilities	• Incentives use of facilities		
mode choice	**pedestrian**				• **Pedestrian zone**	• Increase sidewalk safety
mode choice	**bicycle**			• Bicycle subsidies	• **bicycle zone**	• Parking facilities • Racks on buses • Infrastructure safety • Public bicycle system
mode choice	**PT**			• Employee transit/trial pass • Subsidies • Shuttle services • Extended area services		• Vehicle improvements • HOV lanes • Priority systems
mode choice	**car**		• carpool • Car sharing	• **Road pricing** • **Parking pricing** • Parking cash out	• Parking supply management	
mode choice	**multi modal**	• Traveller info system				• Park+ride
departure time choice			• **Staggered/ shortened work week** • Flexible work hours	• Peak hour avoidance rewarding • **Decentives for traveling during peak hour/ congestion pricing**		
route selection				• **Road pricing**		

Table 10 MM measures suitable for IRP's. Organised according to the decision moment in the in the trip choice process and the type of policy instrument. (Push measures are shown in bold and underscored.)

2.4. Effects mobility management measures

Essential in the case of MM strategies for IRP's is the temporary need and high urgency for transport policy. These aspects need to be considered when evaluating MM measures during the design process. The combination of temporary measures with a high need for direct effects increases the importance of the primary goal: reduce/resolve congestion, compared to other type of MM strategies. Where a more balanced sustainable approach is desirable.

The impacts of different MM measures on the transportation system differs significantly, but is often relatively small. The cumulative sum of different measures, though, can affect the transportation system to a larger extend, causing a significant increase in efficiency. When the right mixture of measures is applied, mobility management is an effective policy instrument in achieving the goals set to improve the efficiency of the transportation system by increasing accessibility, liveability and equity (Litman, Potential Transportation Demand Management Strategies, 1999). Several studies are analysed to determine a short list of potentially effective measures.

Effectiveness of mobility management general findings.

Current research on the effects of MM mainly focusses on commuters. A recent evaluation, conducted in 2010, of the *taskforce mobility management*, an organisation founded to bring governments and employers together to participate in mobility management programs, shows that potentially 9-12% of commuters change travel behaviour because of mobility management strategies (Savelberg & Korteweg, 2011). This study focusses mainly on highways, but indicates that a significant amount of travellers can be affected by a strategy containing the right measures. These number can be achieved when local governments and companies work together with shared interests in increasing efficiency of the transportation system. Other trip purposes have not been subject to much research. Known is, that non-commuters in general are more willing to change travel behaviour. Commuters are more sensitive for departure time alternatives, while non- commuters are more sensitive for alternative transport modes (Savelberg & Korteweg , 2011).

Push measures are more effective, compared to pull measures. An exception is peak avoidance rewarding. Though it is questionable if the effectiveness of peak avoidance rewarding is as high as the effectiveness of push measures, the effectiveness of this specific type of pull measures is significant. A positive characteristic of peak avoidance rewarding is the fact that rewarding is more accepted, than punishing (Bliemer & Van Amelsfort, 2010). Rewarding, on the other hand, involves extra costs, which is from a general social perspective a negative effect.

IRP's influencing central business districts.

Rosenbloom (1978) ranks the effectiveness of mobility management in reducing congestion for different type of infrastructure segments in relation with the urban context. The ranking is merely an order. Rosenbloom does not say anyting about the quantified effects of measures. Transit treatments and pricing techniques are considerd to be the most effective. Subtitutes for travel and prearranged ride sharing are considerd to be the least effective (table 11). If the renovation project affects the central business district and limited alternative routes exist, access restrictions are considerd to be very effective.

Table 11 Ranking of measures for IRP's (Rosenbloom, 1978).

	Major problem areas (CBD = central business district)	**Special problem areas**
measures	CBD's of large cities	Renovation link has got limited options for alternative routes.
Work hour changes	4	4
Pricing techniques	2	5
Access restrictions	3	1
Prearranged ride sharing	5	3
Substitutes for travel	6	6
Transit treatments	1	2
Ranking: 1 =most effective,6 = least effective		

Most effective MM measures and relation with other aspects in the Dutch context.

Savelberg & Korteweg (2011) discuss a broad scala of different MM meassres. The measures summerized in table 12 are potentially the most effective. From these measures fiscal discounts are difficult to implement for MM measures for IRP's, because of two reasons. Decissions about fiscal discounts are made on a national level, where the design and implementation of MM stategies for IRP's will be made on urban/regional levels. And, decision-making and implementation of these measures takes a long time, where MM for IRP's demands short term and quick implementation.

Parking pricing has proven to be an effective measures. Research of the institutes PBL & CE (2010) mention an elasticity of parking pricing between -0.2 and -0.3 on the short term. This type of measure is not considered to be popular, because it affects local shops and the level of public acceptance is very low.

Improving mulitmodal transfer nodes and bicycle parking at stations can contribute to a highger attractiveness of PT for short distances (Savelberg & Korteweg, 2011). Peak avoidance rewarding is in The Netherlands an increasingly used tool to reduce private car use during peak periods. The effects are significant, reducing congestion during peak hours (Bliemer , Dicke-Ogenia, & Ettema, 2009).

Table 12 Effectiveness of MM measures on different aspects (Savelberg & Korteweg, 2011).

	Measure	Congestion reduction effect	Liveability	Governmental costs	Feasibility
1.	Peak avoidance rewarding	+	+	-	+
2.	Parking pricing	++	+	+	-
3.	Fiscal discount teleworking, carpooling, PT and bicycle.	++	+	-	+
4.	Multimodal transfer node	+	+	-	+
5.	Investment in bicycle parking stations	+	+	-	+
Congestion effects: **++ = strong positive effect,+ = positive effect, O = neutral effect**					
Liveability: **+ = positive, O = neutral, - = negative**					
Feasibility (public opinion): **+ = positive, O = neutral, - = negative**					
Governmental benefits: **+ = benefits , O = neutral, - = costs, -- = high costs**					

Effective and non-effective under specific conditions.

Henstra et al., (2005) also discusses several MM measures. The most effective measures found in this report are summarized in table 13. Specific conditions, explaining the effectiveness of different measures in relation with the urban context, are added for certain measures. Henstra et al., (2005) also mentions measures not considered to be effective (table 14). Again parking pricing is mentioned as effective measure. The possibility of temporary parking pricing policies increases the suitability of this measures during IRP's. The report states that a price increase on parking of 10% can lead to a reduction of car use of 3%. These users switch to other modes. Bicycle stimulations are only effective for short distance trips in large urban areas in combination with parking pricing (Olde Kalter, 2007). Teleworking/part time working/ flexible working is considered to be very effective, because these measures eliminate the total amount of trips made. To realise this, collaboration with companies is essential. Collaboration with companies in general is considered to be effective to set up transport management programs and influence large groups of commuters (Savelberg & Korteweg, 2011).

The report supports the fact that park and ride facilities and PT subsidies have little effect. The crosswise price elasticity of car use and PT use is only 0.02. Reducing the price of PT with 10%, leads to a modal shift of approximately 0.2% from car to PT. The potential for short distances is considered to be larger in combination with better transfer quality. Bicycle parking facilities can contribute to the attractiveness of short distance trips using public transport. Park and ride facilities in combination with train transportation only contribute to 0.1% of all trips (AVV, 2002). Even if MM can double this amount, the absolute numbers are negligible.

Table 13 Measures considered to be effective under specific conditions (Henstra, Akkersdijk, pol, Pieper, & Voerman, 2005).

	Effective	Conditions
1.	Car sharing	Good PT, high parking pressure
2.	Carpool	Bad PT system
3.	Bicycle stimulation	Short distance <7,5km
4.	Parking pricing	Only for commuters
5.	Teleworking/part time work/ flexible work hours	Only applicable for commuters
6.	Multimodal information	In combination with other measures
7.	Transport management by companies	Accessibility /parking problems

Table 14 Measures considered to be ineffective (Henstra, Akkersdijk, pol, Pieper, & Voerman, 2005).

	Non effective
1.	Public bicycle system
2.	Park and ride
3.	PT subsidies
4.	Shuttle services

2.5. Conclusions:

Characteristics mobility management

Mobility management for IRP's can be distinguished from mobility management in general, because an infrastructure renovation projects entails four specific demands:

1. Temporary effect
2. Short implementation time
3. Short incubation time
4. High level of effectiveness

The need to protect the transportation system from temporary failing compared to the opportunities to improve the efficiency on the long term of other type of MM strategies, justifies a more extreme type of MM strategies with more impacts on the city. This results in the following definition for MM strategies for IRP's:

*'Mobility management for IRP's refers to a broad variety of quickly implementable strategies aimed at **temporary** influencing people's travel behaviour to **directly** distribute demand more efficiently **to protect** the transportation system.*

Policy measures aimed at influencing the supply side of the transportation system and land use related transport policy are not considered to be part of this definition. Supply side related transport policy is not part of mobility management in general. Due to the need for a short implementation and incubation time of MM measures for IRP's, land use related measures are not suitable, as land use measures will not realise the necessary effects in time. The implementation of land use MM strategies can take up to years, and the time before effects are visible can take up to decades.

Effects of MM measures

Push measures are considered to be more effective than pull measures (Garling & Schuitema, 2007). An exception is, arguably, peak avoidance rewarding (Bliemer & Van Amelsfort, 2010). Peak avoidance rewarding generates high number of car trip reductions during peak hour. Push measures have a low level of public acceptability, but the high urgency of network protection of IRP's and the temporary demand can justify the implementation of push measures.

Different pull measures, have a relative low level of effectiveness, but enforce the effectiveness of specific push measures. Adding these measures to the MM strategy can compensate for the low public acceptability of push measures.

Communication and marketing strategies increase the effectiveness of MM strategies, but should be combined with other policy instruments, to become useful (Loukopoulos, Jakobsson, Garling, Schneider, & Fujii, 2003). Collaboration with employers can be included if many commuter trips are performed, as part of MM marketing (Savelberg & Korteweg, 2011).

A MM strategy based on push measures, with additional pull measures, as compensating instruments is advised. A good communication and information plan and stakeholder involvement (employer collaboration) should increase the effectiveness of the strategy (figure 7).

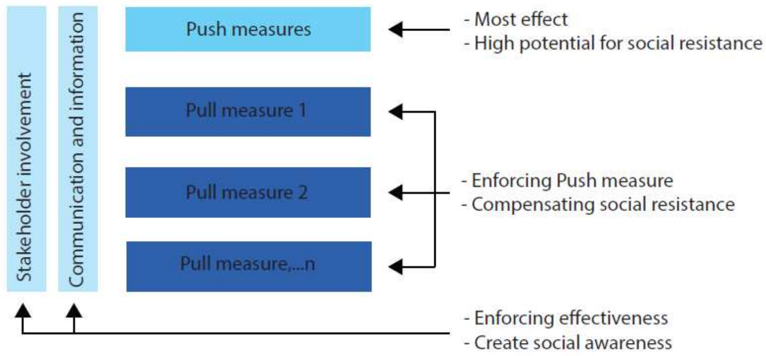

Figure 7 MM strategy elements and purpose.

Table 15 and 16 summarise the measures found in literature with the highest potential. When designing a MM strategy these need to be considered first, unless the project scope (for example, the political viewpoints or the geographical context) indicate other measures. The measures are divided into main measures and additional measures.

Table 15 main MM measures with proven effectiveness. Certain measures are considered to be effective in specific conditions. For these measures, the specific conditions are mentioned.

Main measures	Push/pull	conditions
Access restrictions	Push	Few route alternatives
Parking pricing	Push	
Road pricing	Push	
Peak avoidance rewarding	pull	

Table 16 Additional MM measures with proven effectiveness, and additional contextual conditions for the effectiveness.

Additional measures (all pull)	conditions
Carpool	Bad PT system
Car sharing	High parking pressure and good PT system
Mutimodal/transit treatments	
Bicycle stimulations	For short trips, > 7.5km
Trip generation/departure time choice influenced work schedules	
Transport management by companies	High parking pressures/low accessibly
Discounts PT	In combination with measures decreasing the attractiveness of car trips.

The fact that most of the effects of measures analysed in this section focus on the Dutch market must be noted. Most findings will be general applicable. But cultural and geographic factors may influence the effectiveness of specific measures. For example, cycling is in The Netherlands part of the transportation culture. The geographical context is also perfectly suited for cycling, due to the absence of large height differences. In other countries, the cultural and geographical context might lead to smaller results, when promoting the use of bicycles. In countries where the PT system is relatively undeveloped, compared to the high standards in The Netherlands, PT improvements can be a very effective instrument to reduce private car use. For every situations a critical view on cultural and geographical aspects must be considered.

3. Evaluating mobility management strategies

Figure 8 Position chapter 3 in literature review

This chapter first describes important aspects of the evaluation of MM strategies (section 3.1). After this the most relevant impacts of IRP's are discussed (section 3.2). This list enumerates the most important impacts. For every individual project, the existence of other important aspects need to be researched. The impacts are linked to goals for MM strategies. From these MM strategies, the relevant strategies for infrastructure renovation projects are selected. This is described in section 3.3. Section 3.4 sets out the different criteria related to the goals for MM strategies for IRP's. The chapter is finalised with the conclusions.

3.1. Ways to evaluate MM strategies

'Policy makers approach urban transport issues nowadays in a much broader context. Not just objectives for vehicle performances are set, but comprehensive strategies are developed, defining different goals and analysing a wide range of impacts; benefits and costs' (Litman, 2013). The broad variety of mobility management measures and strategies will all have different impacts on the transport network and the city. These impacts need to be considered, when designing a MM strategy.

The effectiveness and efficiency are considered to be important system performance indicator for a long time (Stopher & Meyburg, 1976). The position and need of stakeholders can be added as third important evaluation indicator (Freeman, 2010).

The effectiveness determines to what extent the strategy fulfils the goals of the project. The goals are set by linking measureable criteria to the essential impacts, the so called key performance indicators (Cekerevac, 2013). These key performance indicators (KPI's) need to be specific, measurable, achievable, realistic and smart (SMART) to be useful for evaluation (Shahin & Mahbod, 2007). The efficiency shows the cost-benefit ratio of measures and strategies, considering different impacts. These impacts need be translated into performance indictors too. All impacts influence certain stakeholders. Identifying the relevant stakeholders and their position and need is important for the success of transport policies (Walter & Scholz, 2006). The way stakeholders are approached helps by creating social acceptance. Therefore stakeholder analysis should be included in the evaluation process. Involving stakeholder needs in the design process for MM strategies will provide more information about the essential impacts for a specific project.

3.2. Impacts of MM measures

Different impacts are related to the implementation of mobility management measures. These impacts can be sorted according to different criteria. Eijgenraam et al., (2000) mention three important criteria.

1. Effects inside municipality/outside municipality (location related).
2. Affected stakeholder.
3. Direct/indirect/external impacts.

Whether impact are visible inside or outside the municipality is important from a governmental perspective. A municipality does not want to invest in transport measures that do not benefit their own city and citizens. The affected stakeholders are important for the implementation of the MM strategies and for a fair distribution of effects. Specifying effects according to direct, indirect and external impacts creates understanding of how costs and benefits are distributed among stakeholders. The monetized impact of indirect effects can be substantial, approaching the same order of magnitude as the direct costs (Hoefsloot & De Pater, 2011).

Direct impacts, are the effects that impact the part of the transportation system, the mobility management measures aim to influence (Schade W. , 2004). Traveller benefits expressed in travel cost savings are in transport policy evaluations in principle the most important direct impacts (Geurs & Van Wee, 2004). Indirect effects are the derivative of to the direct effects. For example, a more efficient road network can lead to better accessibility of economic functions and higher levels of social participation. But it can also lead to higher levels of social accessibility equity (Manaugh & El-Geneidy, 2011). And finally there are external effects. External effects are effects influencing parties not related to the project (Verhoef, 1994). Table 17, illustrates the most important impacts of MM measures.

Table 17 Impacts mobility management based on (Rijkswaterstaat, 2004)

	Direct effects	Indirect effects	External effects
1.	Investment costs	Economic welfare (local GDP)	Noise pollution
2.	Traveller benefits/costs (direct financial compensation/extra costs)	Social welfare (participation)	Air pollution
3.	Network effects (travel time/congestion reduction)	Social welfare (health)	Road safety
4.		Distribution effects (mode specific)	

3.3. Goals used for MM strategies for IPR's.

General goals for MM strategies

The policy instrument mobility management in general can serve several goals. Broaddus et al., (2009) distinguish nine main goals for mobility management. These goals can be linked to three purposes. All three purposes, accessibility, liveability and equity, are related to improving the efficiency of the transportation system. Related to the goals are the impacts as formulated in table 18. The most common goal is to reduce or eliminate congestion. But there are more possibilities. Often a combination of several goals, serving different purposes, is set when a mobility management strategy is developed. This way an integrated approach, creating a higher efficiency can be realised. Defining the goals of the MM strategy is important to be able to define proper criteria and understand the relation between the costs and benefits of the different goals (Litman, 2010). The criteria are necessary to evaluate the developed mobility management strategies.

Table 18 Goals of mobility management (Broaddus, Litman, & Menon, 2009) related to different impacts.

	goal	Purpose	Related impacts
1.	Reduce/resolve congestion	Increase accessibility	Network effects (travel time)
2.	Improve mobility options (compared to car use)	,,	Distribution effects (mode specific)
3.	Reduce parking problems	,,	Distribution effects (mode specific)
4.	Reduce emission	Improve liveability	Air pollution
5.	Increase fitness and health	,,	Social welfare (health) Distribution effects (mode specific)
6.	Increase road safety	,,	Road safety
7.	Reduce noise pollution	,,	Noise pollution
8.	Road cost investment savings	Increase equity	Investment costs
9.	Increase access equity	,,	Economic welfare (local GDP) Social welfare (participation)

Goals relevant for MM strategies for IRP's.

For infrastructure renovation projects not all goals are relevant (the related impacts though should still be considered in the evaluation to assess the overall efficiency). The following goals are relevant to include in mobility management strategies for infrastructure renovation projects:

- The main goal of mobility management during every IRP is primarily to mitigate temporary short term network problems, reduce/resolve congestion, caused by the renovation (Meyer, 1999). If this is not necessary, there is no need to include a MM strategy in the project scope.

- It is possible that associated problems regarding air or noise pollution emerge because of increasing traffic intensities at alternative routes. This can be a reason for governments from different levels to define goals to reduce or limit air and noise pollution. Especially long-term exposure to pollution can cause serious health issues (Van Rooosbroeck, et al., 2008). But also short-term exposure can negatively affect citizens with reduced immunity (Schwartz, 2000). The project duration is decisive in the decision to consider emission goals in MM strategies for IRP's.
- The same reasoning can lead to goals regarding road safety. If the renovation project causes severe safety issues, the need for specific demands regarding the mobility management measures can be determined. Safety is a highly valued aspect by decision makers. They do not want to take any risks regarding the traffic safety of the users of the transportation system. *'Costs of accidents make up an important part of the total external cost of traffic'* (De Blaeij, Florax, & Verhoef, 2003).
- When certain groups of society are more affected by the renovation project, equity reasons can lead to the goal to reduce transportation costs. Equity refers to the distribution of costs and benefits, whether this is conceived to be fair and/or appropriate (Schlag & Teubel, 1997). When a link is closed, the relative extra costs for traveling for certain groups of society can increase. Reallocating transportation costs can be included as goal in these situations, to increase equity.

Goals not relevant for IRP's.

- Improving mobility options is in this type of projects not a goal. For long term strategies it can be a goal, but for short term mitigation problems it is rather a way to reduce/resolve congestion.
- Reducing parking problems is not a goal of mobility management strategies for IRP's. This can also be considered as measure to reduce/resolve congestion, but not as goal.
- Increasing fitness and health is also not a goal of MM strategies for IRP's. Like improving mobility options, it can be a convenient feature of certain MM measures, but not a goal in itself for this type of project.
- Road cost investment savings can be considered as goal of an infrastructure renovation project, but not of the mobility management strategy.

Table 19 Goals suited for MM strategies for IRP's

Primary goal	Secondary goal	No goal IRP's
Reduce/resolve congestion	Reduce emission	Road cost investments savings
	Reduce noise pollution	Improve mobility options
	Increase road safety	Reduce parking problems
	Access Equity	Increase fitness and health

3.4. Criteria for the different goals of MM strategies for IRP's.

Table 19 summarises the goals relevant for MM strategies for IRP's; one primary goal and four secondary goals are defined. Connected to these goals, criteria need to be formulated to evaluate if MM strategy achieve the necessary effects. These criteria can be used to define KPI's for MM strategies for IRP's. For all five goals the relevant criteria will be set out.

Reduce/resolve congestion

To measure congestion, literature distinguishes several types of criteria: volume, demand/capacity ratio, speed, travel time, delay and Level of service (Rao & Rao, 2012).

- Level of service does not provide continuous values and is therefore harder to apply. For this reason it will not be considered.
- If the volume or demand/capacity ratio is used as criteria, the direct effects on network users is not exposed. It indicates whether the specific link is saturated or not, but it does not show to what extent network users are affected. It is also more difficult to accurately define the secondary goals, like reduction in noise and air pollution, when merely volume or demand capacity criteria are used. Using the volume can be useful as additional criteria to determine tot total impact of measures on the transportation system. It provides a clear image of the direct impact of measures.
- Speed (distance/time) related measures are the most useful. When the speed of network users on their routes is known, the travel time/delay can also be distinguished. '*Congestion measurement criteria based on speed can be adopted, because traffic speed is a highly sensitive parameter and directly related to the vehicle operating cost* (Rao & Rao, 2012).' This citation illustrates the possibility to determine not only the effectiveness, but also the efficiency (difference in costs/benefits) of MM measures when speed-related data are available. A change in speed is directly translatable in travel time and delay. These criteria can also be used to measures secondary goals. When the difference in speed of network users on their routes is known, the difference in air and noise pollution can be determined (Höglund & Niittymäki, 1999).

Table 20 Reduce/resolve congestion: Criteria and units.

	criteria		unit
1.	Volume	Reduction of amount of vehicles in system.	Number of vehicles
2.	Speed	The ratio of the average speed during the most congested period p with respect to the maximum speed (Panayotis & Ibanez Rivas, 2012).	Km/h
3.	Delay	The total reduction in delay during period p expressed in minutes per km (Panayotis & Ibanez Rivas, 2012).	Min/km
4.	Travel time	Reduction of total hours travelled in the system (vehicle loss hours).	h

Reduce emissions

Health studies, highlight the negative effects of short-term exposure to emissions (Ministerie van VWS, 2015). The most important emissions regarding health issues are: CO2, NOx, and PM10. For NOx and PM10 there are limits concerning temporary location-based exposure. IRP's can cause temporary increased traffic intensities at specific areas. This can lead to emission levels that exceed set limits. If this happens MM measures can be used to change the demand of the transportation system in a way these limits are not exceeded. For CO2, no location-based temporary limits regarding exposure exists.

Criteria to evaluate the goals of emission reduction can be set for the entire geographical project scope and for specific areas, where the traffic intensity is at a high level, threatening public health and harming the liveability. To measure the impact of emissions, criteria are defined for amounts of produced emissions per defined area (kg/km^2). Limits are often included in national/international law and regulation. Local governments can determine to set higher limits, to increase public health.

Table 21 Reduce emissions: Criteria and units.

	criteria		unit
1.	NOx	Total production per defined area	Kg/km^2
2.	PM10	Total production per defined area	kg/km^2

Reduce noise pollution

Limits are defined for different urban functions. Limits will be more critical for residential areas, than for industrial areas. Also in this case, public health can lead to the decision by local governments to sharpen limits. Goals regarding noise pollution are formulated in decibel (DB) per defined urban function.

Table 22 Reduce noise pollution: Criteria and units.

	criteria		unit
1.	Sound intensity	Total production per defined area and function	DB

Increase road safety

Minimizing road accidents can be part of the goals of MM strategies for IRP's. Road safety is measured using the amount of casualties. This can be translated into monetary units. This is done based on the value of saving a statistical life (VOSL). Using revealed or stated preference surveys, these values can be established.

	criteria		unit
1.	Casualties fatal	Total amount of casualties	No.
2.	Casualties non-fatal	Total amount of casualties	No.

Increase access equity

The quality of the transportation system affects people's economic and social opportunities. The effects of infrastructure renovation projects can lead to increased transportation access inequity. This can be a reason for governments to set goals to reduce transportation costs to increase equity and enable groups of society, considered to be underprivileged, to access transportation. Mobility management strategies can contribute to a higher level of equity. There are different ways to define equity related to accessibility (Thomopoulos, Grant-Muller , & Tight, 2009). Equity can be based on income and social class or it can be based on need and ability (Litman, 2015). From a social point of view, vertical equity is the most important dimensions (Though the definition of equity is strongly dependant of political viewpoints). This relates to the welfare distribution over different income groups (Viegas, 2001).

Different criteria can be used to measure the change in equity caused by MM measures. A simple way of defining criteria regarding equity is to set values for the difference in travel costs or travel time. This can be done by comparing income groups. The absolute or relative increase of travel time/costs can be used to analyse if specific groups of society are disproportional affected. Where the IRP can cause costs of traveling to rise, either directly by higher prizes or indirect by increased travel times, criteria can be set to reduce the direct price of transportation (for example by lowering the price of public transportation), or to reducing the travel time (for example by increasing frequencies of public transport services). Areas, housing citizens with lower incomes, should benefit from these measures.

A more complex way to define the level of access equity is by using the Gini index (Gini, 1912). This illustrates the total distribution of effects regarding the transportation system over the different income groups. Using a combination of welfare distribution and the change in level of accessibility (travel time/costs) for different functions, this Gini-index can show the change in equity caused by the MM measures. Also the possibility of social exclusion can be used as important indicator to measure equity (Van Wee & Geurs, 2011). While this is difficult to measure, the Gini index is a clearer method, providing quantified information about distribution effects in relation to access equity. Data are needed regarding level of income in different areas and the travel times/costs from these areas to different urban functions.

Table 23 Reduce transportation costs (increase access equity): Criteria and units.

	criteria		unit
1.	Price	Average price of transportation	€/km.
2.	Travel time	Average travel time	Min.
3.	Relative change in travel costs	Relative and/or absolute change in travel costs of different income groups of society compared to society as a whole.	Gini-index, based on relation travel costs/income ratio.

3.5. Conclusions:

For the evaluation of MM strategies for IRP's different impacts need to be evaluated. The combined evaluation of these impacts, translated into performance indicators illustrates the efficiency. The different impacts can be translated into project goals. The primary goal of MM strategies for IRP's is to solve/reduce congestion. Besides this, secondary goals can be formulated related to road safety, noise/air pollution and equity. For the different goals, selected for a project, criteria need be formulated, to evaluate the effectiveness. These criteria functions as the KPI's of the project.

During the design of a MM strategy, the different impacts need to be linked to stakeholders. This helps by understanding how MM strategies impacts society and which parties are affected. The way stakeholders are affected influences the position of society regarding MM strategies. Generating this knowledge in an early stage of the design process, can help by influencing the position of society using communication and marketing strategies (see section 2.5).

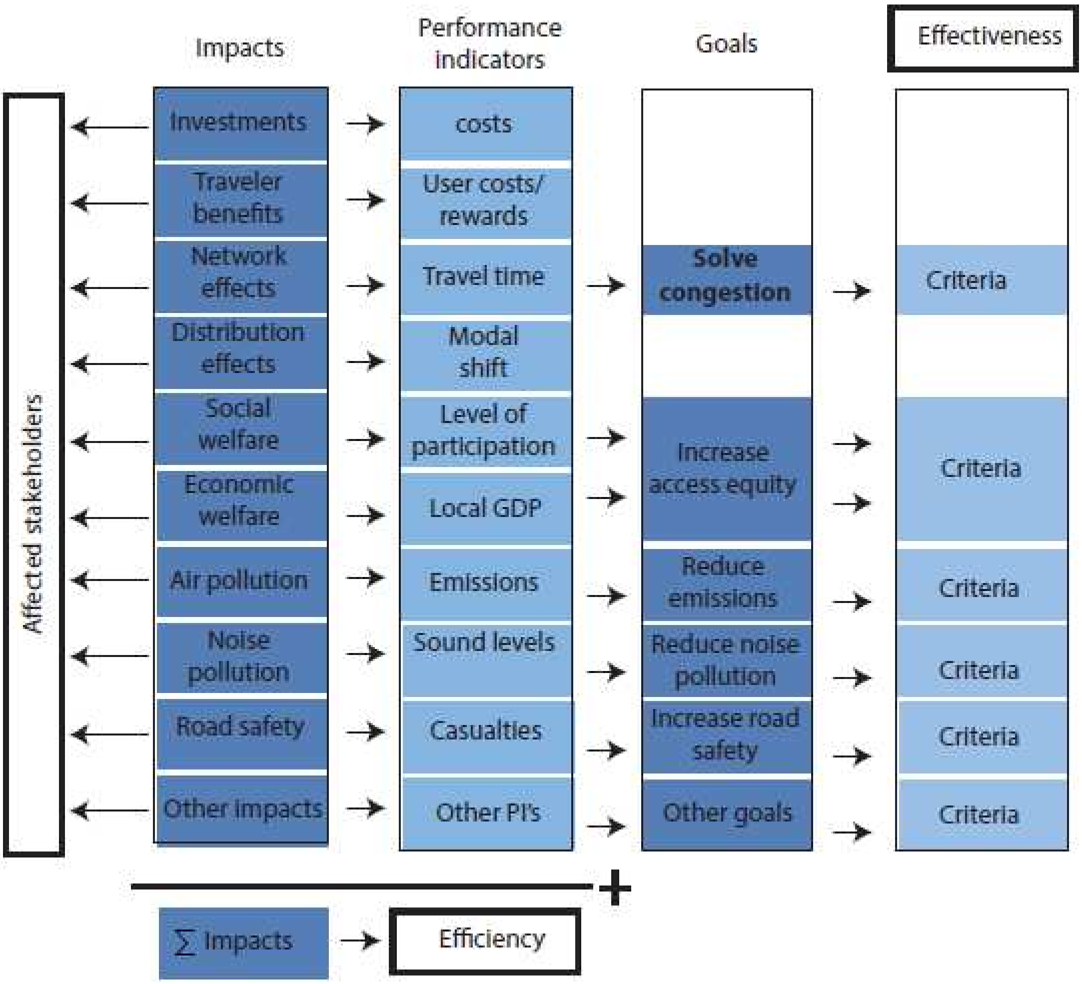

Figure 9 Relations impacts, stakeholders, performance indicators, goals, efficiency and effectiveness

4. Factors influencing the level of success of mobility management for IRP's.

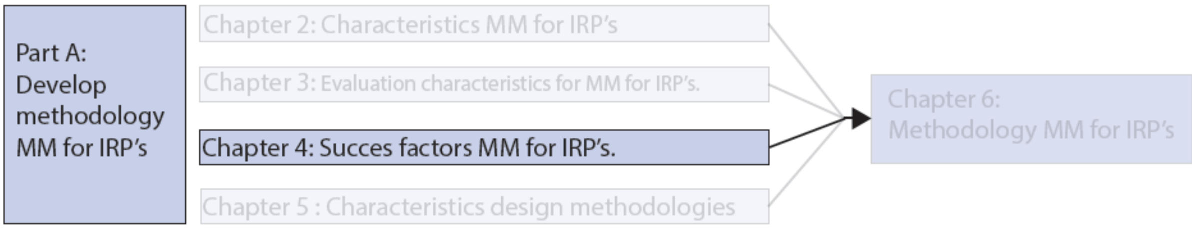

Figure 10 Position chapter 4 in literature review

Understanding the success factors of mobility management is essential in developing the right MM strategy for infrastructure renovation projects. This chapter analysis the success factors and the related characteristics. First the success factors are discussed (section 4.1). After this the specific characteristics influencing these success factors are analysed (section 4.2 – 4.5). Section 4.6 concludes this chapter by relating the findings of the characteristics and factors influencing the level of success of MM strategies to the characteristics of IRP's.

4.1. Success factors for Mobility Management

There are several characteristics influencing the success of mobility management. Garling & Schuitema (2007) mention three main factors influencing the success of mobility management (Table 24). For every success factor, there are different characteristics. These characteristics influence which MM measures have the highest potential. A fourth factor can be added; efficiency. These factors are related to the three evaluation indicators; efficiency, effectiveness and stakeholder need and position (see chapter 3). The political feasibility relates to the total evaluation from the perspective of the responsible stakeholder: the local/regional government.

Table 24 Four main factors determining the success of mobility management strategies.

Factors influencing the success of mobility management strategies.	
1.	Effectiveness (in achieving goals of MM strategies for IRP's)
2.	Public support (of stakeholders regarding MM strategy)
3.	Efficiency (cost benefit ratio of measures and/or strategies)
4.	Political feasibility (regarding all goals set for MM strategy, from the perspective of the responsible government)

When designing a MM strategy all four success factors need to be analysed to research which MM measures should be applied. The three factors influencing the success of mobility management by Garling & Schuitema (2007) and the efficiency are interrelated (figure 11).

The effectiveness determines to what extent the goals of the strategy are fulfilled. The specific characteristics influencing this success factor, form the context in which the measures are applied. Different MM measures are effective in different contexts. Therefore, it is essential to understand these characteristics to decide which MM measures have got the highest potential in the specific project context. If measures are perceived to be effective, the public support will rise and measures will become politically more feasible. The effectiveness is one of the indicators for the characteristics of the efficiency. Therefore, higher effectiveness leads to a better efficiency (though it may also lead to higher costs).

The public support is one of the key factors determining the political feasibility of proposed MM strategies. The public support determines how well MM measures are interpreted and adapted by society. This is essential for the execution of mobility management. If stakeholders are not aware of the situation and the need for change in the transportation system and if they are not willing to participate in changing travel behaviour, the potential effectiveness will not be achieved. Stakeholders can put major pressure on governments. Their support is therefore essential.

The different indirect effects are included in the decision making process, indicating the efficiency, which is necessary to evaluate the overall performance of the policy interventions. Efficiency influences the public support. Because the perception of the public influences the level of support of society. The efficiency also influences the political support. The higher the level of efficiency, the more attractive it is from a political viewpoint.

Political feasibility, as said, is influenced by the public support, efficiency and effectiveness. Policy makers need to guarantee social and economic welfare. To do this they need come up with effective and efficient measures to achieve all goals set in an efficient way, supported by society. The political position of the different representatives determine the weight of the different factors and characteristics in the final judgement, establishing the political feasibility.

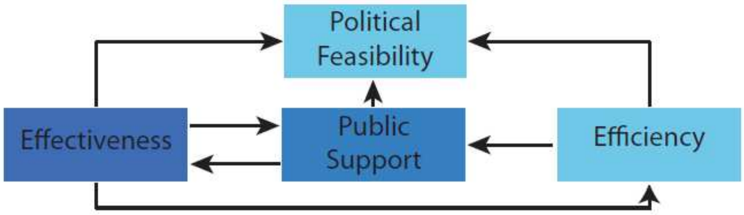

Figure 11 Factors determining level of success of MM strategies and relations.

Figure 12 shows the different characteristics influencing the four success factors and the relationships between them. Section 4.2 – 4.5 will elaborate on these characteristics.

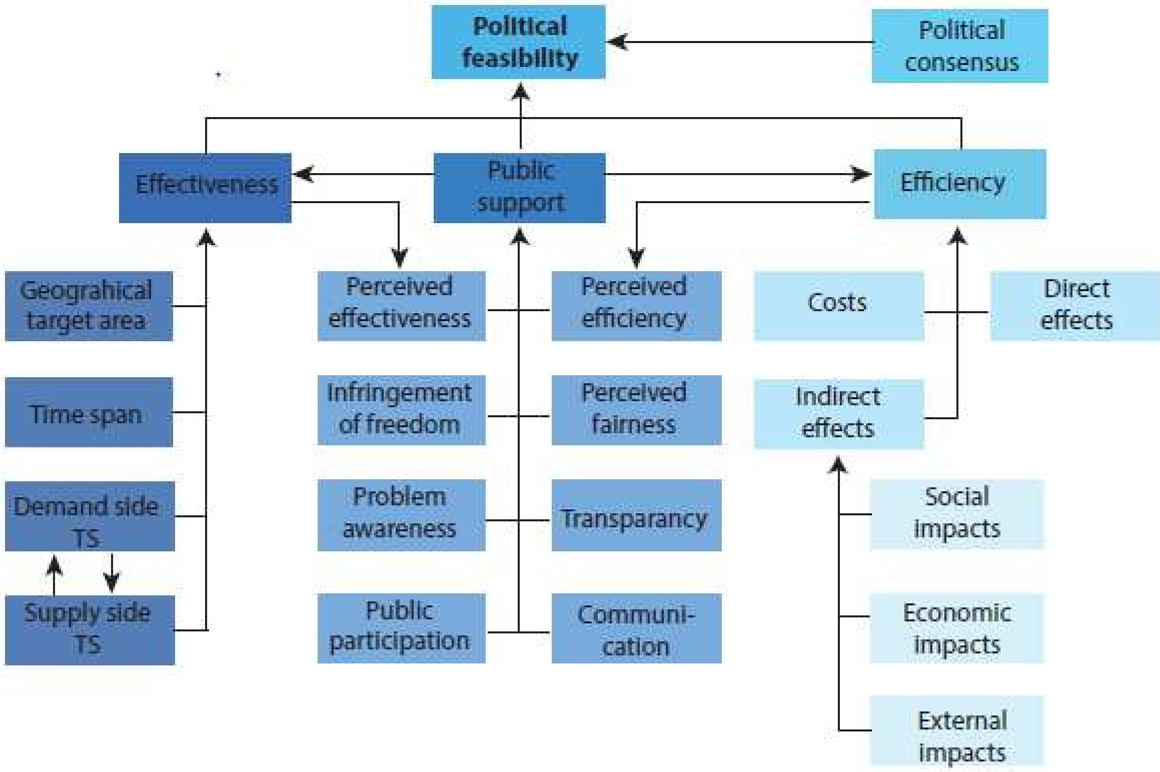

Figure 12 Characteristics determining the success factor of MM strategies for IRP's.

4.2. Effectiveness

The effectiveness of mobility management depends on whether the mobility management measures can change travel behaviour in order to reduce private car use. This, to resolve congestion and possible other goals (Schuitema, Steg, & Rothengatter, 2010). In other words, to make the transportation system more efficient and achieve the primary and secondary goals of MM strategies for IRP's (table 19). Meyer (1999) emphasises the importance of the characteristics of the scope and substance of policy interventions, regarding the level of success, when applying mobility management. He identifies three characteristics directly influencing the effectiveness of policy strategies.

- Time span
- The geographical target area.
- Travel market. Different travel markets serving different trip purposes exist. The effectiveness of different MM measures differ per travel market. All travel markets combined result in the total demand for transportation. The demand of the travel market initiates the trip choice decision process, demanding transport and traffic supply from the transportation system.

This third aspect of Meyer (1999) automatically leads to a fourth important characteristic influencing the effectiveness of MM measures: the transportation system. The transportation system and the travel market are closely related. The travel market creates demand, which is supplied by the markets of the transportation system: transport and traffic market. The layer system of the transportation model (Schoemaker, Koolstra, & Bovy, 1999), in which the activities are derived at the travel market, illustrates this market interaction (Figure 6). To create a clearer overview of the transportation system and travel market, the analysis of the characteristics is done, divided in the demand side of the system and the supply side of the system. The different steps of the trip choice model are analysed (demand side) and the way the transportation system responds to this (supply side).

Table 25 characteristics influencing the effectiveness of MM strategies.

Characteristics influencing the effectiveness of mobility management	
1.	Time span.
2.	Geographical target area.
3.	Demand side transportation system
4.	Supply side transportation system

4.2.1. Time span

The first characteristic influencing the effectiveness of mobility management strategies is the time span. Chapter 2 already elaborates on different aspects of the project time span. Different time spans are important.

- Implementation time.
- Incubation time.
- Renovation project duration.

The implementation time determines how long it takes before MM measures are ready to implement. The preparation of MM measures should fit the time between the start of the design of the MM strategy and the start of the IRP. Measures need to achieve direct results, no long term effects are demanded. Finally, the renovation project duration defines how long effects should be visible. This can differ significantly between different IPR's.

4.2.2. Geographical target area

The geographical context significantly influences which MM can be effective. Meyer (1999) defines two main types of geographical target areas: Site specific target areas and area wide target areas (Table 26). For IRP's an area wide geographical target area needs to be considered, due to the social and economic impacts on the urban context.

The scale of an area wide project influences the effectiveness of measures. Especially when it comes to getting people to change from private car use to other modes of transportation, the scale is important. Incentives for train usage will be effective on a national/regional level, where incentives for bus/tram usage will be effective on district/city level. Bicycle stimulations will change travel behaviour of short distance trips (mainly district/city level).Analysing this scale gives relevant information about the possibilities of different mobility management options.

Table 26 Characteristics influencing the effectiveness of mobility management: geographical target area

Geographical target areas			Mode potential
1.	Site specific		
2.	Area wide	District-level	Walk, bicycle
		City level	Bicycle, PT (bus/tram/metro), car
		Regional level	(Bicycle), PT (metro/train), car
		National level	Train, car

Another important distinction can be made between the target and management area. The target area is the area where the problems in the network occur. Travelers with destinations and origins outside this area also make use of this part of the network, and are therefore also possible subjects for mobility management measures. Including the origins and destinations of these network users, results in the management area (table 27). The target area can be divided in the critical area and the area of direct influence. The critical area is where the bottleneck(s) are located; where the origin of congestion can be defined. This is often the infrastructure subject to renovation and/or alternative routes. The area of direct influence is the area where the accessibility decreases, caused by the congested links (indirect network effects).

Table 27 target and management area of mobility management

Target area		Scope
1.	target area	Area where mobility management effects should be visible
2.	management area	Area where mobility management is implemented

4.2.3. Demand side of the transportation system

Analysing the characteristics of the demand side (in relation with the supply side) of the transportation system is important because it determines how, when, where and why people travel. Analysing these patterns illustrates how travel behaviour is formed in a specific urban context and how it can be influenced. For example, knowing that many people travel from one area to another by car for shopping, shows that the efficiency of the transportation system can be increased by improving PT between these areas, or making parking more expensive, etc. The demand side of the transportation system is formed by the demand derived from the five steps in the trip choice model (Figure 5).

Analysing these five characteristics is necessary to understand where alternatives can be found in the system (Gris Orange Consultant, 2012).

Table 28 steps in the trip choice model

Step in 5 step model	
1.	Trip generation
2.	Trip distribution
3.	Mode choice
4.	Departure time choice
5.	Route choice

Trip generation

Understanding the reason why people travel, which activities they want to perform (trip purpose), is essential in determining which mobility management measures are the most effective. For example, specific mobility management strategies aimed at changing travel behaviour by eliminating the trip of commuters (teleworking) can be very effective, but can be ineffective in changing travel behaviour of tourists. Regarding the trip generation two aspects need to be researched.

Table 29 Characteristics trip generation

	Characteristics trip generation
1.	Trip purpose
2.	Amount of trips per purpose

If more trips are performed for one specific trip purpose, the potential of a mobility management measures for that trip purpose increases. Table 30 Show the most common trip purposes in The Netherlands for passengers. The trip purpose freight transport should be added. Freight transport can impact the transport system (dependent on the urban and economic context) and the social and economic environment significantly. It also requires a different approach, compared to passenger transport.

Table 30 Different trip purposes (CBS, 2014a)

	Trip purposes passengers	Type: person (P) or freight (F)
1.	Commuting	P
2.	Business	P
3.	Education	P
4.	Shopping	P
5.	Visits	P
6.	recreation	P
8.	Freight	F
7.	Other…	P

Trip distribution

Understanding the travel destinations (and origins) helps by understanding the traffic flow patterns. Regarding potential MM measures aimed at influencing the trip distribution, this is less important, because land use related measures, which influence the trip distribution, are not effective for short term mitigation of problems during IRP's. But, the travel destinations and origins of network users influence the relevance of the geographical target area, both the target and the management area. The demand of travellers with respect to where they want to perform their activity has a major effect on the transportation system. Although this destination choice is often not flexible on the short term, the information is crucial for understanding the system.

Mode choice

Where the goal of mobility management is to change travel behaviour and reduce private car use, knowing the mode choice of people and the related modal split is useful for understanding the possibilities of modal shifts. Knowing the amount of cars in the system, explains the theoretical potential of MM regarding modal shift from car to other type of modes. But also de demand on other transport modes should be researched. This in combination with the capacity of these modes determines if there are possibilities regarding mode choice mobility management measures.

Departure time period

The time at which people travel influences the densities on the network. When this information is known, it is easier to understand when congestion arises and how this can be mitigated. Especially, the travellers travelling during peak hour are interesting for mobility management. During this period, under normal circumstances, most congestion arises.

Route choice

The route choice of people largely influences on which links congestion arises. Understanding these patterns, shows insight in how demand could be distributed differently and which links should be influenced by mobility management strategies.

4.2.4. Supply side of the transportation system

The demand derived from the five steps of the trip choice model is supplied by the travel, transport and traffic market. Knowing the supply in terms of modes, services and infrastructure and the capacity and quality of the supply side shows the possibilities to improve the transportation flows in the system. For example, if the safety of bicycle lanes is not at a high level, people will feel less attracted to travel by bicycle. MM measures aimed at increasing safety can cause a modal split in favour of cyclists. Another example: If there is a lot of unused capacity in urban PT systems, and an IRP causes a sever decrease in capacity on the road network, road network problems can be mitigated by shifting people to PT. The system must be analysed first, to detect the possibilities to match demand to supply in a different way.

Travel market

The demand on the travel market, explained by trip generation and trip distribution, is matched by the supply of the travel market: the geographical distribution of activities and ways to accomplish trip purposes. The demand is derived by the need from society to perform activities. Three main characteristics should be analysed (Table 31). For short term mitigation, not much changes can be made regarding the supply side of the travel market, but the characteristics show how travel patterns are derived. This is important, for understanding the functioning of the transportation system. What happens on the travel market, forms the functioning of the transport and traffic market.

Table 31 Travel market characteristics influencing MM possibilities

	Characteristics supply side travel market
1.	Locations (geographical position)
2.	Functions (activity type)
3.	Levels of supply (capacity per function)

Transport market

The transport market supplies the demand produced on the travel market. This is the demand derived from trip generation and trip distribution. This demand results in the need of persons to move. The transport market supplies this by offering modes of transportation (mode choice). Public transportation modes have specific departure times, where persons using private modes of transportation are normally free of determining their own departure time. Figure 13 shows the different modes and related geographical scale.

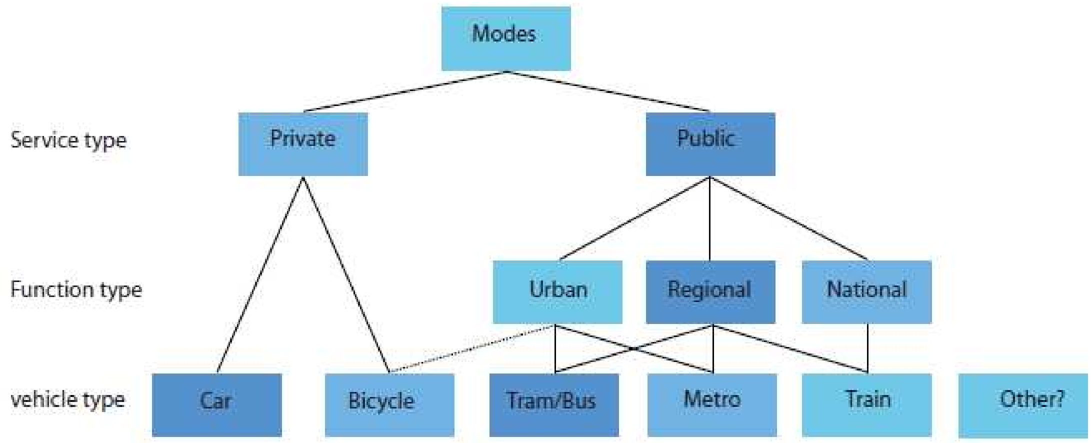

Figure 13 Different type of modes and geographical applicability (Van Nes, 2002)

Related to developing a MM strategy for an infrastructure renovation project the characteristics of the supply side of this market are essential. There are four key characteristics attached to the attractiveness of the supply side of the transport market (Table 32).

Table 32 Characteristics influencing the attractiveness of transport modes

	Characteristics supply side transport market
1.	Total amount of vehicles
2.	Capacity of vehicles
3.	Level of service
4.	price

The amount of vehicles per type influence the densities on the network. Combined with the capacity of vehicles, it illustrates the possible capacity for transport modes in the system. The level of service and the price, finally, contribute largely to the attractiveness of different modes.

Traffic market

The third market, the traffic market, supplies a physical network to facilitate demand of vehicles derived from the transport market. For every type of transport mode there is a physical infrastructure. These networks are formed by links and nodes. In some cases this is mode specific (for example, rail networks), in other cases infrastructure can be shared by different modes (an example is the road infrastructure, used by bicycles, cars and busses). When the mode choice (and time period choice) are completed, this physical infrastructure delivers the network in space (route choice) and time (departure time choice) for the vehicles to move from origins to destinations. The capacity, quality and speeds of the link connected by nodes, determine the possibilities in the network. These characteristics together with the demand show the possibilities within the network to apply mobility management to solve congestion at certain points and periods in the transportation system.

Table 33 characteristics of the supply side of the traffic market influencing the effectiveness of MM measures.

	Characteristics supply side traffic market
1.	Capacity
2.	Quality
3.	speed

4.3. Public support

Meyer (1999) emphasises the importance of societal/public support for the success of MM strategies. This is important from a stakeholder perspective. The characteristics influencing the level of public support can be divided in two main categories (table 34).

Table 34 Main characteristics determining the level of public support of MM strategies for IRP's.

	Main characteristics determining level of public support.
1.	Public perception of the content.
2.	Project process approach.

The first main characteristic, public perception of the content, relates to the way society experiences the effects of MM strategies. Not every stakeholder notices the same effects, and not every stakeholder judges all effects the same. For policy makers, project teams and (local/ regional) governments, it is essential that the public perception is as positive as possible, otherwise great resistance can emerge. The personal norm of people influences this public perception (Eriksson, Garvill, & Nordlund, 2006), but there are other characteristics. First of all the MM strategy, should have an overall contribution to society, to obtain public support. To achieve this the second characteristic, the project process approach, is decisive. Communication, of the process, the goals, the purpose and effects of the project is essential. Also involving society in the process and being transparent is essential to gain public support. For MM strategies for IRP's the communication is of extra importance, as public less accepted measures might be needed, to temporary solve arising network problems.

These characteristics influence the public support of society. The public support of business groups is also essential. Governments need to protect their economies, to guarantee economic and social welfare. The support of businesses, largely responsible for the economic welfare, is essential (Meyer, 1999). Besides this companies can help significantly by executing certain types of MM measures (Vanoutrive, et al., 2010). So the characteristics determining the public perception of the content and the characteristics of the project process approach are essential for the success of MM strategies from a societal and an economic viewpoint. Where society demands transportation, by creating the need to perform activities on the travel market, businesses are part of the supply of activities.

The following sections will elaborate on the different characteristics determining the public support from society and from business groups.

4.3.1. Public perception of the content.

For the public perception of the content, four characteristics are determinant (Table 35).

Table 35 Characteristics determining the public perception of the content of MM strategies for IRP's.

	Public perception of the content.
1.	Perceived effectiveness (Garling & Schuitema, 2007; Schade & Schlag, 2003)
2.	Perceived efficiency (Schade & Schlag, 2003)
3.	Infringement of freedom (Schade & Schlag, 2003)
4.	Perceived fairness/ equity principal (Schade & Schlag, 2003)

MM measures can limit the freedom to choose, this is called the infringement of freedom. This negatively influences the public support, as people want to be able to freely make their own decisions. Related to the perceived effectiveness, Schade & Schlag (2003) mention the perceived efficiency. Where perceived effectiveness indicates how the public judges the effect of the measures in reducing congestion and achieving possible other goals, perceived efficiency indicates the cost benefit ratio of strategies. Perceived fairness is another characteristic accountable for the level of support of society. It defines the way the public thinks of how the effects of measures are distributed among different individuals and groups of society. This strongly relates to the concept of equity (Viegas, 2001). All these characteristics are part of the way the public values the content of the strategies.

Perceived effectiveness

Perceived effectiveness relates to the opinion of society regarding to what extend the policy interventions fulfil the primary goal set for the project to resolve/reduce congestion and possible secondary goals. For project teams these are measureable, quantifiable numbers. But to gain the approval of society, their perception should match the numbers, to increase public support.

Perceived efficiency

The perceived efficiency indicates how the overall cost- benefit ratio of effects is judged by society. This efficiency is also quantifiable. Some impacts, however, are difficult to quantify and it is difficult to include all impacts (Mouter , 2012). Different stakeholders will not encounter different effects of MM measures, resulting in different efficiency ratios.

Infringement of freedom

Infringement of freedom through policy measures causes a considerable decrease in public support. People attach high value to the freedom to choose. If this freedom is limited due to transport policy, policy and decision makers need to explain why it is necessary. This relates to the project process approach characteristics (section 4.3.2).

Perceived fairness (equity principal)

Perceived fairness of society illustrates how fair people think the impact of a MM strategy are. It depends on the view of individuals regarding their own position (are they disadvantaged) and on the overall opinion of society. Fairness is a general feeling which is difficult to clarify, but it can be largely translated in the principal of equity. Table 36 illustrates the different dimensions of equity (Viegas, 2001). The way people perceive the change in fairness caused by the MM strategy influences public support.

Table 36 dimensions of equity.

	Dimensions of equity (Viegas, 2001)	
1.	Horizontal	Principle of equal opportunities (everybody equal). Everyone should have accessibility.
2.	vertical	Principle op proportional equity (based on income). Protection of those with less resources, guaranteeing them accessibility.
3.	territorial	Principal of equality for different districts. All districts should have equal accessibility.
4.	longitudinal	This relates to the change in equity over time. The level of accessibility over time should stay equal.

4.3.2. Project process approach

An important characteristic of public perception is the process approach. Four characteristics relate to this (Table 37).These four characteristics influence how society perceives the content of the MM strategies.

Table 37 Characteristics of the project process influencing the public support of MM strategies for IRP's.

	Project process approach
1.	Problem awareness (Eriksson, Garvill, & Nordlund, 2006)
2.	Transparency (Gühnemann, Laird, & Pearman, 2012)
3.	Public participation/stakeholder involvement (IAPP, 2007)
4.	Communication (Garling & Schuitema, 2007)

Problem awareness

Creating problem awareness is important from the start of the project. The fact that there will be changes in the transportation system and why, helps people to understand the need for the IRP and the need for the developed MM strategy.

Transparency

Applying a transparent project process also helps to increase the public acceptability. If people know what is happening combined with understanding how it is happening will contribute to a better understanding of the policy implementations. Also transparency in changes during the process will contribute to a higher level of support. It is important to determine which part of the process need to be transparent and at what moment. The planning process and the interaction between planning and political decision-making is a part that can contribute to public support if made more transparent (Short & Knopp, 2005).

Public participation/ stakeholder involvement

Involving stakeholder to increase public participation helps by creating problem awareness and by creating a more transparent process. Besides this, '*it increases the chance of project success, as the needs of various sectors of society would be considered before a finalized plan and solution is derived* (LI, Thomas, & Skitmore, 2013).*'* This quote emphases the importance of early stakeholder involvement in the process. This, to develop a more comprehensive overview of existing interests. Which will help by raising public support.

Communication

Finally, a very important characteristic of gaining public support, necessary to successfully implement MM strategies during IRP's, is the communication. During the entire process communication is essential. From, both, a process and a content related viewpoint. To influence the perception of society towards effectiveness, efficiency and fairness and to enlarge transparency and problem awareness, proper communication is essential. This is specifically highlighted by Garling & Schuitema (2007).

4.4. Efficiency

The efficiency of a mobility management strategy or measure indicates the relation between the different impacts of a project (in this case of a MM strategy). Different effects determine this ratio. The effects can be either positive (benefits) or negative (costs). C*ost Benefit Analysis is the most used evaluation technique for assessing infrastructural investments in the transport field, it is the basic tool in the majority of countries in Europe* (Beria, Maltese, & Mariotti, 2012).

The different impacts enumerated in section 3.2 need to be included when determining the efficiency of a MM strategy. This is formed by the direct, indirect and external impacts. Another way of categorising these impacts is by costs, direct effects and indirect effects. . Where the indirect effects can be separated in economic, social and external/environmental effects. Depending on the project context other impacts need to be included too.

4.5. Political feasibility

Finally, the political feasibility is decisive for the success of MM strategies for IRP's. Where decision makers determine which policy interventions are implemented, this political feasibility is essential. For strategies to be political feasible, there are four indicators (Table 38).

Table 38 Characteristics determining the political feasibility of MM strategies.

	Characteristics determining the political feasibility
1.	Effectiveness
2.	Public support
3.	Efficiency
4.	Political consensus

Section 4.2, 4.3 and section 4.4 elaborate on the first three factors influencing the level of success for MM strategies for IRP's. The results of these three factors are three of the four characteristics influencing the political feasibility. The fourth characteristics, political consensus, relates to the need for a majority of votes in the local or regional (or national) parliament. In order to obtain this majority, political consensus is needed between governing parties. This depends on the political positions of the committed government.

4.6. Conclusions:

Conclusions chapter 4

There are four main factors determining the success of MM strategies. The effectiveness is influenced by the characteristics of the transportation system and the scope of the IRP (target area and time span). The public support of MM measures is influenced by the perception of society regarding efficiency, effectiveness and fairness and the way measures influence the freedom to choose. This attitude can be positively influence by good communication and information strategies, explaining the need for mobility management. The efficiency is from an overall governmental perspective important, to consider the different impacts of measures. The political feasibility is the overarching factor. The interpretation by governments of the combined results of the effectiveness, the public support and the efficiency determines the political feasibility. Governments need to achieve political consensus of a majority of the parliament to approve MM strategies. This is influenced by the political colour of local parliaments. Due to importance of a functioning transportation system, the main focus must lies on the effectiveness. This success factors should attain the highest value.

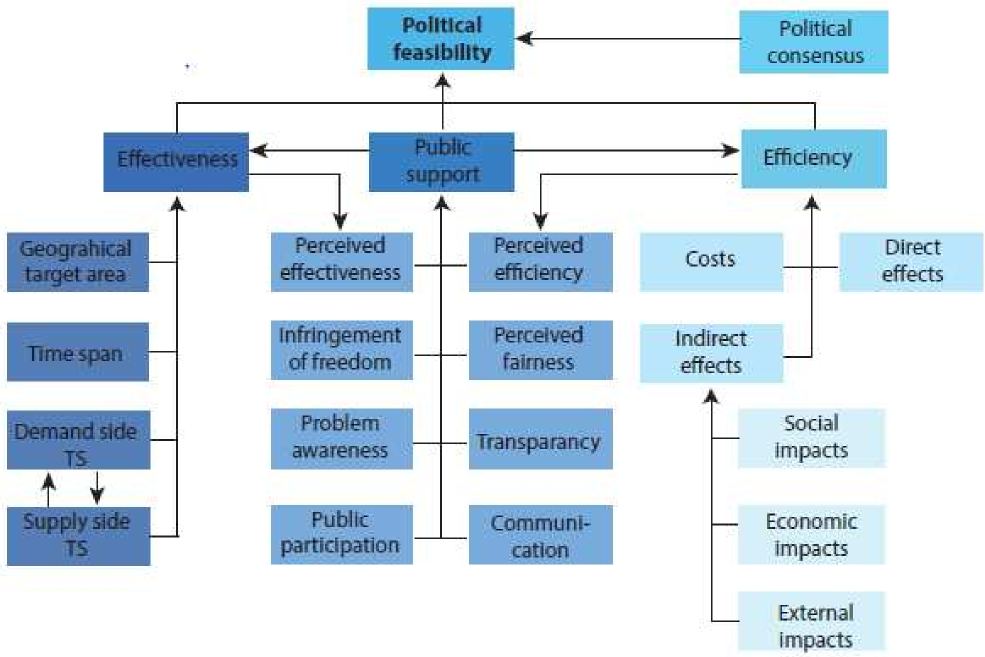

Figure 14 Characteristics determining the success factor of MM strategies for IRP's.

Conclusions related to chapter 2 and 3.

The need for a proper functioning transportation system, combined with the primary goal, of MM strategies for IRP's to mitigate congestion during the renovation project, increases the importance of the effectiveness of measures. This need for a high effectiveness of the MM strategy can demand more extreme measures: push measures. Push measures in general realise low levels of public support. Especially the perceived fairness and the freedom to choose (infringement of freedom) will decrease significant. A good communication strategy, creating problem awareness is necessary to limit the decrease of the perceived fairness. Public participation and transparency can contribute to higher levels of perceived effectiveness and efficiency, because stakeholders know that their interest are considered. Therefor stakeholder participation is important during the entire design process. The efficiency is gives an indication of the overall effects of the measures. The transportation system exist to service the economic and social urban systems. If the overall impacts on these systems are negative, measures are not efficient.

5. Analysis of existing Design methodologies

Figure 15 Position chapter 5 in literature review

This chapter elaborates on the essential steps and relations for this design process. First several design methodologies are researched. The design process, based on the project lifecycle is analysed first (section 5.1). This is followed by an analysis of the basic design cycle (5.2). These two methods are basic approaches for design/projects processes. After this, two more specific design methodologies are analysed, related to the design of a MM strategy for IRP's. First, in section 5.3, the sustainable traffic management process diagram (STMPD) approach is set out. This method is used for the design of Traffic management strategies. After this the ToeKan method, a design method for MM strategies, mainly used for highway corridors is described (section 5.4). Section 5.5 compares the essential characteristics of the methods and section 5.6 describes the conclusions of this chapter.

5.1. Project lifecycle as design approach

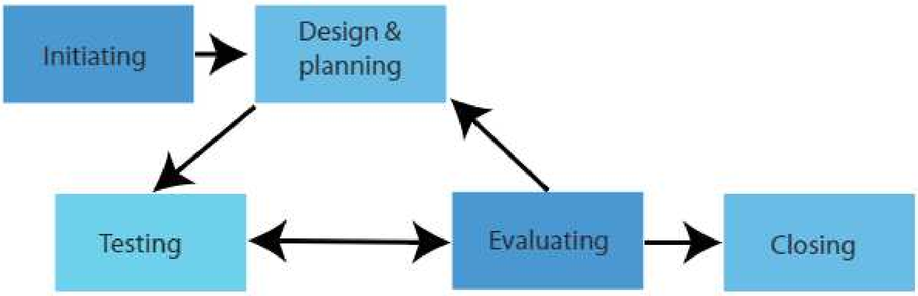

Figure 16 Steps for the design of a MM strategy adjusted from (Project Management Institute, 2008)

Theory

The process of designing a MM strategy, within the renovation project, can be approached as a project lifecycle on its own.

- The design starts with an initiation stage, where the purpose and deliverables are defined. The project deliverables are essential for the success of the project/design, to evaluate the design later on during the design process (Poli & Shenhar, 2003).
- Then the design and planning stage starts. The context is analysed and the design is produced. Attached to this design, a planning is determined for the project.
- After this the design is tested on its properties. Normally this stage exist of the execution of the project, but because of the design characteristics of this type of assignment, it is replaced by the stage testing.
- Finally the design is evaluated, by comparing the project deliverables with the results of the test stage.
- The design ends when it is approved. Then the project lifecycle of designing the MM strategy is closed. There is a difference with the normal project lifecycle though. Because of the theoretical feature of designing, compared to the practical feature of a renovation project, there is no execution stage, but a testing stage. The theoretical feature of designing also eliminates the need to monitor& control, and demands the need to constantly evaluate the design during the process to improve the MM strategy until it is approved.

Relation between project management lifecycle and design of a MM strategy for IRP's.

Table 39 illustrates how different characteristics of MM strategies for IRP's are related to the steps in this design approach.

Table 39 Relations between the project lifecycle and the design of a MM strategy for IRP's.

	Stage	Content design of a MM strategy for IRP's.
1.	Initiating	This part focuses on initiating the project design. The project scope, goals and deliverables are defined. The scope can be related to the geographical, transport, economic and social context. The deliverables to the function and demands of the design. Criteria can be included to evaluate the design.
2.	Design (and planning)	During the design stage, a MM strategy is designed, based on a design process. This project life cycle method is rather vague, regarding the exact design process.
3.	Testing	Different methods to test the project results should be used, to obtain values that are comparable with the criteria.
4.	evaluation	Based on the results of the test stage and the criteria and deliverables determined during the initiating stage, the design is evaluated.
5.	Closing	The design is approved or a new iteration starts. If the design is approved, the project is closed.

5.2. Basic design cycle

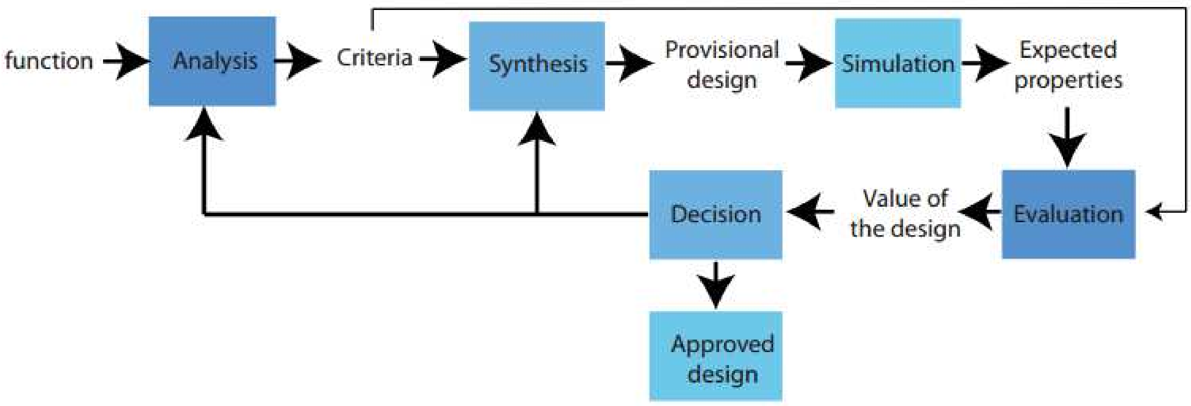

Figure 17 The basic design cycle (Roozenburg & Eekels, 1995)

Theory

Roozenburg & Eekels (1995) describe the steps of the basic design process (figure 17). This is an approach containing the basic steps for a design process. It is applicable in mutliple contexts, where the specific demands of the type of design should fill in the details. The arrows in figure 17 illustrate that the proccess has an iterative nature, where the design should become more detailed in every iteration. This process continues untill the properties of the design match the criteria and the design is approved.

The followings steps are executed:

- Function: The design approach starts with the function of the design. This function explains why the desing process is started. The end product is described.
- After this, a (problem) analysis is conducted. The function of the design is analysed in the broadest context possible, including technical, social, ecomic, cultural, geographical and other aspects (Roozenburg & Eekels, 1998). This is necessary to determine the problem, set goals and define criteria.
- Then, the critera are defined. This is a critical point in the process, because the citeria are used later in the process to evaluate the design.
- After the criteria are defined the step 'synthesis' comes up. The different essential characteristics and aspects of the design are combined.
- The synthesis stage results in a provisional design.
- This design is tested using the simulation stage. The results of this stage are the properties of the design.
- These properties are evaluated according to the citeria, determined earlier during the process.
- Finally the design is valued and either approved or a new iteration starts.

Relation between basic design cycle and design of a MM strategy for IRP's.

Table 40 illustrates how different characteristics of MM strategies for IRP's are related to the steps in the basic design cycle.

Table 40 Relations between the basic design cycle and the design of a MM strategy for IRP's

	stage	deliverables	Content design of a MM strategy for IRP's.
		function	Design of a MM strategy for a specific IRP in an urban context.
1.	analysis		The analysis should focus on the potential problems of the social, economic, transportation, project and geographical context. The important impacts should be listed. A problem statement should be stated and translated into goals. Attached to these goals criteria need to be formulated.
		Criteria	The criteria attached to the goals are the result of this stage.
2.	Synthesis		The transportation system (plus the travel market) should be analysed to determine the possibilities in the project context. This analysis should be compared with the potentially effective measures, derived from chapter 2
		Provisional design	A MM strategy with measures results from the synthesis.
3.	simulation		Different methods to analyse the project results should be used, to obtain values that are comparable with the criteria.
		Expected properties	The results of the simulation are the properties where the criteria are compared to.
4.	evaluation		Based on the properties of the design and the criteria the level of effectiveness, efficiency, public support and political feasibility is evaluated.
		Value of the design	A value is attached to the evaluation
5.	decision		The design is approved or a new iteration starts.
		Approval/new iteration	

5.3. Sustainable traffic management process diagram (STMPD)

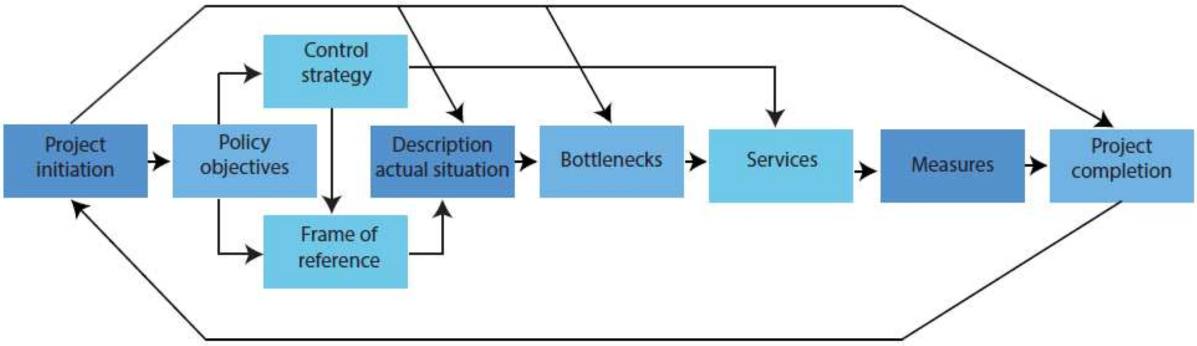

Figure 18 STMPD approach

Theory

In the handbook for sustainable traffic management some essential actions are mentioned regarding the development of a transport policy strategy (Rijkswaterstaat, 2003). This handbook is developed for sustainable traffic management, but several of the actions described, will contribute to the design of a good MM strategy. The following steps are used in this methodology.

- Initiating the project. In this stage the problem is analysed, the main stakeholders are identified and approached and the assignment is determined.
- This leads to the definitions of the policy objectives. Together with the main stakeholders the objectives of the project are determined.
- Develop the control strategy. The geographical target area is defined and the impacts are analysed combined with the relevant stakeholders.
- Set the frame of reference. The relevant criteria used to evaluate the strategy are set during this stage.
- Describe the situation. Describe the actual situation and the context.
- Analyse the bottelnecks. Anlyse where the bottelnecks are in the system.
- Services: Determine the general approach on how the problem should be approached. Not the exact measures are determined, but the type of measures.
- Determine measures: The specific measures are chosen during the step, to complete the strategy.
- Finish the project. If the strategy with measures is established. The design process is finished and the strategy is ready for implementation.

Relation between STMPD and design of a MM strategy for IRP's.

Table 41 shows how different characteristics of MM strategies for IRP's are related to the steps in the sustainable traffic management process diagram.

Table 41 Relations between STMPD and the design of a MM strategy for IRP's.

	stage	Content design of a MM strategy for IRP's.
1.	Initiating the project	The problem caused by the IRP is analysed. This results in a problem statement. The main stakeholders are analysed and approached.
2.	Defining general objectives	Together with the stakeholders, or in collaboration with stakeholders, the goals are defined.
3.	Develop the control strategy	The geographical target area is analysed and the essential impacts are determined and linked to stakeholders.
4.	Set the frame of reference	The criteria /KPI's are determined. This is necessary for the evaluation of the MM strategy.
5.	Description actual situation	The situation is described. The transportation system and the context can be analysed to see where the possibilities and limitations are in the system.
6.	Bottlenecks	The problem areas in the transportation system are defined. The locations where congestion is caused is analysed.
7.	services	The general strategy is determined. One or several leading MM measures are defined and a communication strategy is set out.
8.	measures	The complete package of measures is created in a way the strategy represents a comprehensive approach on how to solve the problem.
9.	Finish project	If the MM strategy with associated measures meets the criteria, the design is finished.

5.4. ToeKan method (seize opportunities).

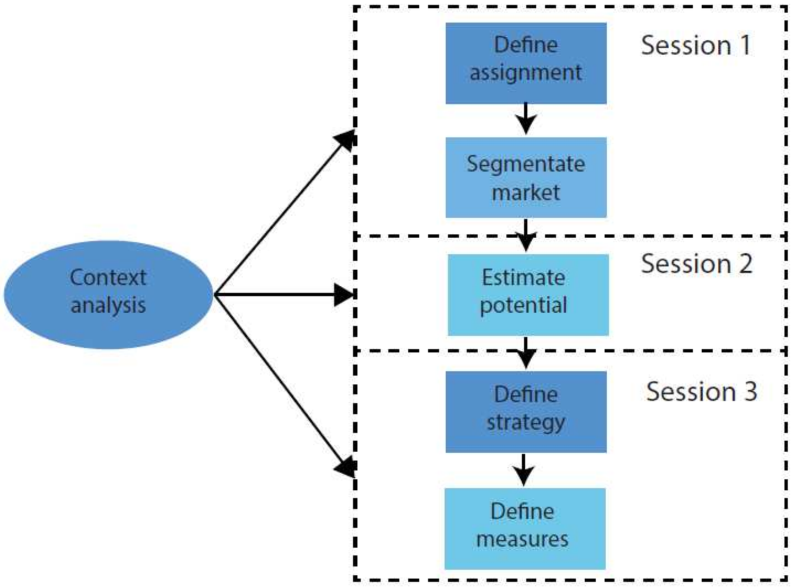

Figure 19 ToeKan method

Theory

The ToeKan method is a design method to mitigate short term problems for IRP's (Rijkswaterstaat, 2010b). It analyses only the transport related problems (cost effectiveness) of MM measures. It exists of five steps:

- Define project.
- Define (travel) market segments.
- Determine potential effects different markets.
- Determine strategy
- Define measures.

Interesting about this method is that it is divided in three 'sessions'.

- The first two steps form session 1. This is the definition of the assignment. The problem is analysed and the goal of the design is formulated, with relevant criteria.
- The third step is session 2. Here the potential of different possibilities is researched. The project context is used to research the potential. The potential is purely based on the travel market. So based on different trip purposes.
- Finally, the last two steps form session 3. This is the design of the strategy to fulfil the project goal.

Relation between ToeKan and design of a MM strategy for IRP's.

Table 42 shows how different characteristics of MM strategies for IRP's are related to the steps in the sustainable traffic management process diagram.

Table 42 Relations between TOeKan method and the design of a MM strategy for IRP's.

	stage	Content design of a MM strategy for IRP's.
1.	Define project	The project scope and deliverables of the infrastructure renovation project are defined.
2.	Define market segments	Analyse how many trips are made for the different trip purposes on the infrastructure element subject to renovation.
3.	Determine potential effects different markets	Analyse which steps in the trip choice process can be influenced and to what extent, to define the potential of MM.
4.	Determine strategy	A strategy aimed at specific travel markets or decisions of the trip choice process can be set up.
5.	Define measures	The exact composition of measures is defined, and the cost-effectiveness is estimated.

5.5. Comparison design methodologies

Table 43 summarises the different steps of the analysed design methods. Vertically the different methods are displayed and horizontally similar stages are shown. Table 44 illustrates the different deliverables needed during the design process.

Table 43 deliverables and steps in the different design approaches.

Project lifecycle	Basic design cycle	STMPD	ToeKan
Initiating	Function	Project initiation	Define assignment
		Define policy objectives	
		Frame of reference	
	analyse	Develop the control strategy	Context analysis
		Describe the situation	Divide travel market
		Analyse the bottlenecks	Estimate potential
Design	Synthesis	Define services	Define strategy
		Determine measures	Define measures
Test	Simulation		
evaluate	evaluation	Based on criteria[1]	Cost effectiveness[2]
Close project	Decision/approved design	Close project	

Table 44 Deliverables found in design methodologies.

	Deliverables
1.	Geographical scope
2.	Bottlenecks
3.	Goals/objectives
4.	Stakeholder analysis
5.	Criteria
6.	Economic, social and transport network related impacts
7.	System/context analysis (possibilities)
8.	Travel market analysis
9.	MM Strategy
10.	Alternatives
11.	Measures
12.	Effect estimations
13.	Properties
14.	Effectiveness
15.	Efficiency
16.	Public opinion

[1] This method does define criteria for evaluation, the design methodology however, does not elaborate on how this is done.
[2] ToeKan does evaluate the measures, but purely on cost effectiveness.

5.6. Conclusion

Based on the different stages and deliverables found in existing design approaches, six main stages can be formulated with different deliverables attached to the stages (Table 45). Early stakeholder involvement is an essential characteristic, returning in both STMPD and ToeKan. This should be included in the design methodology. The design methodology should be approached as an iterative process.

Table 45 Conclusions: Stages and related deliverables.

	Stages	Deliverables
1.	Project initiation	Stakeholders + interests
		Geographical scope
		Goals/objectives
		Criteria (KPI's)
		Impacts (economic, social and network related)
2.	System analysis	Bottlenecks
		System analysis (possibilities)
		Travel market analysis
3.	Design	MM strategy
		Alternatives
		Measures
4.	Test	Effect estimations
		Properties (related to criteria)
5.	Evaluate	Relation properties/criteria
6.	Project closing	

6. Design methodology for MM strategies for IRP's.

This chapter combines the content analysis of chapter 2-4 and the process analysis of chapter 5 into a design methodology for MM strategies for infrastructure renovation projects. Section 6.1 describes the main methodology. Section 6.2 describes three phases which are run through to execute the design methodology. The methodology is adjusted according to the findings of the case study (chapter 7) and of the focus group session (annex C)

6.1. Main design methodology

General approach

Based on the conclusions of chapter 1-5, a design methodology is derived for MM strategies for IRP's.

Six main stages are distinguished for the design of a MM strategy with related deliverables. The main deliverables of the design methodology are the MM strategy and (as part of this) a communication/marketing strategy. Other important deliverables are shown in figure 20. The different stages are executed using an iterative process to come up with a design that fulfils the demands. The case study brought forward, three design phases. During these phases the different stages are used to produce specific deliverables. Section 6.3 elaborates on the different phases, and the related process and deliverables.

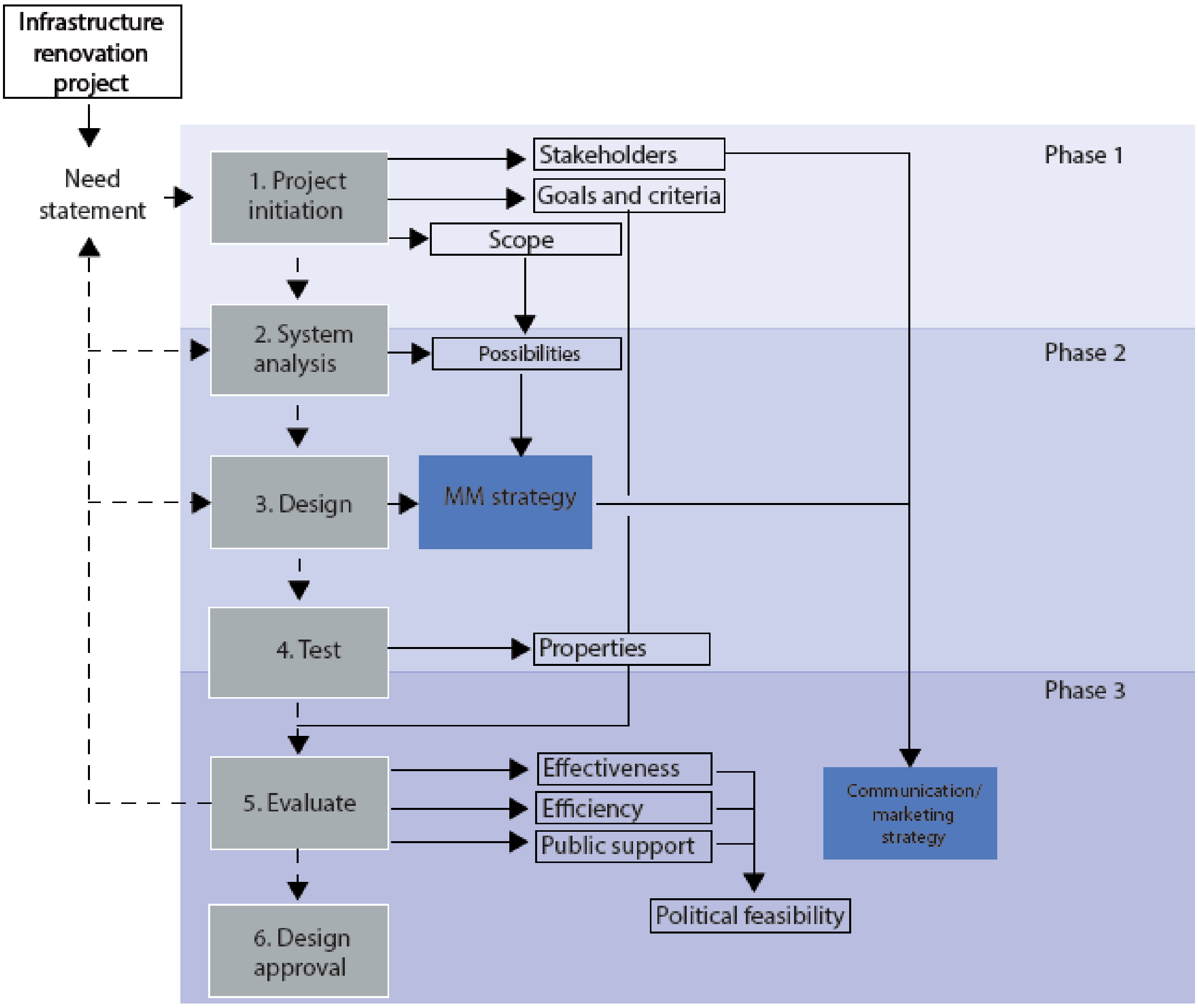

Figure 20 Main stages and deliverables design methodology

Stages

- The design process starts with a need statement, derived from the infrastructure renovation project.
- During the project initiation, the problem is analysed. Important deliverables are:
    - A detailed stakeholder analysis.
    - Essential impacts and clear goals, which are translated in criteria.
    - Define the scope of the project.
- System analysis:
    - The possibilities in the transportation system are analysed (Including the travel market)
- During the design stage, the results of the system analysis are compared to measures with the most potential, found in chapter 2.
    - This results in a MM strategy.
    - As part of this MM strategy, a communication/marketing strategy is defined. This strategy explains the possibilities of employer collaboration to reduce demand and on how to increase social support for the designed MM strategy.
- The measures of the MM strategy are tested.
    - First on the effectiveness in reducing congestion, caused by the IRP.
    - After this, the measures are also tested on effectiveness regarding other goals, the efficiency, the social support and resulting from this the political feasibility.
- After the test stage, properties obtained during the test stage are compared to the criteria and evaluated.
- If the evaluation is positive, the design is approved.

6.2. Phases

The phases are explained into more detail.

1. During the first phase, the problem is analysed and the design deliverables are determined.
2. During the second phase, the main mobility management measures are examined. Different alternatives are chosen, based on the system analysis. The effects on the transportation system are modelled to analyse the effectiveness. A Cost-effectiveness analysis is used and the impacts are roughly estimated.
3. Based on the results of stage 2, one or several alternatives are chosen and additional measures are defined to increase the effectiveness and improve the level of support (if needed). A complementary communication and marketing strategy is defined to increase the level of success of the MM strategy. The entire strategy is analysed and evaluated into more detail.

Phase 1: Problem analysis and developing design deliverables

The problem is analysed in the base scenario, where the IRP is executed without mobility management. The goal is to analyse if push measures are needed to mitigate problems. The main deliverables are the goals and criteria. These are later on in the process used to evaluate the MM strategy. The stakeholders are analysed, to help determine the impacts.

Table 46 Characteristics phase 1

stage	Input characteristics found in thesis	tasks	deliverables
analysis		Define the problem	bottlenecks
	Geographical and time scope (Section 4.2.1 and 4.2.2)		Project scope
		Define the main stakeholders and interests	Stakeholder analysis with related interests
	List with important impacts, goals and criteria (section 3.5).	Determine impacts	impacts
			Goals + criteria
Design		*No design during this phase*	Scope
Test		Determine level of impacts IRP	
Evaluate		Estimate level of effects on transportation system	Decision to include push measures in MM strategy.

Phase 2: main alternatives

During this phase the main alternatives are defined, tested and evaluated on effectiveness. After this phase the effects of the different alternatives regarding the goals is known. Besides this an indication of the cost and social support is given.

Table 47 Characteristics phase 2

stage	Input (characteristics thesis)	tasks	deliverables
System analysis	Characteristics transportation system (Section 4.2.3 + 4.2.4)	Analysis transportation system	possibilities to shift demand
Design	List with effective measures (section 2.5)	Define main alternatives: push or pull measures	Alternatives
Test		Model alternatives	Effect on transportation system (network performance)
Evaluate		Compare effects on transportation system with goals.	Judgement effectiveness
			Indication costs (feasibility)
	Characteristics social support (section 4.3.1)		Indication social opinion

Phase 3: Complete strategy

This is the final phase, where the design process is concluded. The end result is a MM strategy, including a communication and marketing strategy. During this phase the combined results of the effectiveness, efficiency and social support level are improved until a satisfying strategy is obtained. One or more alternatives function as base. Additional measures are added to compensate negative results caused by the main measures.

Table 48 Characteristics phase 3

stage	Input (characteristics thesis)	tasks	deliverables
System analysis	Goals and criteria as defined (Section 3.5)	Analyse possible equity/emission/safety/noise problem areas.	Problem areas
	Potentially effective additional measures (section 2.6).	Analysis characteristics additional measures in relation with main alternatives.	Possible measures
Design		Define complete strategy	MM strategy
			Communication approach
Test		Model alternatives	Effect on transportation system (network performance)
Evaluate		Compare properties with goals.	Effectiveness indictor (are goals fulfilled)
	Different impacts (section 3.5 and 4.4)	Combine properties impacts.	efficiency
	Characteristics social support (section 4.3.1).	Define level of social support	Indication social opinion. Ranking aspects of level of social support.
	Political feasibility (section 4.5)	Combine evaluations into overall judgement	Political feasibility

7. Case study: The renovation of the Maastunnel, Rotterdam

This chapter discusses the case study: The renovation of the Maastunnel in Rotterdam. The goal of this case study is twofold:

1. From a theoretical perspective: Evaluate the design methodology for mobility management strategies for infrastructure renovation projects, derived in this thesis (chapter 6).
2. From a practical perspective: Design a mobility management strategy to mitigate problems during the renovation of The Maastunnel.

Due to time and data restrictions not all aspects of the design methodology are executed into detail. From a theoretical perspective, the focus of the case study is on executing all steps of the process and evaluating this process and the related deliverables. From a practical perspective, the focus will be on determining effective measures. Related to these measures the positive and negative impacts will be analysed and complementary measures will be suggested, to complete a mobility management strategy for the renovation of The Maastunnel.

First the case relevance will be explained (section 7.1). Then a description of the project context is given (section 7.2). After this, the case study approach is set out per phase in section 7.3 -7.6.

7.1. Case relevance

The characteristics of the renovation of The Maastunnel make it particularly suited for the development of a comprehensive mobility management strategy to cope with problems caused by the renovation of the link. The impact and complexity of the project and its context demand a thorough systematic approach to come up with a proper MM strategy, which should guarantee the functioning of the transport network and the related economic and social structures. The project fulfils the three demands set for a project to be suited for the development of a comprehensive MM strategy (section 1.5.1):

- First, the project must concern a renovation project:

The renovation of The Maastunnel, is a project where a link is temporary taken out of the system, demanding short term mitigation measures to keep the system in balance.

- Second, the link or node subject to renovation should play a decisive role in the urban/regional transportation system:

The Maastunnel plays a decisive role in the functioning of the Rotterdam' transportation system. Model studies show that the closing of the tunnel in one direction significantly impacts the functioning of this urban transportation system. Traffic jams will arise affecting the entire urban transportation system and causing a major increase of congestion in the city centre (Municipality of Rotterdam, 2013a)*.*

- Finally, the project should have a significant influence on the economic and social structures of the city, and there must be a certain degree of urban complexity in order to make the application of this MM strategy design method feasible.

Rotterdam, which is one of the most important economic areas of The Netherlands and houses the second biggest amount of people within The Netherlands has a high level of complexity, from a transport related, economic and social viewpoint. Without additional transport measures during the renovation period, both the economic and social structure of the city and the region would be largely affected due to the occurring network problems.

The urban complexity of Rotterdam also eliminates the possibility of major supply side related policy measures to deal with the decrease in capacity during the renovation. This enhances the need for a mobility management strategy to cope with the occurring problems during the renovation.

Summarizing, the important economic and social position of the city of Rotterdam and the critical position of the link, The Maastunnel, in the transportation system, together with the complex urban context make this renovation project eminently feasible to use as case to test and evaluate the MM strategy design methodology. The characteristics of the context fulfil the three demands set for a project to be suited for the design of a comprehensive MM strategy. The possibilities within the Rotterdam context regarding other type of transport measures to mitigate temporary network problems is limited. This is also emphasised by the municipality of Rotterdam, with the need statement to develop a MM strategy and the high value they attach to this MM strategy to cope with a significant part of the transport network related problems during the renovation project.

7.2. Introduction case

Background

Rotterdam is the second biggest metropolitan agglomeration as well as the second biggest municipality of the Netherlands, with respectively 1.2 million and 600.000 inhabitants (CBS, 2014b). The Port of Rotterdam and Rotterdam/The Hague airport enforce a strong economic position for Rotterdam on an international level. The port of Rotterdam, the largest European port, functions as important intercontinental connection between ports all over the world and the European hinterland. It attracts many international companies and positions Rotterdam as one of the most important economic areas of The Netherlands (Municipality of Rotterdam, 2013b)

Figure 21 Rotterdam (red area) with important national/international hubs and ring road.

The city centre of Rotterdam is surrounded by a ring road called 'The Ruit' of Rotterdam, facilitating regional and national traffic flows. Most urban interaction takes place inside this ring road. The largest part of the inhabitants is housed in this area, as well as a lot of companies.

Many urban functions are located in the area near the Erasmus Bridge and the Willems Bridge. Mainly only the north side, but also on the south side of these bridges, many offices, shops and facilities are situated. This 'urban city centre' (figure 22) is the heart of Rotterdam, creating social and economic welfare. The facilities in this area attract many travellers, creating large traffic flows from and to the city centre.

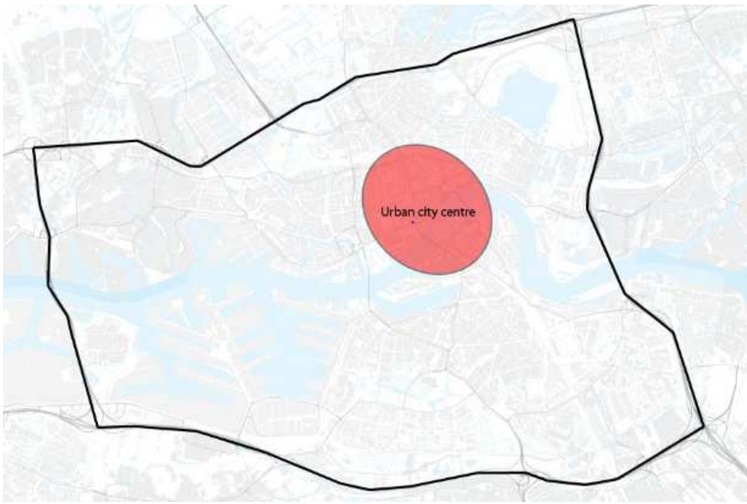

Figure 22 Urban city centre (red oval), facilitating social and economic welfare. The black links represents the ring road of Rotterdam.

The city is divided by The River Maas, impeding traffic flows between the North and South side of the city. The bridges and tunnels crossing this river are essential for the functioning of Rotterdam's transportation network and the city's economy. There are three bridges and two tunnels connecting the North and South side of Rotterdam (figure 23). The Maastunnel, Erasmus Bridge and Willems Bridge are located inside the city, enabling urban and regional traffic flows between the two riversides. The Benelux tunnel and the Van Brienenoord Bridge are located at the edges of the city. They function as links of the national transportation system. From the urban/regional river crossings, The Maastunnel handles the most traffic. Double the amount of cars are using The Maastunnel compared to The Erasmus Bridge. And three times as much trips are performed using The Maastunnel compared to the Willems Bridge (Table 49).

Table 49 Average amount of vehicles crossing the river crossings on a daily base (Municipality of Rotterdam, 2013a).

	Benelux tunnel	Maastunnel	Erasmus Bridge	Willems Bridge	Van Brienenoord Bridge
type	National link	Urban/ regional transport links			National link
vehicles	130.000	60.000	30.000	20.000	230.000

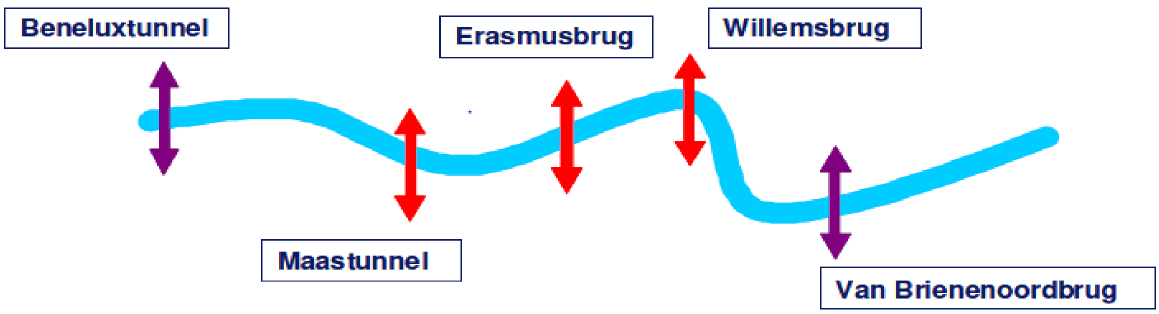

Figure 23 North- South connections Rotterdam (Municipality of Rotterdam, 2013a, p. 4).

The Maastunnel renovation project

In 2011 inspections of The Maastunnel showed that the construction of the tunnel has been damaged. Together with new Dutch law and regulations regarding tunnel safety as of May 2019, this resulted in the need to renovate The Maastunnel. Proceedings of the renovation are planned from June/July 2017 till May 2019.

A daily average of 60.000 vehicles is crossing The Maastunnel, making it the most important urban link connecting the two riversides (table 49). The Maastunnel will be renovated by the consecutive closing of one of the two driving directions. During proceedings traffic will constantly be able to drive through the tunnel in South- North direction to ensure direct access to the Erasmus Medical Centre.

Renovations of the tunnel will impact the city of Rotterdam: *'The Maastunnel is one of the essential links in the urban and regional traffic network. Restrictions in the use of the tunnel will have a significant impact on the functioning of the city* (Municipality of Rotterdam, 2013a). The impact of the project will cause direct problems for the transportation network of Rotterdam, resulting in economic and social damage for the city and its citizens.

Before deciding on how to renovate The Maastunnel, preliminary research has been done commissioned by The Municipality of Rotterdam, investigating the effects on the transportation system of alternative ways to renovate the tunnel. This preliminary research is not part of the scope. The results are included to illustrate the decision process. Four renovation alternatives have been analysed, based on two criteria:

- Continuous closing vs. Closing during summer periods
- Complete closing of tunnel vs. Tube for tube closing (In the tube for tube variants traffic is allowed to travel from the south side of the river to the north side. This direction is chosen to maintain the accessibility of the Erasmus medical centre (main hospital of the Rotterdam area).

The results of the four alternatives on the transportation system have been researched, using the macroscopic regional transport model (RVMK) of Rotterdam in combination with microsimulations of PARAMICS. This study showed the following main results:

- The complete closing of the tunnel causes a negative effect on 'The Ruit' of Rotterdam (figure 2), affecting traffic flows on a national level.
- The tube for tube variants only impact the urban/regional traffic within 'The Ruit'.
- Traffic intensity is lower during the summer periods. Concentrating renovation proceedings during this period is preferred, because it will cause less significant problems.

From the four renovation alternatives, the municipality decided to select the continuous tube for tube closing. This choice has been made because the tube for tube variants showed less significant network problems than the complete closing variant and the renovation deadline of 2019 did not provide enough time to execute proceedings merely during the summer periods.

7.3. Phase 1: Problem definition

The goal of this phase is to define the problem(s) caused by the IRP. The level of impact in the base scenario (scenario without mobility management during the renovation project) is analysed, together with other impacts on the city. This scenario is used as references scenario. Based on the level of impact, the main strategy is defined. In case the level of impact is significant, harming large parts of the city, the decision will be made to design a strategy with a higher level of effectiveness, based on push measures. If the problem analysis indicates a lower level of impact, a MM strategy based on socially more accepted push measures, with a lower level of effectiveness, will be sufficient. The following steps will be executed (table 50)

The system analysis indicates the problems in the system. Together with the stakeholder analysis, the relevant impacts and on the city are identified and linked to societal/business groups. Based on these two analysis the project scope is defined. The decision to design a MM strategy based on push measures or merely including pull measures is made by comparing the project scope with the results of analysis.

Table 50 Phase 1: Problem definition

stage	Task	Output
analysis	System analysis	Bottlenecks
		Level of impact on the transportation system
	Stakeholder analysis	Stakeholders
		interests
	System and stakeholder analysis	impacts
design	Determine project scope	Target and management area
		Time span
		Performance indicators
		Goals + criteria
evaluate	Compare impacts with project scope	Decision to include push measures

7.3.1. Analysis: problem definition

This part analysis the problem caused by the renovation of The Maastunnel. The deliverables are the bottlenecks in the transportation system and a list with stakeholders and related interests.

System analysis

The results of the system analysis are based on a model study performed by Grontmij using the dynamic Paramics in combination with the macroscopic static Omnitrans model of The Municipality of Rotterdam (Municipality of Rotterdam, 2013a).

The renovation of The Maastunnel will cause significant problems. The closing of The Maastunnel in North South direction will force traffic to search for alternative routes. Most trips will shift to the Erasmus Bridge and the Willems Bridge. The increase of traffic on the Erasmus Bridge and Willems Bridge causes significant problems on both sides of the river. The traffic, trying to cross the river, will be hindered, blocking large areas on both sides of the river (red areas figure 24). These two areas, especially the north part (the city centre), are from an economic and social perspective very important for the city Rotterdam. Many shops, offices and hospitality facilities are located in these areas. The blocked bridges will cause a relapse on both sides of the cities, hindering large parts of Rotterdam insdie the ring road. The congestion on the Nort-South connections functions as obstacles on the West-East corridors. This way the congestion reaches further towards the ringroad. The congestion caused by the closing of The Maastunnel in North-South direction will approach the access roads of the ring of Rotterdam, connecting the city centre. The ringroad itself is not affected by the closing of The Maastunnel. Sparing national traffic flows from congestion caused by the renovation of The Maastunnel.

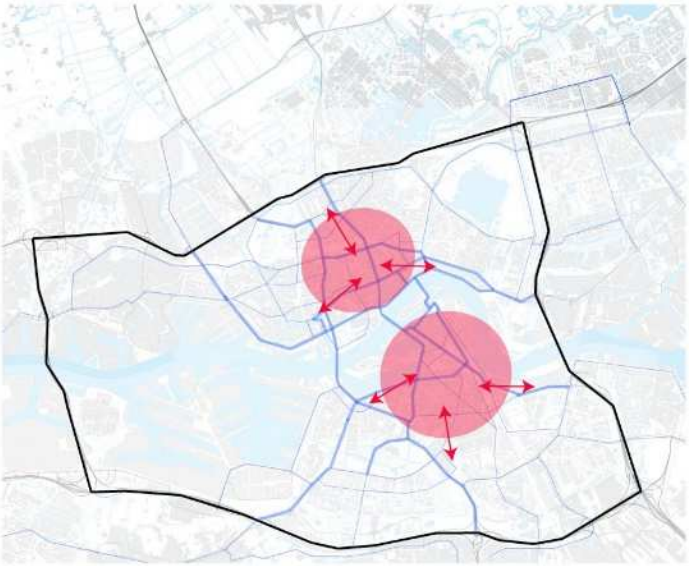

Figure 24 Accessibility problems caused by renovation on roads connecting the city centre and the ring road of Rotterdam.

Problems only occur during peak hour. During the morning and the evening peak, traffic jams occur. The problems during the evening peak are slightly larger than during the morning peak, because more cars are crossing the river during this period.

Stakeholder analysis

An overview of the important groups of stakeholders in the Rotterdam area is presented in table 51. Related interests are connected to the stakeholders. The interests of certain stakeholders are not affected by the network problems. The final column in table 51 shows if the interests are directly affected or not.

The stakeholders with interests, that are not affected, are mainly dependent on the national transport network (highway system). This are the two international hubs: Port of Rotterdam and Rotterdam/The Hague Airport, the national government (Though a part of national welfare is created in Rotterdam, the effect on a national level is less significant.) and Rijkswaterstaat. The public transport providers are not negatively affected. Only one bus line is hindered. The demand for PT is likely to increase though.

Table 51 Stakeholders and interests in the accessibility of the Rotterdam transportation system

stakeholder	interests	affected
~~National government~~	• ~~Accessibility Port of Rotterdam & Rotterdam-The Hague airport.~~ • ~~National welfare~~ • ~~National accessibility~~	~~No~~
~~Rijkswaterstaat~~	• ~~No distribution effects/congestion national highway system~~	~~No~~
~~Port of Rotterdam~~	• ~~Accessibility~~	~~No~~
~~Rotterdam/The Hague airport~~	• ~~accessibility~~	~~No~~
Local government Rotterdam	• **Costs** • **Accessibility city** • **Economic welfare** • **Social welfare** • **Accessibility equity (access to the cities functions for all citizens)** • **Safety** • **health**	**yes**
Society/citizens of Rotterdam	• **Participation** • **Accessibility** • **Travel time (travel costs)**	**yes**
Network users	• **Travel time**	**Yes**
Shops/hospitality services	• **Accessibility** • **Attractiveness** • **health**	**Yes**
employers	• **accessibility**	**yes**
Commuters	• **accessibility**	**yes**
Erasmus medical centre	• **accessibility**	**yes**
~~Erasmus university~~	• ~~accessibly~~	~~No~~
~~NS/RET~~	• ~~Income~~ • ~~Accessibility~~ • ~~connectivity~~	~~No (one bus line is disrupted, this is at a negligible level for the RET)~~

Bottlenecks

Based on the system analysis the following two bottlenecks are found. Though The Maastunnel is the part of the infrastructure subject to renovation, the problems occur at the other two urban river crossings. This is where the origin of congestion is found. These are The Erasmus Bridge and The Willems Bridge (Figure 25).

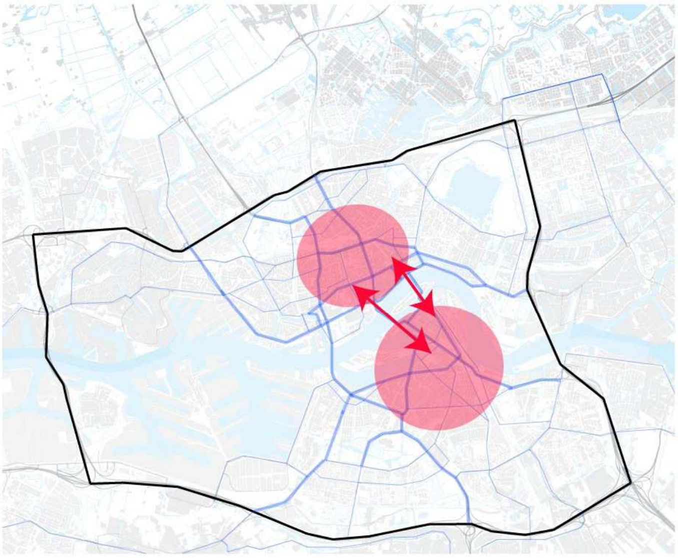

Figure 25 Bottleneck: problems on Erasmus Bridge and Willems Bridge (red arrows), blocking large parts of the city centre of Rotterdam (red circles)

Impacts

Based on the system analyses, with related bottlenecks and the stakeholder analysis, the relevant impacts are determined. The impacts stated in chapter 3 (table 52) are adopted. They largely resemble the interests of the stakeholders. Economic welfare is added. This is an important impact for the shop/facility owners of the city centre.

Table 52 Impacts of the renovation of The Maastunnel.

Type of impact	impact
Accessibility	Congestion (network effects)
	Travel time (network effects)
	Demand PT (distribution effects)
Liveability	Road safety
	Air pollution
	Noise pollution
Equity	Economic welfare (income urban functions)
	Participation (access equity)
	Costs (investments costs)
	Traveller benefits/costs (distribution of different groups of society)

7.3.2. Design: project scope and evaluation criteria

Here, based on the stakeholder analysis and the bottlenecks, the project scope and the evaluation criteria are defined. The project scope exist of the time frame, the target area and the management area of the MM strategy. The evaluation criteria exist of the goals and performance indicators (PI's). Where the PI's, directly related to the goals, are considered as the key performance indicators (KPI's). For the KPI's, criteria are defined.

Scope

The primary goal of the MM strategy is to mitigate short term problems during the period of May 2017 till June/July 2019, when the renovation project will be executed, resulting in congestion.

The possibility to prolong the measures should exist, in case the renovation project is delayed. If the possibility of delay is not taken into account, the transportation system can still collapse after the planned two years, harming local society and economy.

The target area during the renovation of The Maastunnel is the city centre and the adjacent neighbourhoods of Rotterdam within the ring road. Network problems will occur within this area (dark orange oval figure 27) (Municipality of Rotterdam, 2013a).

The management area (light orange oval) is the area where users of the Rotterdam transportation system should be influenced by the mobility management measures in order to achieve sufficient results of the MM measures in the target area. Data acquired from the regional transport model (RVMK) show that most travellers with an origin or destination in the target area travel within this management area (>75%).

Zooming in on the target area, this area can be divided in a critical area and an area of direct influence (figure 28). This distinction is made because the critical target area houses a lot of economic and social activities and it is directly feeded by the infrastructure defined as bottlenecks (figure 25). The critical area exists of the neighboorhoud called 'city centre' and a part of the area called 'Feijenoord'.The area of direct influence exists of the neigbourhoods: Noord, Charlois, Kralingen, Delfshaven, IJsselmonde and the other part of Feijenoord.

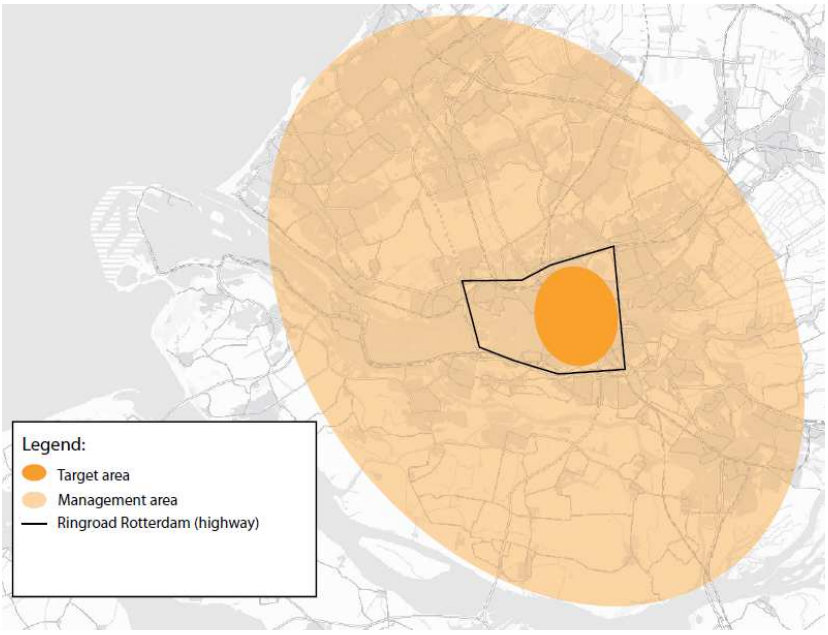

Figure 26 Target and management area

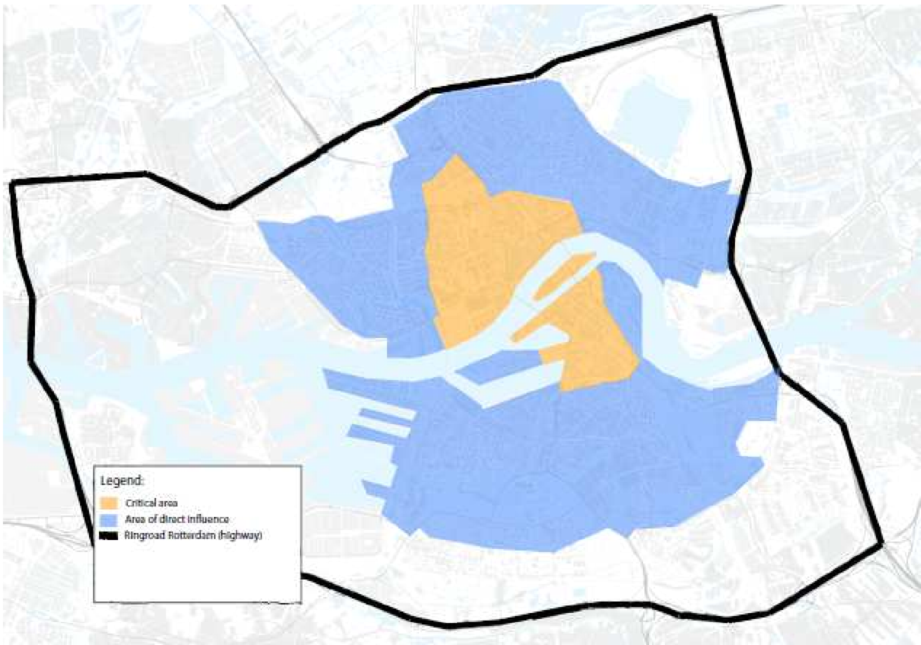

Figure 27 Critical area and area of direct influence.

Performance indicators

For the different impacts, performance indicators are formulated. This way the impacts can be incorporated in the evaluation, to determine the effectiveness and efficiency of different MM measures and strategies.

Table 53 Performance indicators, related to the impacts

Impact	PI's
Congestion (network effects)	No. of vehicle reductions
Travel time (network effects)	Vehicle loss hours
Demand PT (distribution effects)	Modal shift
Road safety	casualties
Air pollution	Production emissions (Focus on NOx and PM10)
Noise pollution	Sound levels (in decibel)
Economic welfare (income facilities)	Revenues local facilities
Participation (access equity)	Difference in travel time to urban functions for groups of society.
Costs (investments costs)	Investments costs (in €)
Traveller benefits/costs (distribution of different groups of society)	Total costs/benefits for travellers in direct financial compensation

Goals and criteria

Related to the essential impacts, goals are formulated with related criteria. The goals and criteria are summarized in table 54. As described in chapter 3 (section 3.3), the main goal of every MM strategy for an infrastructure renovation project is to mitigate temporary network problems (congestion), caused by the renovation project. Also for the renovation of The Maastunnel, this will be the main goal.

Regarding congestion reduction, the criteria is to reduce 2000 vehicles during the evening peak. Research of The Municipality of Rotterdam in collaboration with Grontmij showed that mobility management effective in reducing 2000 vehicles in the city centre of Rotterdam during the evening peak, is sufficient in mitigating network problems caused by the renovation of The Maastunnel (Municipality of Rotterdam, 2013a).

Besides this, secondary goals are set regarding air and noise pollution and access equity. Redistribution of traffic flows can lead to local emission and sound limits being exceeded. Due to the fact, that the renovation project will take at least two years, this can harm the health of citizens of Rotterdam. Access equity goals are defined, because additional travel time/costs can lead to inequity for underprivileged groups of society. This can lead to inaccessibility of social and economic functions for these groups. From a social policy perspective this is unacceptable. Therefore this goal is included in the project scope.

For noise pollution, Dutch legislation denotes an upper limit of 58 dB, according to L_{den} measurements (Nieuwenhuis, Stolke, & Valk, 2013). (L_{den} is the time weight average of the period-punished equivalent noise-levels. Based on three daily periods: day, evening and night (De Vos, 2006).) Due to the high need for a functioning transportation system and the temporary characteristics of the renovation project, the upper limit is used. For air pollution the norms will be used as criteria, as defined by the European Union (EU, 2008). Also for this criteria the upper limit is used, due to reduced health risks because of the temporary characteristics of the renovation project.

Access equity is included in the goals to guarantee social welfare for all citizens. It is difficult to exactly define proper criteria for this goal. Essential is that all groups of society have got access to social goods (Rawls, 1971). Underprivileged groups are not allowed to be affected disproportional by the renovation project.

Table 54 Goals and criteria MM strategy during The Maastunnel renovation project.

<table>
<tr><th colspan="2">Goal</th><th colspan="2">criteria</th></tr>
<tr><td colspan="2">Reduce congestion</td><td colspan="2">Reduce 2000 cars during the evening peak.</td></tr>
<tr><td colspan="2">Maintain accessibility level/ access equity</td><td colspan="2">No relative increase in travel time for underprivileged groups of the Rotterdam society, compared to other groups. Effects should be distributed evenly.</td></tr>
<tr><td rowspan="4">Control air pollution (EU, 2008)</td><td rowspan="2">NO2</td><td>Hour limit</td><td>70% of the upper limit (140 µg/m3) cannot be surpassed more than 18 times a year.</td></tr>
<tr><td>Annual limit</td><td>80 % of de upper limit (32 µg/m3).</td></tr>
<tr><td rowspan="2">PM10</td><td>24-hour limit</td><td>70% of the upper limit (35 µg/m3) cannot be surpassed more than 35 times a year.</td></tr>
<tr><td>Annual limit</td><td>70 % of de upper limit (28 µg/m3).</td></tr>
<tr><td colspan="2">Control noise pollution (Nieuwenhuis, Stolke, & Valk, 2013)</td><td colspan="2">No exceeding of 58 dB based on L_{den} measurements</td></tr>
</table>

7.3.3. Evaluate level of impact IRP

Based on the analysis and the project scope, the decision is made whether to design a MM strategy including push measures. This depends on the level of impact of the infrastructure renovation project.

Based on the report of The Municipality of Rotterdam (Municipality of Rotterdam, 2013a), stating the need to reduce 2000 vehicles during the evening peak, **the decision is made to include push measures in the MM strategy**, to reach the required effect on the transportation system. Based on evaluation studies of MM, it is not likely that pull measures (except peak avoidance rewarding) will be have the necessary effect, unless high investments are made (Henstra, Akkersdijk, pol, Pieper, & Voerman, 2005; Ministerie van infrastructuur en milieu, 2011; Savelberg & Korteweg, 2011).

7.3.4. Conclusions phase 1

The conclusions regarding phase 1 are denoted, related to the case and to the methodology.

Case

Regarding the case, the scope and evaluation criteria are defined. These are used in the following phases to design the MM strategy.

Design methodology

The different stages and related deliverables of phase 1 of the design methodology are discussed.

<u>Analysis</u>

The execution of the different tasks of phase 1 did not show many complications. The focus during the case study has been on the system analysis. The system analysis provided the necessary information about the bottlenecks and magnitude of the impacts on the transportation system caused by the renovation project.

The groups used in the stakeholder analysis of this case are fairly general. To improve this analysis, a more detailed level of stakeholder groups need to be analysed. This will help by identifying the exact needs of groups of society. For example, the citizens of Rotterdam can be split in more specific groups, based on residential area. Different groups within Rotterdam will have different interests. Another example is the group network users. Network users with different trip purposes and origins and destinations will have different needs and interest regarding the renovation project. Besides more detail, characteristics regarding the level of influence, the need for collaboration and the position towards the project can be included to create more understanding of the relation between the stakeholders and the project. This can lead to a better definition and understanding of the impacts considered during the design of the MM strategy. Which will help during the design stage of

<u>Design</u>

With regard to the design stage of phase 1, some difficulties appeared regarding the criteria related to the goals. Especially for noise and air pollution, more information is needed, regarding the short term effect of exposure to different sound levels and particles. The other deliverables were relatively easy to obtain and specify.

<u>Evaluate</u>

The evaluation stage of this phase did not show complications due to the detailed modelling results of Grontmij. The level of impact on the city is of such a level, that the decision for more effective, push measures, was evident.

7.4. Phase 2: Main alternatives

During this phase, alternatives are defined and tested on their effectiveness. The effectiveness regarding the different defined goals is analysed. The main focus will be on the effectiveness in reducing congestion. The first phase, the problem definition, illustrated the need for a MM strategy with a high level of effect. This resulted in the need for push measures. First the transportation system is analysed. Based on the results of this analysis in combination with the potentially effective measures defined in section 3.5, main alternatives are chosen. These main alternatives are tested and evaluated regarding the effectiveness. An indication is given of the level of public support and the costs. This is used for choosing the best alternative(s) and the next phase of the design process. The steps and deliverables of this stage are illustrated in table 55.

Table 55 steps and deliverables phase 2

stage	Input	tasks	deliverables
System analysis	Characteristics transportation system (Section 4.2.3 + 4.2.4)	Analysis transportation system	possibilities to shift demand
Design	List with effective measures (section 2.5)	Define main alternatives: push or pull measures	Alternatives
Test	alternatives	Model alternatives	Effect on transportation system (network performance) regarding different goals.
Evaluate	Goals and criteria defined in section 7.3.2 and the properties of the test stage of this phase.	Compare effects on transportation system with goals.	Judgement effectiveness
			Indication financial feasibility
	Characteristics social support (section 4.3.1)		Indication social opinion

7.4.1. Analysis: transportation system

The system analysis is summarised. Based on the different characteristics of the Rotterdam transportation system conclusions are derived regarding the possibilities of mobility management measures. The travel market, supply side and demand side of the transportation system are analysed. The detailed findings of the analysis of the transportation systems are found in annex D.

Conclusions analysis transportation system

Several conclusions can be derived from the analysis of the transportation system of Rotterdam.

1. There is a high concentration of facilities to perform activities in the city centre. Especially, jobs, hospitality services, shops and cultural activities are clustered in the city centre.
2. This cluster of activities in the city centre attracts a lot of trips. Different modes of transportation are used to travel from and to the city centre.
    a. A high amount of travellers uses the car, compared to other big cities in The Netherlands.
    b. Public transport is used relatively often to travel between origins and destinations Inside Rotterdam. Especially the metro system holds an important position, transporting a relative high amount of travellers.
    c. On a regional scale public transport (train) has a lower modal share for people traveling to and from Rotterdam, compared to the three other big cities in The Netherlands; Amsterdam The Hague and Utrecht.
    d. Inside Rotterdam the percentage of people traveling by bicycle is extremely low, also compared to the big cities. This can partially be explained by the cultural background of inhabitants, but the difference is quite extreme (De Vries, 2013). <20% trips are made by bicycle in Rotterdam, compared to <35% in Amsterdam and Utrecht.
3. The infrastructure networks in Rotterdam are of a high quality. Systems for all modes have a focus towards the city centre, where the network density increases. The public transport system is of a very high quality. This contributes to the high modal share of public transport inside Rotterdam.
4. The combination of the high demand on the city centre by car users, the high network density in this area and the scarcity of river crossings, puts a lot of pressure on the Rotterdam road system in the city area. There are few alternatives. This means that taking out one of the river crossings, puts a significant amount of additional pressure on the other river crossings.

7.4.2. Design: main alternatives

Based on the analysis of the transportation system and the list of push measures (and peak avoidance rewarding) with a high potential and the characteristics of these measures, alternatives are chosen, which are potentially the most effective.

Alternatives:

Two alternatives are chosen and worked out into more detail in order to test and evaluate them on their effectiveness. These alternatives are access restrictions and parking pricing. Two other MM measures were found in literature to have a very high level of effectiveness: road pricing and peak avoidance rewarding. Implementing a road pricing system is likely to be difficult, due to administrative complexity of implementation (Gakenheimer, 2008). Where a quick implantation time and process is demanded, this does not seem to be the best solution. Peak avoidance rewarding is a measure, from which the results are already analysed by the Municipality of Rotterdam for this case (Municipality of Rotterdam, 2013a). Therefore, it will not be researched again. More detail is now given about the two alternatives that will be tested and evaluated in this case study.

1. Access restriction. Because of the limited amount of alternative routes (conclusion number 4, in the previous transportation system analysis, section 7.4.1), this seems to be an effective measures (Rosenbloom, 1978). The even/uneven number plate system could potentially realise a high level of car reductions to mitigate congestion problems.

One similar study, regarding number plate restrictions is found. This research focusses on the city of Beijing. The even/uneven number plate access restriction policy in Beijing shows a reduction of 22.5% of cars (Liguang, 2010). The restricted area, for the case of the renovation of The Maastunnel, is the critical area (figure 27), the arterials are excluded, so drive through traffic is not hindered. Cars will be able to use the two bridges: The Willems Bridge and The Erasmus Bridge. The goal is to generate less traffic from and to the city centre by car. A bandwidth between 15% and 30% is analysed, due to the uncertainty of the effects. This is based on the assumption that the results will be similar to the Beijing case.

2. Parking pricing. The position of network problems in the central business district/city centre (conclusion number 1, in the previous transportation system analysis, section 7.4.1), combined with relative low existing parking fares in Rotterdam, create possibilities for effective parking price increases to reduce the amount of trips made by car (Rosenbloom, 1978; Savelberg & Korteweg, 2011).

The effects of parking fee raises are based on three variables:

- Price
- Area
- Elasticity

Fare increases differentiate between 25% and 100%. According to literature the elasticity of parking pricing is expected to range between -0.1 and -0.3 (Geilenkirchen, Van Essen, & Schroten, 2008; Concas & Nayak, 2012; Kuzmyak, Weinberger, & Levinson, 2003). The critical area is called area 1. This area exist of the city centre and Feijenoord North. The area Feijenoord South, Charlois, Kralingen, Noord and Delfshaven is considered as area 2. The price increases are varied over the two defined areas. Scenarios with different price elasticities are tested.

Table 56 variables parking pricing

Variable	Range
Price elasticity	-0.1 - -0.3
Price increase	25% – 100%
Area	Area 1: City centre + feijenoord north
	Area 2: Feijenoord south, charlois, Kralingen, Noord, Delfshaven

Scenarios

The scenarios tested are illustrated in table 57 and 58. For access restriction, four scenarios are researched (table 57). The scenario with 17.6% car trips reduced is used, because this results in a total amount of 2000 car trips reduced during the evening peak, which is the goal of the MM strategy. For parking pricing, six scenarios are researched, where the effect is tested with different price elasticities (table 58).

Table 57 Scenarios for access restrictions

Access restrictions
15% of car trips reduced
17.6% of car trips reduced
22.5% of car trips reduced
30% of car trips reduced

Table 58 Scenarios for parking pricing

Parking pricing	
Area 1	**Area 2**
25% fare increase	-
50% fare increase	-
75% fare increase	-
100% fare increase	-
50% fare increase	25% fare increase
25% fare increase	10% fare increase

7.4.3. Test: Main alternatives

The effects of the two alternatives are tested on their effectiveness in achieving the goals set in section 7.3. First, based *on price elasticities, the reduction in trips made by car, during the evening peak, is estimated in different scenarios. Based on these results, for relevant scenarios the matrices in the regional transport model of Rotterdam (Omnitrans, RVMK) are adjusted to test the effects on the transportation system.*

Step 1: Car reductions, testing on effectiveness in resolving congestion

Based on the variables defined in section 7.4.2, the effects on the transportation system are estimated. To make the results applicable in the Omnitrans transport model of Rotterdam a special job is used. A percentage is determined for car reductions during different time periods (morning peak, evening peak, rest day) between areas. There are 45 areas used (45 * 45 matrix), based on the boundaries of the Rotterdam transport model. Areas further away from Rotterdam have got a lower level of detail. The job translates the percentage in trip reductions for all relevant OD pairs in the Omnitrans model of Rotterdam from the 45 * 45 matrix in the 5612 * 5612 matrix of the Omnitrans model (there are 5612 centroids in the regional model of Rotterdam). An example of the job is illustrated in annex E. Table 59-62 show the results of the job runs in trip reduction during the evening peak.

Access restrictions

Table 59 Amount of car reductions based on different percentages of travellers changing mode due to the MM measure.

Percentage car reduction	Time	Car reduction
15%	Evening peak	1705
17.6%	Evening peak	**2000**
22.5%	Evening peak	2556
30%	Evening peak	3409

Parking pricing

Table 60 Amount of car reductions, based on different price elasticities, when parking fares are increased in area 1.

elasticity	Price increase			
	25%	**50%**	**75%**	**100%**
-0.1	-696	-1391	-2087	-2782
-0.2	-1391	-2782	-4173	-5565
-0.3	-2087	-4173	-6261	-8346

Table 61 Amount of car reductions, based on different price elasticities, when parking fares are increased with 50% in the area 1 and with 25% in area 2.

area	Price increase	Elasticity -0.1	Elasticity -0.2
Area 1	50%	**-3508**	-7016
Area 2	25%		

Table 62 Amount of car reductions, based on different price elasticities, when parking fares are increased with 25% in the area 1 and with 10% in area 2.

area	Price increase	Elasticity: -0.15
Area 1	25%	**-2632**
Area 2	10%	

Results regarding goal of congestion reduction:

- If 17.6% of the travellers changes to another mode or does not perform the planned trip when access restrictions are introduced in the city centre, the criteria regarding congestion reduction are met.
- 50% parking fare increases in area 1 would result in the 2000 car reductions during the evening peak, if, the price elasticity is -0.15 or higher. Parking price increases of 75% or more in area 1 will guarantee the 2000 car reductions. A price elasticity of -0.1 is necessary in this case.
- If parking prices are increased both in area 1 and area 2, an increase of 25% in area 1 and 10% in area 2, result in 2632 car trip reduction if the price elasticity is -0.15.

Step 2: Test effectiveness other goals

First a deterministic user equilibrium (DUE) network assignment of the base scenario, the scenario without mobility management, is executed. For the relevant scenarios of the two alternatives, the effects on the transportation system, are modelled, with the goal to determine the effectiveness regarding the other goals:

- Air pollution,
- Noise pollution
- Access equity.

Unfortunately, due to the model limitations of the variant of The Maastunnel renovation, a lot of data could not be obtained (See annex F for model specifications and more detailed information about the model limitations and possibilities). Due to the fact that the model variant did not include a trip generation, trip distribution, mode choice and departure time choice, distribution effect could not be researched. Combined with the static characteristic of the model, which did not show congestion effects over time and recoil effects from one link to another, no properties were obtained, to evaluate the criteria set for these goals later on during the design process.

The results of the different model runs are illustrated to show what the effects of the measures are, according to the Omnitrans model. The model used, is adjusted, based on the renovation of The Maastunnel. In the model, The Maastunnel is closed in North-South direction and eight physical adjustments of the infrastructure are included in the model variant. These eight physical adjustments are going to be executed on the Rotterdam' transportation system, to improve traffic flows during the renovation period (Municipality of Rotterdam, 2013a).

<u>Reference scenario:</u>

A bandwidth plot is displayed, illustrating the intensity/capacity (IC) ratio during the evening peak (Figure 28). The problem areas are indeed, the urban river crossings, as decribed in section 7.3.1: The Erasumus Bridge and The Willems Bridge. On the Erasumus Bridge, the IC ratio in North-South direction is 110. This indicates that more cars are crossing this bridge, then that the capacity allows. This will result in congestion. The bandwidth plot does not illustate recoil effects due to congestion. On the Willems Brdige the IC ratio from North to South is 88. Demand does not exceed capacity on this link. But an IC ratio above 80 already results in trip delays (Van Den Brink & Wismans, 2012).

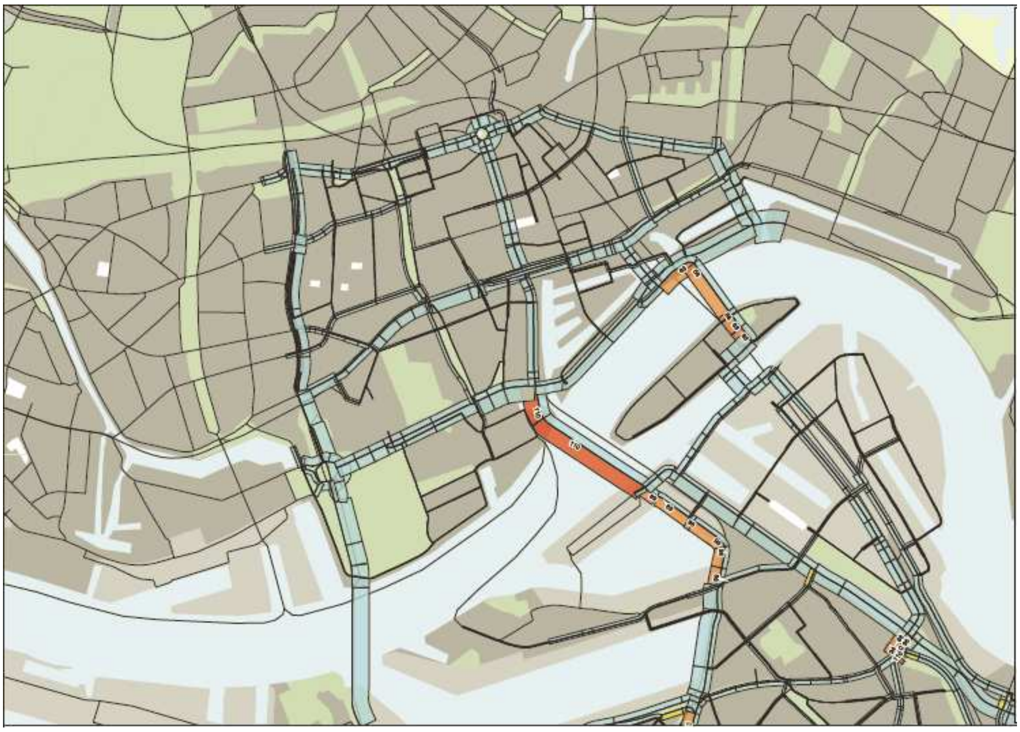

Figure 28 Bandwidth plot of the urban river crossings, illustrating the IC ratio during the evening peak.

<u>Access restrictions</u>

For the different scenarios, the DUE assignment is run. The IC ratios are illustrated in table 63. One bandwidth plot is displayed to show the results of the model run on the transportation system (figure 29). The bandwidth plot of the scenario with a car trip reduction of 17.6%. All bandwidth plots show approximately the same results. The bandwidth plots show no distribution effects or indications for large increase of access equity (No links to other areas are congested, except for the bottleneck bridges). The IC ratio indicates, that congestion is not resolved in all scenarios.

Table 63 IC ratio bottlenecks during the evening peak in North-South direction, including the results of the reference scenario.

Percentage car reduction	Erasmus Bridge	Willems Bridge
Reference scenario	110	88
15%	108	84
17.6%	108	84
22.5%	108	83
30%	107	81

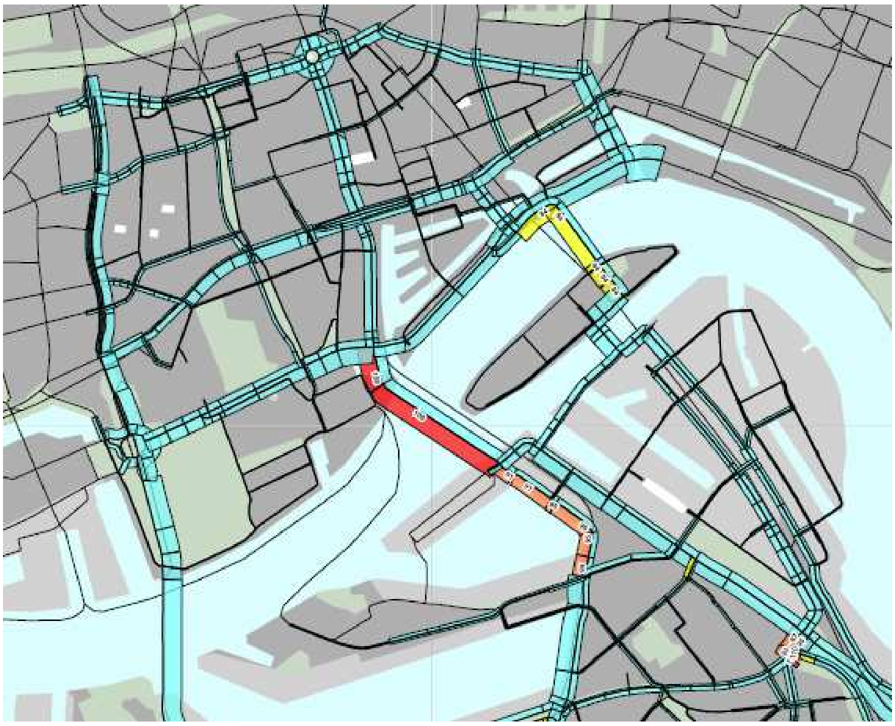

Figure 29 Bandwidth plot during evening peak, when 17.6% of car trips are reduced in the city centre, due to access restrictions.

<u>Parking pricing:</u>

For parking pricing the same assignment (DUE) is run for the different scenarios. The IC ratios are shown in table 64. The bandwidth plots show similar results as for the access restriction scenarios. There is still congestion on the Erasmus Bridge. Which will cause problems in the city centre, which is not shown by the model.

Table 64 IC ratios during evening peak for different parking pricing scenarios.

Percentage parking price increase		Price elasticity	IC ratio	
Area 1	**Area 2**		**Erasmus Bridge**	**Willems Bridge**
50%		-0.1	109	86
75%		-0.1	109	85
100%		-0.1	109	84
100%		-0.2	107	81
25%	10%	-0.15	109	85
50%	25%	-0.2	108	82
50%	25%	-0.1	109	84
Reference scenario		0	110	88

7.4.4. Evaluate main alternatives

The results of the test stage of this phase are evaluated. The main purpose is to see if the MM measures, defined as alternatives, in this design process, are effective in achieving the different defined goals. Also, an indication of the level of public support is given and an indication of the financial feasibility.

Effectiveness

Resolve congestion

The estimations, based on price elasticity for the parking price measure scenarios and the estimations based on a reference study of Beijing for access restrictions (even/uneven number plate system) showed that both measures can potentially realize 2000 car trip reduction during the evening peak in the city centre.

- For access restrictions a percentage of 17.6% les car trips to and from the city centre results in a reduction of 2000 car trips during the evening peak.
- For parking price increases, merely in area 1, 2000 car trips are reduced, if:
  - The prices are increased with 50% and the price elasticity is -0.15.
  - The prices are increased with 75% and the price elasticity is -0.1.
  - The prices are increased with 100% and the price elasticity is -0.1 (a slightly lower price elasticity already fulfils the goal of 2000 car reductions).
- For parking price increases in area 1 and 2 more than 2600 car trips are reduced, if the prices are increased with 25% in area 1 and 10% in area 2 and the price elasticity is -0.15.

The model runs in Omnitrans of the different scenarios, do not illustrate the same traffic images as the dynamic model runs by Grontmij. The reference scenario, where The Maastunnel is closed in North-South direction shows congestion on The Erasmus Bridge, but besides this barely any congestion in the city centre. The dynamic model runs of Grontmij (model used: Paramics) illustrated almost a completely congested city centre.

Bandwidth plots of the IC ratios, to indicate the intensity on the links in the network, show a minimal reduction of cars on the bottleneck links. For example, 5000 car trip reduction during the evening peak in the city centre shows an intensity on the Erasmus Bridge of 107 and on The Willems Bridge of 81. This would mean that there is still delay on The Willems Bridge and congestion on The Erasmus Bridge, while the criteria of 2000 car reduction during peak hour is easily reached.

Two main reasons are found to explain the inaccurate results of the model runs of the regional transport model of Rotterdam:

- A static assignment is used. No interaction over time is considered and recoil effects are not modelled.
- The model variant of The Maastunnel renovation project does not include a trip generation, trip distribution, mode choice and departure time choice. Therefore, effects of the measures on these model stages are not taken into account when running the model. Providing inaccurate results of the effects of the measures.

Access equity

To analyse the difference in accessibility of different groups of society, results regarding increase in travel time are needed. These data are not obtained during the test stage. In the reference scenario, the dynamic traffic assignment of Grontmij showed a limited increase of travel time between different areas (Municipality of Rotterdam, 2013a).

Access restrictions in the city centre would mean that inhabitants of this area are limited in the accessibility to and from their houses. This can lead to a significant increase in travel costs for this group (Based on additional travel time). For parking pricing the same problem occurs. Citizens living in this area are affected on a daily base. If the prices are increased in area 1, this does not lead to major problems, because inhabitants in this area, already have parking permits. If parking pricing is introduced in area 2, this can lead to problems, because not all parts of area 2, are paid parking areas.

Air and nose pollution

Because the transport model did not illustrate the traffic flow changes, data regarding local air and noise pollution are not available. For the MM measure access restriction, a change in intensity in the roads surrounding the city centre is expected. This can lead to large increases of cars using the links surrounding the urban city centre. If this will lead to exceeded noise or emission limits cannot is not known with the limited data obtained.

Also parking pricing measures will lead to higher intensities around the city centre, because car users not willing to pay more for parking their car, will search for parking facilities outside the city centre. For a conclusive answer to the question if exceedances of air and noise limits are reached more research is needed.

Public support

There are four characteristics describing the level of public support: Perceived effectiveness, perceived efficiency, perceived fairness and infringement of freedom

The perceived effectiveness and perceived efficiency are difficult to predict for both measures. Perceived fairness depends e.g. on the fact, if people attach more value to ‘equality’ or to ‘pay for use’. If access restrictions are introduced, everyone is treated equally, except the inhabitants of the city centre. They are restricted in their daily life. Parking pricing will negatively influence the perceived fairness, as costs are increased. Parking pricing can be seen as a way for car users to pay for the public space they use and the external costs of pollution. This argument can be used in the information campaign. The exact levels for both type of measures regarding perceived fairness demand further research.

Regarding infringement of freedom, parking pricing will score better in society, because travellers still keep the freedom to choose. Access restriction eliminate the freedom to choose.

Costs

An indication of the feasibility regarding the costs is given. Phase 3 will elaborate further on the cost aspect.

Access restrictions

Due to the existing ‘milieu-zone’ in Rotterdam, the implementation costs should be limited. Cameras can already detect number plates. Only the software needs to be adjusted. Suitable software already exists.

Parking pricing

In the city centre, parking pricing already exist, also for this measure, the costs are limited. Only in the areas where parking pricing is not yet introduced, additional costs are made, due to the implementation of the system. For the existing parking pricing areas, merely software adjustments are needed.

7.4.5. Conclusions phase 2

The conclusions of the second phase are set out.

Case

Assuming that the criteria set by The Municipality of Rotterdam, that 2000 car trips reduced during the evening peak is sufficient to guarantee a proper functioning transportation system, both access restriction and parking pricing can meet the criteria. Information regarding the other goals is scarce. A dynamic model is needed including all five steps of the trip choice process to obtain accurate information about change in travel behaviour caused by the measures.

Considering the different evaluation criteria, parking price increases in area 1 seems the best solution. A MM strategy based on parking pricing increases in area 1 will be designed and evaluated in phase 3. Prices should be increased with at least 50%, with a price elasticity of -0.15, to obtain 2000 car reductions during the evening peak. If the price is increased with 75% or more, a price elasticity of -0.1 will lead to enough car reductions.

- Regarding access equity parking pricing seems to be fairer, compared to access restriction.
- Regarding air and noise pollution, local impacts are likely to be lower than those of access restrictions.
- Also for public support, especially looking at the infringement of freedom, parking pricing will score better.
- Due to the fact that parking pricing is already introduced in area 1, and not in all parts of area 2, area 1 is more suited for this type of mobility management measures. Implementing the system in area 1 is easier, than implementing the system in area 2.
- Because inhabitants of area 1 already have permits, parking price increases will affect them less, than people without permits in area 2.

The two alternatives peak avoidance rewarding and road pricing are not researched. Peak avoidance rewarding is potentially also a very effective measures, which creates less social resistance. But the costs are higher. Road pricing on the bottlenecks might be an alternative, which effectively eliminates the trips causing congestion. Travelers might search for alternative routes, blocking the city centre from other directions.

Design methodology

<u>Analysis</u>

The analysis of the transportation system, provided insight in the functioning of the travel, transport and traffic market. The combined analysis of the demand and supply on these market, resulted in a detailed overview of the possibilities within the transportation system to apply different MM measures. Regarding the design of the main alternatives, the analysis provided useful information for the following design stage.

<u>Design</u>

Based on the analysis, the decision for the design of the different alternatives was a logical result. No issues appeared in this stage.

Test

During the test stage multiple issues appeared. The model used did not provide the necessary information, needed to evaluate the alternatives in the next stage. Where mobility management thrives to change travel behaviour, a model is needed that includes the different trip choice decision moments influencing travel behaviour and illustrates the effects over space and time. The trip generation, distribution, mode choice and departure time choice steps were not present in the model variant. This resulted in the elimination of useful information regarding the effects on the transportation system of the researched alternatives. Only the existing matrices could be adjusted, by reducing the total amount of trips per OD-pair, departure time period and mode.

To evaluate if congestion is being resolved, recoil effects need to be incorporated in the model. Preferably a dynamic model is used, showing the effects over time and space. To evaluate noise and air pollution goals, speeds and intensities on the network over time are needed. A static model does not provide accurate data regarding these goals. To obtain proper data to evaluate these goals, a dynamic model is needed.

The model used is based on trips. Because the infrastructural element subject to renovation is closed in one way, a tour based model would generate more realistic travel behaviour. With a trip based model, the model can assume that travellers will travel through The Maastunnel in South-North direction to arrive at their destination without considering the closing of the tunnel in the other direction. At the moment the travellers will go home and want to drive through The Maastunnel in North-South direction, the model will detect the problem of the closing of the tunnel in this direction. According to the transport model, this will be the moment that travellers will consider the closing of the tunnel, while in real life they would consider this before they leave home. This results in less accurate travel behaviour. For example, in real life the traveller could have made the decision to change mode or departure time. With a tour based model this can be incorporated.

Evaluate

Due to the lack of behaviour incorporated in the transport model, the criteria set for the different goals cannot be evaluated. Regarding the level of public support much more information is needed. The actual implications of the measures regarding public support are not known, as is the effect of the public support on the political feasibility. This relation needs more research to properly incorporate the effects regarding public support in this design methodology.

7.5. Phase 3: complete strategy

This phase involves the completion of the MM strategy and a thorough analysis of the different impacts on the city of Rotterdam and its society. MM measures are added to strengthen the effectiveness of the MM strategy and to compensate the negative impacts of the main measures. Based on the conclusions of phase 2, a MM strategy based on parking pricing in area 1 will be developed.

Table 65 tasks and deliverables phase 3

stage	Task	Output
analysis	Analyse weaknesses MM alternatives (In this case only the alternative, increase parking prices, is analysed).	Negative effects caused by parking price increases
	System analysis	Possibilities within the transportation system for additional measures.
	Analyse additional measures with high potential.	Relation between parking pricing and other measures.
design	Complete strategy	Define additional measures
test	Model additional measures and complete strategy	Impacts on the city Rotterdam
evaluate	Compare properties with goals.	Effectiveness indictor (are goals fulfilled)
	Determine effects of different impacts	efficiency
	Define level of social support	Indication social opinion.
	Combine evaluations into overall judgement	Political feasibility

7.5.1. Analysis possibilities additional measures

Three types of analysis are conducted. The first explains the negative impacts of parking price increases. The evaluation of phase 2 already points out some of these impacts. This section elaborates further on this. The results of the analysis of the transportation system are used again, to define the possibilities in the system for complementary mobility management measures. Finally, the list with potential additional measures from chapter 2 (table 16) is analysed in relation with parking price increases and the project scope. The combined results of these analysis should indicate which measures should be added to the MM strategy during the design stage.

Negative impacts of parking price increases

Raising parking prices in the city centre, will cause certain negative effects. The most significant negative impacts are effects on the local entrepreneurs and on the citizens of adjacent neighbourhoods. The city centre, will become less attractive, due to higher travel costs. Though, a case study research of ten shopping centres in The Netherlands does not show a causal relationship between parking pricing and economic functioning of the city centre, an increase in travel costs, will lead to a decrease in attractiveness of the urban facilities (Van Velzen & Wagemakers, 2001).

The increase of parking fares in the city centre, will cause distribution effects of car trips to adjacent neighbourhoods, where parking prices are lower or no parking fees are charged. Research shows that both commuters (Marsden, 2006) and occasional visitors of city centres (Henser & King, 2001) can be willing to shift to adjacent neighbourhoods to park their cars (Both results are case specific. The commuter case is based on Edinburgh, Scotland. The occasional visitor research is based on Sydney, Australia.).

This effect can lead to increased parking pressure in adjacent neighbourhoods of the Rotterdam city centre, and the increased amount of car trips to these areas can lead to increased air and noise pollution.

Also, the public opinion of citizens of the adjacent neighbourhoods will be influenced negatively. A way to improve this is by good communication, to create problem awareness and by reinvesting the revenues of the pricing measures in society to improve accessibility (Schade & Schlag, 2003).

System analysis

From the analysis of the transportation system (Annex D), the following results are relevant:

a. The public transport system of Rotterdam is of a high quality. Especially the city centre has got a very high accessibility by PT.
b. On a regional scale public transport (train) has a relative low modal share for people traveling to and from Rotterdam.
c. Inside Rotterdam the percentage of people traveling by bicycle is relatively low.

Additional measures with high potential

Based on the list of additional (pull) measures with high potential, the following measures are relevant for the case of The Maastunnel:

- Car sharing
- Mutimodal/transit treatments
- Bicycle stimulations
- Trip generation/departure time choice influenced work schedules
- Transport management by companies
- Discounts PT

7.5.2. Design: Complete strategy

Additional mobility management measures for the parking price increases are suggested. This is done based on the different analysis of section 7.5.1

Because no exact information is obtained during this design process, regarding the fulfilment of all design goals (No distribution effects are known of time space, and modes), the analysis of the negative impacts of parking price increases of section 7.5.1 is used to determine demands for the additional measures. Following from this analysis, three demands are derived, which the additional measures should fulfil:

- Increase accessibility city centre.
- Reduce parking pressure in adjacent neighbourhoods.
- Increase level of social support.

Looking at the possibilities of the transportation system and the potentially effective additional measures, the following measures show the highest potential as additional measures in improving the effectiveness, increasing social support and realising a higher efficiency:

- Focus on transport management of commuters (transport management by companies). Different measures can be enforced in corporation with employers. Especially trip reduction and off peak traveling can be stimulated: teleworking and adjusted/flexible working schedules.

- Focus on parking in garages outside the city centre. By reducing parking tariffs in parking garages, parking in these facilities should become more attractive. This should be implemented in corporation with employers and shops, to limit the attractiveness for additional car trips. Only trips with a destination in the city centre should benefit from this discount.
- Invest in bicycle parking facilities near parking garages and urban functions. This way bicycle use is stimulated. And the connectivity between parking garages and the city centre is improved.
- If it is financially feasible, provide discounts on the use of PT for trips towards the city centre. Or subsidies on the use of bicycles in collaboration with employers.

7.5.3. Test additional measures in combination with main measure(s)

No additional modelling test stage is executed due to limited possibilities of the model scenario of The Maastunnel renovation project. Ideally, the effects of the different additional measures in combination with parking price increases would have been tested during this stage in a suitable transport model.

7.5.4. Evaluate phase 3

The different analysed impacts of phase 1 are evaluated. The effectiveness regarding the different goals and the combined efficiency of the analysed impacts is quantified for the parking pricing measure if adequate data were available. The impacts of the additional measures and the public support of all measures and the relation between them is, where possible, qualitatively evaluated.

Effectiveness parking price increases

The effectiveness of parking pricing regarding the goals is already discussed in section 7.4.3 and 7.4.4. The effects of the additional measures are not modelled during the test stage, because the outcomes of the model do not provide much useful information. Because of these two reasons, only a short recap of section 7.4.3 and section 7.4.4 is given regarding the different goals, combined with the expected effects of additional measures.

<u>Resolve congestion:</u>

The goal is to reduce 2000 car trips in the city centre, during the evening peak. Even with additional measures, which can stimulate the effects of parking price increases, a parking price increase of 25% seems inadequate. The price elasticity needs to be -0.3. A price elasticity of -0.3 is seen as the upper limit in literature (Geilenkirchen, Van Essen, & Schroten, 2008). The chance that the price elasticity will be -0.3 or higher is relatively small. If the price elasticity turns out to be lower, the city centre will encounter congestion problems, creating social and economic problems. A parking price increase of 50% is sufficient if the price elasticity is -0.15. With additional measures, stimulating the effects of the parking price measures, this seems feasible. A parking price increase of 75% is sufficient, when the price elasticity is -0.1. -0.1 is considered as lower limit in current research into parking price elasticities (Geilenkirchen, Van Essen, & Schroten, 2008). This would guarantee a proper functioning transportation system. A parking price increase of 100%, seems to be unnecessary high, creating unnecessary public discomfort.

Access equity:

As mentioned before, the model used did not provide information about access equity changes. There is not a high probability of disproportional travel time increases for underprivileged groups of society. Traffic flow changes, due to parking price increases, will cause increased traffic intensity in the areas around the city centre. With additional measures, stimulating bicycle use, and parking in garages instead of street parking, this effect should be reduced.

Noise and air pollution:

Also for these two goals, no accurate data were obtained using the regional transport model. The increase of traffic intensity in the areas surrounding the city centre, due to lower parking prices in these areas, will result in higher levels of noise and air pollution. The additional measures, stimulating bicycle use, and, if financially viable, PT discounts, will contribute to reduce air and noise pollution in these areas.

Impacts parking price increases

The different relevant impacts determined in phase 1 and the related performance indicators will be briefly discussed (table 66). Where possible the impacts will be quantified and monetized to show the impact on Rotterdam as a city. Because parking pricing generates additional income for The Municipality, this impact is added.

Table 66 Different relevant impacts.

Impact	PI's
Congestion reduction	No. of vehicles
Travel time (network effects)	Vehicle loss hours
Demand PT (distribution effects)	Modal shift
Road safety	casualties
Air pollution	Production emissions (Focus on NOx and PM10)
Noise pollution	Sound levels (in decibel)
Economic welfare (income facilities)	Revenues local facilities
Participation (access equity)	Difference in travel time to urban functions for groups of society.
Costs (investments costs)	Investments costs (in €)
Income Municipality	Additional income parking pricing (in €)
Traveller benefits/costs (distribution of different groups of society)	Total costs/benefits for travellers in direct financial compensation

Congestion reduction/no. of vehicles:

This impact is already discussed in the evaluation of the effectiveness to resolve congestion (see section 7.4.3).

Travel time (network effects)/vehicle loss hours:

The network effects, resulting in travel time changes, are expressed in vehicle loss hours. During the test stage, the obtained model results did not provide data about the amount of vehicle loss hours (VLH's) reduced. To estimate the effects on travel time changes caused by the parking price measure, the results of a quick scan cost benefit analysis of transport measures, designed for the renovation of The Maastunnel, by an expert panel, existing of members of The Municipality of Rotterdam, TNO and TU Delft are used (Vonk-Noordegraaf, Katwijk, & Van Wee, 2015).

Annex G elaborates further on this quick scan CBA. Based on this study (with peak avoidance rewarding as leading measure) 3317 vehicle loss hours are reduced during the evening peak (15:00-19:00) and 615 during the morning peak (6:00-10:00). This is a total of 3932 VLH reductions, based on a car trip reduction of 2500 during the evening peak. This ratio of 2500 car trip reductions during the evening peak and a reduction of 3932 VLH's will be used to estimate the travel time reductions realised. This results in a ratio of 1.57 VLH's/ evening car trip reduction. The relation between these two variables will not be linear in reality (if more car trips are eliminated, the amount of additional vehicle loss hours will decrease). But, due to a lack of better indicators, a linear relation will be assumed. The results are illustrated in table 67.

Table 67 Daily reduction of vehicle loss hours for different parking pricing scenarios.

Area 1	Price increase		
elasticity	50%	75%	100%
-0.1	2185	3278	4371
-0.2	4371	6552	8737

Based on the quick scan CBA performed by The Municipality of Rotterdam, TNO and TU Delft, a value of time (VOT) of €11.50 is used (this is based on weighted average of the car/truck ratio. With a VOT of €9.00 for cars and of €42.20 of trucks.) A travel time reliability factor of 25% is added (Vonk-Noordegraaf, Katwijk, & Van Wee, 2015). Tale 68 illustrates the monetized value of the vehicle loss hour reductions based on a VOT of €14.38 (including 25% travel time reliability increase).

Table 68 Monetized effects of vehicle loss hour reductions for different scenarios in € on a daily base.

Area 1	Price increase		
elasticity	50%	75%	100%
-0.1	€ 31,420	€ 47,137	€ 62,840
-0.2	€ 62,840	€ 94,275	€ 125,681

<u>Demand PT (distribution effects)</u>

No information is available regarding modal shifts caused by the MM measures (the mode choice function is not present in the model variant). The modal share of PT and bicycle use is expected to grow, but no data are available or obtained with the transport model.

<u>Road safety:</u>

There is already disagreement in literature whether reduced levels of congestion lead to higher or lower levels of road safety (Marchesini & Weijermans, 2010; Wang, 2010). Stipdonk & Reurings (2010) state that there is a negative effect on road safety if car trips are substituted for bicycle trips for short distance trips. This is mainly caused by the vulnerable position of bicycle users in the transportation system compared to car users. Due to limited information about the distribution effects of the MM measures, no clear statements can be made regarding road safety.

<u>Air pollution:</u>

The levels of air pollution in the city centre will decrease, and the levels of air pollution in the adjacent neighbourhoods are likely to increase. The total amount of air pollution will decrease, due to the reduction of cars in the network and due to the elimination of traffic jams. Traffic jams are seen of one of the major contributors to air pollution (Oduyemi & Davidson, 1998).

The effects realised by car reductions will be negligible, due to the relative small part of the total car trips in the city centre. The elimination of congestion in the entire city centre will have a more significant contribution to air quality. The exact effect is not known. Therefore, the effects of air pollution are not quantified.

Noise pollution:

Noise pollution is considered in the goals, analysing the effectiveness of parking price increases. The available data did not show the precise effects of noise pollution in the city. It is expected that in the city centre, the amount of noise pollution will decrease. Noise pollution will increase in the adjacent neighbourhoods, because of the reduced amount of cars in the city centre and the redistribution towards the adjacent neighbourhoods. Because the exact traffic flows and speeds are not obtained, more detailed statements cannot be made. The quantified impact is not known.

Economic welfare:

Improving the accessibility of the city centre by resolving congestion is considered as positive effect on the local economy. Based on the quick scan CBA meeting of experts of The Municipality of Rotterdam, TNO and TU Delft the effect of MM on the local economy is between 0-30% of the direct benefits of the measures (monetized results of vehicle loss hours), with an average of 20% (Vonk-Noordegraaf, Katwijk, & Van Wee, 2015). Parking price increases will decrease the attractiveness of the city centre. The benefits will therefore be reduced. Resulting in a percentage lower than the 20% mentioned.

Participation (access equity)

As discussed in the section about effectiveness, no major access equity changes are expected. The general effects of accessibility are already considered with the vehicle loss hours.

Investment costs

The exact costs are not known. As mentioned in section 7.4.4, the systems for parking pricing are already implemented in the city centre and Feijenoord North. The only adjustment is a change of the software. The costs of software adjustments are not known, but are not expected to be significant compared to other measures.

Income Municipality

The annual revenues of paid parking in the city centre are currently €5.132.089. 70% of this amount, €3.653.855, is collected by temporary paid parking (Rekenkamer Rotterdam, 2015). This is the amount that will change due to parking price increases. Table 69 shows the financial results, including the additional benefits and the missed revenue due to car trip reductions, based on the parking price increase and the price elasticity the amount of car trips are reduced (For an elasticity of -0.1 and a parking price increase of 100%, 10% of the car trips to and from the city centre are reduced. This indicates that 10% of the initial revenues is lost. The remaining 90% of the revenues of temporary parking is doubled for this scenario. This way table 69 is completed for the different scenarios).

Table 69 Yearly parking income Municipality of Rotterdam in the city centre in different scenarios.

		Price increase		
	elasticity	50%	75%	100%
Missed revenue (Annual)	-0.1	€ 182,693	€ 274,039	€ 365,386
	-0.2	€ 365,386	€ 548,078	€ 730,771
Additional revenue (annual)	-0.1	€ 1,735,581	€ 2,534,862	€ 3,288,470
	-0.2	€ 1,644,235	€ 2,329,333	€ 2,923,084
Balance (annual)	-0.1	€ 1,552,888	€ 2,260,823	€ 2,923,084
	-0.2	€ 1,278,849	€ 1,781,254	€ 2,192,313

Traveller costs/benefits (direct financial impact)

The traveller costs are based on parking price increases in the city centre. Parking price tariffs in the city centre currently are €3.33 and the adjacent neighbourhoods €1.67 per hour (Centrumparkeren.nl, 2015). The adjusted tariffs and additional costs after parking price increases are shown in table 70.

Table 70 Parking tariffs per hour after parking price increase in the city centre.

Area 1	**Price increase**		
elasticity	50%	75%	100%
Additional costs	€1.67	€2.50	€3.33
New tariff	€5.00	€5.83	€6.67

Efficiency parking pricing

Ideally, a cost benefit analysis would have been performed to indicate the overall efficiency, and the weight of the different impacts, of the alternatives: In this case, of the parking price increase scenarios, with additional measures. Due to the lack of quantified impacts, this is not feasible. The direct financial effects, the network effects (based on vehicle loss hours) and the economic benefits can be monetized for the project (The effects of the additional measures are not included). These effects are listed in table 71, based on a parking price increase of 75% and a price elasticity of -0.1 and -0.2. A yearly average of 225 working days is used. During these days congestion problems occur. A project duration of 2.17 years is assumed (Vonk-Noordegraaf, Katwijk, & Van Wee, 2015).

- The additional income Municipality is based on the current income of temporary parking with the additional income due to the price increases (see table 69).
- The lost revenues is based on the amount of trip reductions (see table 69).
- The vehicle loss hours are based on the calculated benefits per day (table 68).
- The economic benefits are based on 15% of the network effects. This is an estimation based on the assumptions made in the quick scan CBA summarized in annex G (Vonk-Noordegraaf, Katwijk, & Van Wee, 2015). The effect on economic welfare is lowered with 5%, because the parking price increase will also have a negative effect on the economic activities in the city centre, due to a decrease in attractiveness.

Table 71 monetized effects of parking price increase of 75% for a project duration of 2.17 years.

price elasticity	-0,1	-0,2
Direct financial impacts		
Additional income Municipality	€ 5,500,651	€ 5,054,653
lost revenues (Because of cars not parking in the city centre)	€ - 594,665	€ -1,189,329
Balance financial impacts	**€ 4,905,986**	**€ 3,865,323**
Benefits		
Network effects based on vehicle loss hours	€ 23,014,640	€ 46,029,769
Economic benefits	€ 3,452,196	€ 6,904,465

The direct financial impacts show a positive value of approximately 4-5 million euros (dependant of the price elasticity). This is money that could be invested in the additional MM measures (after deduction of the implementation costs of parking price increases), without negative a negative financial result for The Municipality.

The network effects show a large economic benefit for Rotterdam. The results for the price elasticity of -0.1 seem to be more realistic, than the monetized network effects for the price elasticity of -0.2. The additional benefit per car trip reduction will decrease. The total amount of car trip reductions for the scenario with a price elasticity of -0.1 is and a parking price increase of 75% is approximately 2000 during the evening peak. This is the amount stated to solve congestion (Municipality of Rotterdam, 2013a). More car reductions, as included in the scenario with parking price increases of 75% and a price elasticity of -0.2 will not lead to double the amount of financial network benefits.

The same argument can be cited for the economic benefits. If congestion is already resolved, additional car trip reductions will not necessarily lead to economic benefits for the city.

Public support parking pricing and relation with additional MM measures.

The level of public support will be low, for this type of transport measure. The perceived fairness of the measures will be very low, because travel costs will increase. Compared to peak avoidance rewarding, where people receive money, leading to lower travel costs, this measures is conceived as negative. The fact that people still have the freedom to choose, is a positive side of this measure, compared to measures like access restrictions. This evaluation shows that the effectiveness and efficiency of parking pricing are high. The Municipality needs to translate this into high levels of perceived effectiveness and perceived effectiveness. This can be done using a good information campaign and compensation MM measures.

The additional measures need to enforce the parking pricing measure and compensate the negative public opinion. The money obtained with the parking price increases can be used for this. This will also contribute to higher levels of public support.

Political feasibility

The political feasibility, formed by the effectiveness, efficiency, public support and political consensus will be dependent on the public support, efficiency and political consensus. The effectiveness is likely to be of a very high level, eliminating congestion, which is the main goal of the MM strategy. This contributes to the political feasibility. Regarding the other goals less information is known. The public support will be low, though several characteristics of the public support should be high, if the implementation of the MM strategy is done in a smart way. Good communication and clear information to create problem awareness, will increase the acceptability of 'heavier' transport policy. Approaching stakeholders in early stages of the design process to create this problem awareness and to increase public support is essential. Though, many citizens will perceive parking price increases as 'not fair', it can be considered as fair way for paying for use (car use). Also the ease to implement this measure in the Rotterdam context and the fact that there are direct financial benefits contributes to the political feasibility. The political colour of decision makers will be decisive in the end.

7.5.5. Conclusions phase 3

The conclusions of the final phase are described in this section.

Case

Regarding the case, four additional measures are found with the potential to improve the effectiveness of parking pricing and to improve the level of public support aby reducing the negative effects of parking pricing on the city Rotterdam:

- Focus on parking in garages outside the city centre.
- Focus on employer approach
- Invest in bicycle parking facilities near parking garages and urban functions.
- If it is financially feasible, provide discounts on the use of PT for trips towards the city centre. Or subsidies on the use of bicycles in collaboration with employers.

The effectiveness regarding the different goals is already analysed in section 7.4. Regarding the efficiency of the strategy, not enough data were available to determine useful results. An advantage of parking pricing is, that it generates revenues for The Municipality, were many MM measures will generate costs. These revenues can be used to finance the additional MM measures. The revenues are estimated on 4/5 million Euros.

The financial benefits of network performance and economic welfare improvements will be significant, though the results obtained while evaluating the different impacts seem to be excessively high.

Design methodology

<u>Analysis</u>

The execution of the different parts of the analysis in this stage did not show much complications. The negative effects of parking pricing on the city, as mentioned before, were not obtained, due to the model limitations. This resulted in less accurate information regarding distribution effects. For the goals air and noise pollution and access equity, the exact implications have not been obtained.

<u>Design</u>

Based on the analysis stage, the potentially best additional measures are determined. No issues appeared, besides the lack of information regarding distribution effects, due to the model limitations. If these effects would have been known, more adequate additional MM measures could have been included in the design methodology.

Test

The test stage, where the additional mobility management measures are included, has not been performed. The main goal of this test stage would have been to see if the secondary goals will be accomplished. The model could not provide this information. Therefore, this stage has not been executed during this phase.

Evaluate

The problems to evaluate the network performance regarding the different goals are described in section 7.4.5. These problems are the same regarding the evaluation of the effects of additional measures on the network. The evaluation of the different impacts also showed that there is a lack of data to estimate the impacts for the economic, social and transport systems of Rotterdam, because the change in travel behaviour is not known. The data obtained are not sufficient to perform a proper efficiency analysis. Different performance indicators cannot be quantified and monetized. A proper cost benefit analysis, including social aspects, could not be performed, because of this.

Estimating the impacts of the different characteristics of the public support has proven to be difficult. The general effects can be estimated, but more detailed information and the relation with the overall political feasibility is difficult to determine. A more detailed stakeholder analysis can help with this. Involving different stakeholders in the process can provide indications about the public support.

Finally, the political feasibility is dependent on the weight politicians give to the different factors influencing the level of success of MM strategies.

7.6. Conclusions:

The different stages of the design methodology are discussed. First the general findings are set out.

General findings

The sequence of phases and stages provide an integrated design process. Useful deliverables are obtained if the right tasks can be performed during the different stages. The designed MM strategy seems to be constructed in a logic way, integrated in the project context. Different evaluation indicators are incorporated to create an extensive evaluation during the design process of different impacts and effects. The different stages with related deliverables highlight the essential process. The different phases explain the main goals of the design methodology: Specify the problem, determine effective measures (regarding primary and secondary goals) and evaluate a broad range of impact in the urban context. Including the secondary goals, regarding access equity and environmental norms, is important from a social perspective. The social costs should be spread evenly over society. No local or underprivileged groups of society can be affected disproportionally. Analysing these effects during the second phase, highlights problems regarding these goals in an early stadium of the design process. This provides the opportunity to seriously deal with these problems and fulfil the goals of the design of the MM strategy.

Analysis

During the analysis stages of the three phases not much problems occurred. Most analysis could be performed very detailed. The stakeholder analysis deserves more attention. Creating more understanding of stakeholder positions and interests will help by identifying the important social, economic and environmental impacts. Involving stakeholders in the process will help by getting more grip on the characteristics influencing the level of public support. This is essential for determining the political feasibility.

Design

The design stages were executed relatively simple. Because of the extensive analysis, the design of the different alternatives was a logical process. If more time and resources are available, more alternatives can be researched. For example, road pricing on the bottlenecks has not been included in the alternatives during the design stages. This type of MM measure is potentially also effective in solving congestion problems and related negative effects on cities.

Test

The test stages is where the biggest issues are found. This is caused by the model limitations. The model used was not capable of simulating travel behaviour in an adequate way. Two main issues arose during the modelling stages: Absence of trip generation, trip distribution, mode choice and departure time choice and the static characteristics of the model.

The fact that the different step in the trip choice decision process are not incorporated in the model variant, eliminates a lot if information regarding travel behaviour. Distribution effects over time and space within the transportation system are not obtained with the model.

The fact that the model is based on trips does also not contribute to a proper representation of travel behaviour. The model is based on trips, where a model based on tours would simulate travel behaviour in a better way. The fact that the tunnel is closed in one direction has consequences if travellers use the tunnel in two direction to perform a trip at a destination and go back to their origin. They will determine their travel behaviour based on tours, because outbound and return trip influence each other.

Because of the limitations, price elasticities are used to research if the proposed measures can realise the criteria of 2000 car reductions during the evening peak. This method is feasible to test if congestion is resolved, if the criteria set for the goal of resolving congestion are clearly stated and reliable. For this case study this was the case, because an extensive analysis of the problem was conducted, using a dynamic model (Municipality of Rotterdam, 2013a). Regarding the other goals and impacts used for the evaluation, price elasticities do not provide useful information.

Using a static model does not show how traffic flows change because of mobility management measures. To research air pollution, noise pollution and access equity goals, information about traffic flows (intensities and speeds) are needed. A dynamic model would be needed to research the impacts regarding these goals.

Evaluate

Because of the limitation, different parts of the evaluation could not be performed properly. A more detailed stakeholder analysis and, combined with involving essential stakeholders will provide more information about the level of social support.

A dynamic transport model will provide more information regarding travel behaviour and traffic flow in the transportation system. This will enable the evaluation of the secondary goals and the different impacts. If the different impacts can be quantified a proper evaluation of the efficiency can be conducted. Using key figures the different impacts can be monetized to create a cost benefit analysis. Combined with the more detailed stakeholders analysis this will create understanding of the implications of MM strategies for a city.

Determining the political feasibility will become better underpinned if stakeholder analysis and the modelling testing are adjusted, resulting in better underpinned political judgements.

8. Discussion:

This thesis examined how the design of mobility management strategies for infrastructure renovation project should be approached. The urban complexity of large cities with increasing pressure on the transportation system demand a more comprehensive approach to analyse different impact on the city's functioning to design an adequate mobility management strategy. Most mobility management literature focusses on aspects regarding long term mobility strategies. Short term mitigation strategies are underexposed. Especially for IRP's in large cities. Existing design methodologies lack a more comprehensive design and evaluation approach of the different impacts in the urban context. To accomplish the goal of this thesis, to develop a design methodology for infrastructure renovation projects different objectives have been accomplished. A case study and expert panel is used to evaluate the design methodology. The conclusions of this thesis are discussed in section 8.1. This is followed by the recommendations of this research (section 8.2).

8.1. Conclusions:

The conclusions regarding the different research goals and objectives are discussed. The main goal was to analyse the different characteristics influencing the design of a MM strategy and to transform these characteristics in a design methodology. First the different relevant conclusions of the objectives are discussed. After this, the results of the main goal, the development of a design methodology for MM strategies for IRP's is discussed. This section is finalised with the conclusions of the case study, regarding the design methodology.

Objective 1: Determine the specific characteristics of MM measures in the context of IRP's.

Mobility management for IRP's can be distinguished from mobility management in general, because an infrastructure renovation projects entails four specific demands: temporary effect, short implementation time, short incubation time and high level of effectiveness. The need to protect the transportation system from temporary failing compared to the opportunities to improve the efficiency on the long term of other type of MM strategies, justifies a more extreme type of MM strategies with higher levels of effect.

Not all type of mobility management measures fit these specific demands. Four measures with a very high level of effectiveness are found: access restrictions, parking pricing, road pricing and peak avoidance rewarding. Besides peak avoidance rewarding, all these measures are push measures. These push measures achieve high levels of effectiveness, but low levels of public support.

Objective 2: Determine the evaluation criteria of MM strategies for IRP's.

The MM strategy needs to be efficient, effective and it needs to be accepted by important stakeholders. Different relevant impacts are found, that should be included as evaluation criteria. These impacts exist of financial, social, economic and external/environmental impacts. An important aspect of the developed design methodology is to include social and economic impacts to create understanding of the different impacts on the social and economic systems of the city. The combination of these impacts determines the efficiency of the MM strategy.

The main goal of a MM strategy for IRP's is to resolve congestion, caused by the renovation project. Secondary goals are formulated regarding local noise and air pollution limits and access equity. Access equity refers to an even distribution of the costs of the renovation project over society. Where underprivileged groups need to be protected, the mobility management strategy can play a role in decreasing access inequity, caused by the renovation project. Also road safety can be defined as goal, if the IRP creates significantly lower safety levels in the transportation system.

Objective 3: Determine which factors and characteristics influence the success of mobility management strategies.

There are four main factors influencing the level of success of MM strategies, with related characteristics: effectiveness, public support, efficiency and the overall political feasibility. The need for a proper functioning transportation system, combined with the primary goal, of MM strategies for IRP's to mitigate congestion during the renovation project, increases the importance of the effectiveness of measures.

Main goal: develop a design methodology for mobility management strategies during infrastructure renovation projects.

The methodology is illustrated in figure 30. It is an iterative process, existing of 6 stages. Especially the combination of the stages: system analysis, design, test and evaluate are of an iterative nature. These stages are run through in three phases. Phase 1 focusses on the problem definition. Phase 2 on the analysis of the effectiveness of different main alternatives in reducing congestion and fulfilling the other goals. Phase 3 focusses on completing the MM strategy and conducting an extensive evaluation of the important impacts.

A MM strategy based on push measures (or peak avoidance rewarding), with additional pull measures is advised. The push measures are needed to reach the necessary effectiveness. The additional measures can compensate the negative impacts on the city and the level of public support. A good communication and information plan and stakeholder involvement (employer collaboration) should increase the effectiveness of the strategy.

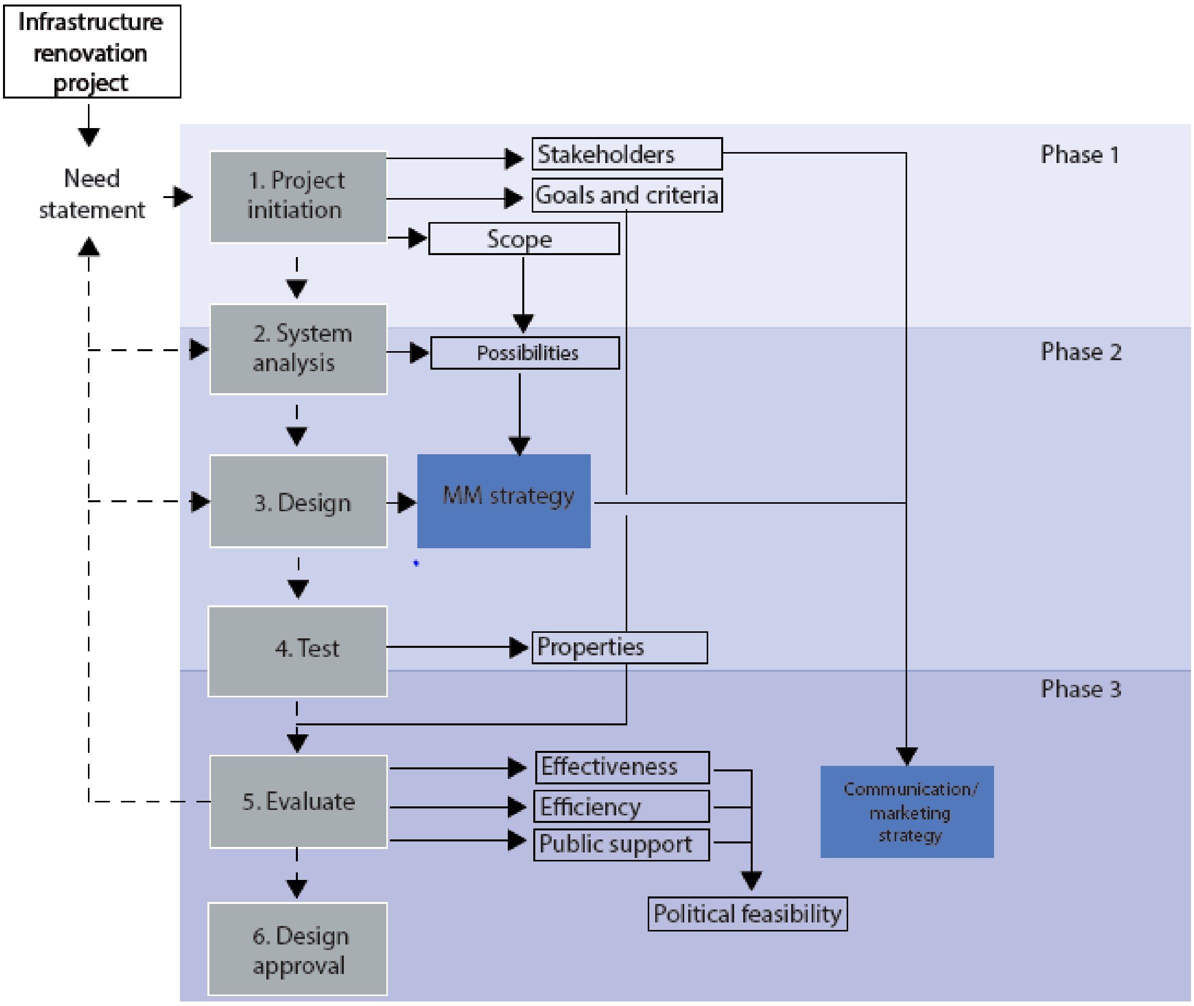

Figure 30 Main methodology

Evaluation Design methodology

The design methodology should be a design approach, applicable in different contexts, used by transport policy makers. The methodology shows potential for a multi-contextual implementation. However, the design methodology is a first design. The combination of phases and stages is chosen, to illustrate the essential process and deliverables. More case studies are needed to evaluate the method. Testing the design methodology will help improving it, filtering unnecessary information and adding possible important aspects.

The implementation of the design methodology for the case study shows good results. The different stages with related deliverables highlight the essential steps in the process, with related outcomes. The main problems experienced during the case study are related to the static regional transport model (Omnitrans model). The model variant used by The Municipality is based on OD pairs per mode per time period. This eliminates a lot of valuable information about the trip choice process. Information regarding changes in the decision to perform the trip, where to perform the trip, when to perform the trip and with what kind of transport mode to perform the trip, caused by the MM measures/strategy is lost.

Because of the limitation, different parts of the evaluation could not be performed properly. A more detailed stakeholder analysis, combined with involving essential stakeholders in the design process will provide more information about the level of social support and how to influence this.

A dynamic transport model will provide more information regarding travel behaviour and traffic flows in the transportation system. This will enable the evaluation of the secondary goals and the different impacts. If the different impacts can be quantified, a proper evaluation of the efficiency can be conducted. The different impacts can be monetized to create a cost benefit analysis. Combined with the more detailed stakeholders analysis this will create understanding of the implications of MM strategies for a city.

Determining the political feasibility will become better underpinned if stakeholder analysis and the modelling testing are adjusted, resulting in better political decision making.

8.2. Recommendations

Based on findings and limitations, recommendations are formulated. The recommendations are coupled to the content of the different chapters, and, the different stages and deliverables of the design methodology.

The design methodology does provide an extensive design and evaluation process. It is, however, a time consuming exercise and the right knowledge and tools must be available. If the complexity of the problem is less significant, a comprehensive approach like this is not needed. Where the relevance of the project and city is smaller, it is suggested to focus on the effectivity of measures. A proper functioning transportation system is essential for a city. This will provide the necessary infrastructure for the social and economic urban systems. Due to the temporary characteristic of renovation projects, other negative impacts will not be permanent, which decreases the weight of them.

Analysing stage

The stakeholder analysis of the design methodology deserves more attention. The relation between the interest and position of different stakeholders will contribute to a better MM strategy. Existing research regarding stakeholders can be implemented to improve the design methodology. This can be implemented in the specific context of MM strategies for IRP's in urban contexts.

Design stage

Regarding the design stage some recommendations can be done. Chapter 2 tried to summarise the existing mobility management measures. Many sources are examined, but there is no guarantee that all measures are included. An up to date overview/database will contribute to a better overall understanding of the wide range of possibilities regarding MM measures.

The effects of the measures researched in section 2.4 are based on a limited amount of sources. Most of the effects of measures focus on the Dutch market. The results will be adequate and general applicable for certain measures. But for other measures this may not be the case. An example is the positive rating of the effectiveness of bicycle stimulations. This is something that will work in The Netherlands, but will most likely not be very effective in cities, with large height differences. More research is needed into the effects of MM measures and more specific regarding the effectiveness in different cultural and geographical contexts. This will increase the existing knowledge and robustness of this knowledge. This is essential for policy makers to easily develop successful MM strategies.

The Municipality of Rotterdam attaches high value to the secondary goals of access equity and noise and air pollution. The exact impacts of temporary changes regarding these goals in the transportation system are not well known. This needs to be researched to define proper criteria attached to these goals.

Test stage

If an extensive overview of the impacts and the implication for a city are demanded, different transport models need to be used. To obtain proper results a model is needed, that can include travel behaviour and traffic flow changes. This way the different goals and impacts can be researched and used during the evaluation. Models based on trips are also not always adequate, if trips are only affected by the IRP in one direction, tour based models will predict travel behaviour in a better way.

Evaluation stage

Chapter 3 analysis the evaluation criteria used to test and evaluate MM measures. The Municipality of Rotterdam stated that they highly value a comprehensive overview of the different impacts during renovation projects and the relation with MM strategies. Which impacts are valued the highest is not known. All impacts in this research are considered to be equal valuable, except for the impacts defined as goals. Where congestion reduction is valued as the most important evaluation criteria. In general more knowledge should be obtained on the value of different impacts considered by different stakeholders regarding the design of a MM strategy and the relation between the different evaluation indicators. A way to determine the weight of the different impacts, goals and characteristics of the level of support should be researched and implemented in the design methodology. Only then, a proper underpinned decision can be made regarding the content of the MM strategy.

Case results: parking pricing

The results of the case indicate a high potential of parking price increases to reduce car trips to and from the city centre, or possible other congested areas. Especially, if parking pricing is already introduced, it shows a high potential for MM strategies for IRP's, due to the ease of implementation. The revenues for local governments, provide them with resources to implement additional transport measures to improve the public support and possible negative effects caused by the parking price increases. Especially in Dutch policy making, there is currently a strong tendency, to choose for peak avoidance rewarding, because of the positive public opinion. With peak avoidance rewarding, people are rewarded for not showing 'bad' behaviour. People already showing good behaviour do not benefit from this. With parking pricing, 'bad' behaviour is punished and revenues are created, which can be used to stimulate good behaviour. More research should be done regarding the relation between the effectiveness and the level of support of MM measures, especially of parking pricing (and possible other ways of pricing), and how the public support can be positively influenced. Potentially this type of MM measures can play an important role for MM strategies during IRP's.

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Appendix

A. Categorisation MM measures.

This annex shows the different categorisation methods found in literature

Table 72 Categorisation method 1

Categorisation 1: MM categories Garling & Schuitema (Garling & Schuitema, 2007)	
1.	Travel constraints
2.	Stimulation of alternative modes
3.	Alternative work arrangements
4.	Land-use planning

Table 73 Categorisation method 2

Categorisation 2: MM categories Taylor et al. (Taylor, Nozick, & Meyburg, 1997)	
1.	Physical measures.
2.	Legal measures.
3.	Economic.
4.	Information/communication.

Table 74 Categorisation method 3

Categorisation 3: MM categories Tanaboriboon (Tanaboriboon, 1992)	
1.	Traffic constraints
2.	Public transportation improvements
3.	Peak- period dispersion
4.	Ride sharing
5.	Parking control
6.	Land-use control

Table 75 Categorisation method 4

Categorisation 4: MM categories Rosenbloom- I (Rosenbloom, 1978)	
1.	Social
2.	Socio-economic
3.	Sociotechnical
4.	technical

Table 76 Categorisation method 5

Categorisation 5: MM categories Rosenbloom- II (Rosenbloom, 1978)	
1.	Reduce number of vehicles used
2.	Reorient travel to off-peak hours
3.	Reorient traffic to alternative routes
4.	Reduce total amount of trips

Table 77 Categorisation method 6

Categorisation 6: MM categories Ferguson (Ferguson, 1990)	
1.	Trip generation
2.	Trip distribution
3.	Mode choice
4.	Route selection (spatial and temporal)

Table 78 Categorisation method 7

Categorisation 7: MM categories Meyer (Meyer, 1999)	
1.	Offering alternative transportation modes and services, with the purpose to obtain a higher per vehicle occupancy
2.	Providing incentives/penalties to reduce the total amount of trips or shifting trips to off-peak hours.
3.	Providing/encouraging ways to accomplish the trip purpose through non-transportation means.

B. List of existing mobility management measures

The articles of Rosenbloom (1978), Meyer (1999), Ferguson (1990) and Gris Orange Consultant (2012) are used to create this long list. A quick scan of other articles did not provide additional measures. The bold measures are considered to be ineffective or not feasible for MM strategies for IRP's.

Table 79 Long list of MM measures

No.	measure
1	bicycle parking
2	bicycle paths/lanes
3	bicycle racks on buses
4	public bicycle systems
5	Bicycle subsidies
6	pedestrian zones/ car free zones
7	increased sidewalk/crosswalks safety
8	**walking school busses**
9	HOV(lanes)
10	employee transit pass
11	shuttle services/ extended area services (PT)/ circulation systems (PT)/ demand responsive transit
12	guaranteed ride home program
13	**universal accessibility**
14	priority systems (PT)
15	transit vehicle improvements
16	transit subsidies/ trial pass transit programs/ transferable transit pass
17	**intermodality**
18	park and ride
19	parking cash out
20	parking pricing
21	parking supply magement
22	road pricing
23	car sharing
24	ride sharing/carpool
25	queue jump lanes
26	**distance based insurance**
27	substitution for travel (telecommunication, teleshopping, teleworking)
28	flexible work hours/ staggered work shifts/ compressed work weeks
29	incentives to off peak travel
30	**transportation managment associations**
31	tourist transport management
32	TDM marketing
33	traveller information sytsem (multimodal)
34	smart network and vehicles
35	**growth control**
36	**zoning restrictions**
37	**street quietening**
38	**mixed use developments**

39	Stay home subsidies
40	Drive restrictions

The bold measures of table 79 are not considered for MM strategies for infrastructure renovation projects. The reasoning behind this is explained in 80.

Table 80 Ineffective and non- feasible MM measures for infrastructure renovation projects.

No.	measure	Reason why not effective/feasible
8	walking school busses	In urbanised areas, the concept of school busses is not very common. The amount of school busses in the transportation system is negligible. The effect of removing school busses out of the transportation system, therefore, will not contribute to decreasing congestion caused by IRP's.
13	universal accessibility	The concept of universal accessibility increases the accessibility of public transport, but it decreases the punctuality, velocity and reliability of transportation in general. There is a higher probability that it will increase congestion, than that it will decrease congestion.
26	distance based insurance	Distance based insurance is a policy instrument which aims to distribute the risks of driving in a fair way among the car users. It is related to increasing equity. There are no indications that this instrument contributes to solving congestion caused by infrastructure renovation projects.
17	Intermodality	The concept of intermodality increase the robustness and reliability of the transportation system as a whole. It is nevertheless not a specific transport measures. Mobility measures like, increased frequencies and expanded bus services will contribute to the concept of intermodality.
30	transportation management associations	Transportation management associations are founded to take over tasks of governments. For long term strategies, they can contribute to increasing the efficiency of the transportation system, by specialising and creating knowledge. For the short term, this does not seem to be feasible.
35	growth control	This is part of land use measures, which are not effective for MM strategies for IRP's (see section 0).
36	zoning restrictions	This is part of land use measures, which are not effective for MM strategies for IRP's (see section 0).
37	street quietening	This is part of land use measures, which are not effective for MM strategies for IRP's (see section 0).
38	mixed use developments	This is part of land use measures, which are not effective for MM strategies for IRP's (see section 0).

C. Results expert panel

In general the experts endorse the main findings and the design methodology for MM strategies for IRP's. The need for a more comprehensive approach is received as very positive. This is something the municipality of Rotterdam is currently integrating in policy making for these type of projects, but it is something that has not been integrated much before.

The design methodology is presented as general policy instrument to design MM strategies for IRP's. Some answers are given in the context of The Maastunnel renovation project. This is because of the fact that all participants are part of The Maastunnel renovation project team.

Findings

- Different members emphases the importance of a positive approach. This relates to the definition of goals and criteria. They would denote the goals in a way that they aim to improve the transportation system, rather than mitigate problems.
- The possibility to integrate the MM strategy with other policy strategies aimed at improving the efficiency of the transportation system is named several time. For local governments, this integration can be necessary from a financial point of view. If MM measures in the strategy also fulfil other goals, the MM strategy can be financed partially with other sources and problems are tackled at once.
- Defining relevant stakeholders at the start, with related interests and impacts is conceived as a very positive aspect. Analysing the interests of different stakeholders can help by determining important impacts. The municipality experiences this as very useful during The Maastunnel renovation project. There are less obvious stakeholders with important interests. For example, in the case of The Maastunnel, The Erasmus medical centre. This stakeholder has the demand to be accessible through the tunnel.
- The expert consider the inclusion of equity goals very interesting, but more difficult to test. Especially with a limited time frame this will be difficult.
- Starting with an indication of the political colour can help significantly by determining the type of measures and goals. Peak avoidance rewarding is highly valued, because of the positive effect on public opinion. Push measures might be more effective, but they are perceived more negative by the public.

D. Analysis transportation system

This annex shows the main findings of the analysis of the transportation system. The analysis is divided in an analysis of the travel market, the supply side of the transportation system and the demand side of the transportation system. The goal of this analysis is to determine the possibilities in the system to change/shift demand. (Data used in this annex, without references are obtained from the data used in the regional transport model of Rotterdam, obtained by The Municipality of Rotterdam.)

Travel market

The travel market determines where trips can be performed and where they originate from. Analysing the land use patterns of different activities within the ring of Rotterdam shows a high concentration of facilities in the city centre. Figure 31 and 32 illustarte this. For most urban functions this pattern is visable. This means that many travelers with different trip purposes use the transportation system to arrive in the ciyt centre to perform their activities.

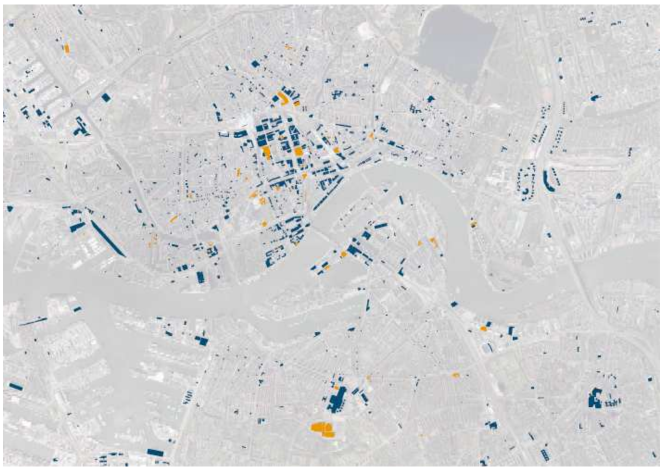

Figure 31 Cluster of activities in the city centre (I). Activities clustered in city centre are: Jobs (blue) and Cultural facilities (orange)

Figure 32 Cluster of activities in city centre (II): Hospitality services (yellow) and Shops (purple).

Supply side transportation system

The different infrastructure networks for the different modes are illustrated in figure 33. All networks in general, and especially the public transport system, are of a high quality. Especially the metro has a large capacity and a high frequency, distributing large amounts of travellers. All infrastructure networks show a higher network density around the city centre. The map of the road infrastructure illustrates that the most important roads lead to the city centre. In this area, the links come together to facilitate the high amount of urban functions and activities. There are few alternatives to cross the river from one side to another. The concentration of cars in the urban city centre puts pressure on the river crossings. Consequently, the importance of the links connected to the river crossings increases (figure 34)

Figure 33 Transport infrastructure per mode. Top left: public transport modes in Rotterdam: bus (red), tram (orange) and metro (blue). Top right: public transport modes on regional and national level: train system (bold black dotted links) with stations (larger white circles) and metro system (smaller black dotted link) with stations (small white circles). Bottom left: bicycle network. Bottom right: car infrastructure: highway system (black links), regional roads (grey links), arterials Rotterdam city centre (bold blue links) and other important urban roads (blue links).

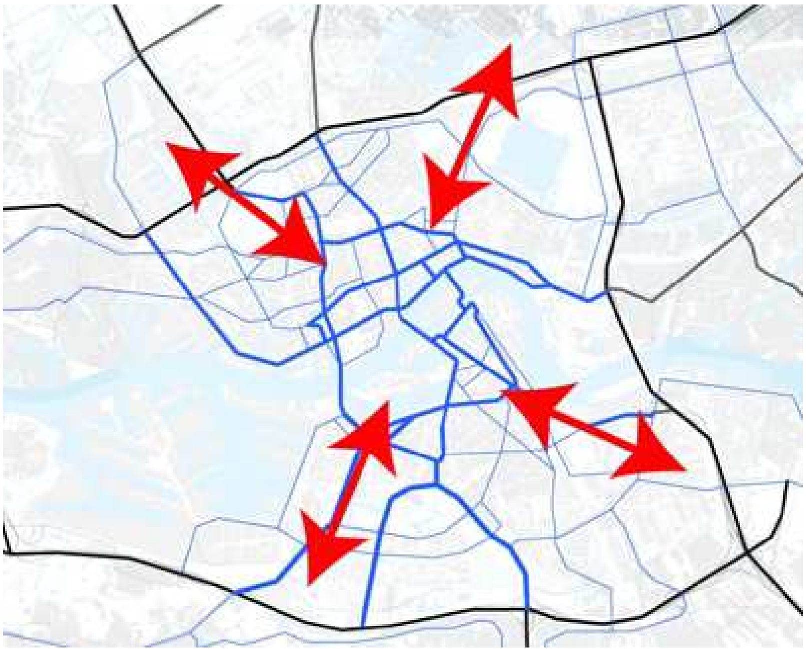

Figure 34 Increased network density due to focus of trips to and from the city centre.

Demand transportation system

The relation between the total amounts of trips and the distribution over the morning peak, evening peak and the rest of the day is examined. This is necessary to interpret the data correctly and understand the travel behaviour during the bottleneck moments: the morning and, especially, the evening peak.

There is no breakdown of the amount of trips/trip purpose over different time periods for the city Rotterdam. For the three existing urban river crossings data are available regarding the total amount of trips per time period. These data only contain trips performed by car. All three river crossings show relative similar results. Therefore the combined numbers of the three river crossings will be used. Table 81 illustrates the amount of trips per trip purpose during the morning and evening peak.

Table 81 Combined amount of trips urban river crossings; evening peak and morning peak for car users.

	trip purpose	Trips (evening peak)	Percentage (evening peak)	Trips (morning peak)	Percentage (morning peak)
1.	commuting	9665	48%	13601	71%
2.	business	2440	12%	2031	11%
3.	shopping	1277	6%	341	2%
4.	education	228	1%	126	1%
5.	other	6593	33%	3094	16%
	total	20203	100%	19194	100%

To analyse the mode choice of travellers, the data of Rotterdam are compared with the largest cities in The Netherlands. These cities are most similar to Rotterdam within the Dutch context. The modal split is analysed for trips inside the city (table 82) and trips with only an origin or destination in the city (table 83).

Table 82 Trips/mode with an origin and destination inside the city centre for four biggest cities in The Netherlands (De Vries, 2013).

		Rotterdam	Amsterdam	Den Haag	Utrecht
1.	car	**19,3%**	11,2%	18,6 %	13,2%
2.	passenger	11,5%	7,2%	9,7 %	7,7%
3.	train	0,2%	0,5%	0,3 %	0,4%
4.	bus/tram/metro	11,3%	10%	9,2 %	5,4%
5.	bicycle	**19,2%**	35%	26,8 %	41,2%
6.	walking	35,5%	32,5%	32,8 %	31,0%
7.	other	3%	3,6%	2,6 %	1,0%
	total	100%	100%	100%	100%

Table 83 Trips/mode with an origin or destination outside of the city centre (De Vries, 2013).

		Rotterdam	Amsterdam	Den Haag	Utrecht
1.	car	49,4%	48,2%	44,5 %	52,3%
2.	passenger	19,0%	15,6%	16,6 %	13,6%
3.	train	**9,4%**	18,1%	12,7 %	17%
4.	bus/tram/metro	10,8%	6%	6,4 %	5,3%
5.	bicycle	6,0%	5,8%	14,5 %	8,7%
6.	walking	1,7%	2,3%	3,3 %	1,3%
7.	other	3,8%	4%	2,0 %	1,8%
	total	100%	100%	100%	100%

Inside the city of Rotterdam relative many people travel by car. The amount of people using the bicycle is, compared to the other cities, extremely low. This can partly be explained by the large amount of inhabitants with a foreign background. They do not have the cultural habit of traveling by bicycle. Looking at bicycle ownership, only 70% of the Rotterdam society owns a bicycle, compared to a national average of 85% (De Vries, 2013).

The largest amount of car trips are traveling between the management area (target area excluded) and the target area (see table 13, for list of areas). Table 84 shows the amount of trips of the most important areas with an origin or destination in the target area and the distance to the Rotterdam city centre. Figure 31 shows where these cities are located and the distance towards the Rotterdam' city centre.

With respect to route choice, many car users will switch to the Erasmus Bridge and The Willems Bridge due to the renovation project. As mentioned before, this is the main problem of congestion.

Table 84 Amount of trips between the target area and most areas with largest attraction.

City	Destination R'dam (Ruit)	Origin R'dam (Ruit)	total	Distance to city centre of Rotterdam
Prins Alexandrium (Rotterdam)	2500	3600	5100	6 km
Hillegersberg/Schiebroek (Rotterdam)	1400	1500	2900	4 km
Schiedam	2800	3100	5900	7 km
Albrandswaard	1500	1900	3400	11 km
Barendrecht	1900	2700	4600	9 km
Ridderkerk	1400	2000	3400	12 km
Capelle a/d IJssel	1900	2500	4400	8 km
Vlaardingen	1900	1600	3500	9,5 km
Den Haag/Delft	1800	2700	4500	22 km/ 14 km
Total:	17100	21600	38700	

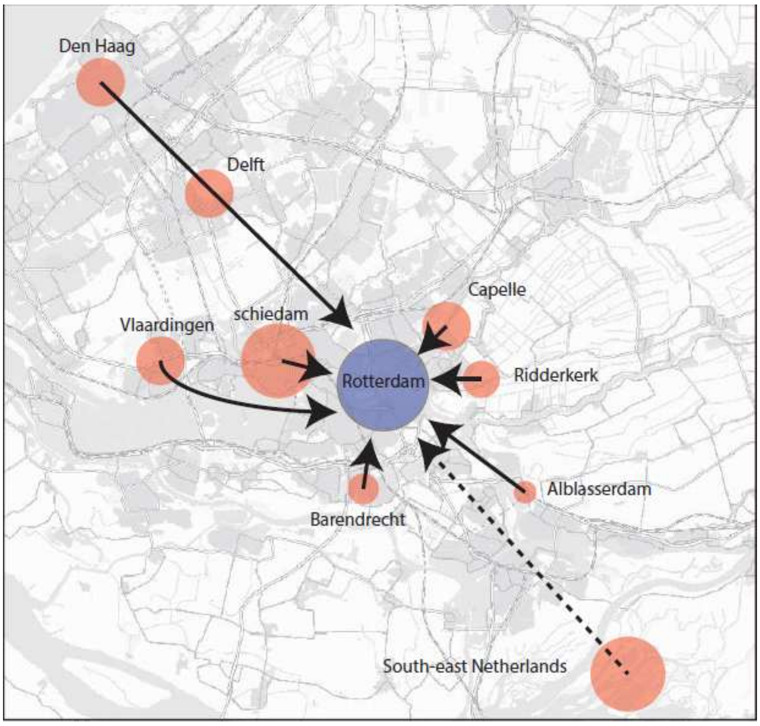

Figure 35 Cities with large amounts of trip origins and/or destinations inside the Rotterdam' city centre.

Conclusions

Several conclusions can be derived from the analysis of the transportation system of Rotterdam.

1. There is a high concentration of facilities to perform activities in the city centre. Especially, jobs, hospitality services, shops and cultural activities are clustered in the city centre.
2. This cluster of activities in the city centre attracts a lot of trips. Different modes of transportation are used to travel from and to the city centre.
    a. A high amount of travellers uses the car, compared to other big cities in The Netherlands.
    b. Public transport is used relatively often to travel between origins and destinations Inside Rotterdam. Especially the metro system holds an important position, transporting a relative high amount of travellers.
    c. On a regional scale public transport (train) has a lower modal share for people traveling to and from Rotterdam, compared to the three other big cities in The Netherlands; Amsterdam The Hague and Utrecht.
    d. Inside Rotterdam the percentage of people traveling by bicycle is extremely low, also compared to the big cities. This can partially be explained by the cultural background of inhabitants, but the difference is quite extreme (De Vries, 2013). <20% trips are made by bicycle in Rotterdam, compared to <35% in Amsterdam and Utrecht.
3. The infrastructure networks in Rotterdam are of a high quality. Systems for all modes have a focus towards the city centre, where the network density increases. The public transport system is of a very high quality. This contributes to the high modal share of public transport inside Rotterdam.
4. The combination of the high demand on the city centre by car users, the high network density in this area and the scarcity of river crossings, puts a lot of pressure on the Rotterdam road system in the city area. There are few alternatives. This means that taking out one of the river crossings, puts a significant amount of additional pressure on the other river crossings.

E. Job script, adjustments matrices

Below is an example of the job used to convert the 45*45 matrix of car trips between the different neighbourhoods in Rotterdam, the cities surrounding Rotterdam and the aggregated amount of trips of other areas in The Netherlands, into car trips between all centroids in the transport model (5612 * 5612). This way car reductions between different zones can be distributed over all relevant OD pairs. For every OD pair of the 45*45 matrix a percentage is determined of the change in car trips during morning peak, evening peak and the rest day. The job translated this percentage for all OD relevant OD pairs in the Rotterdam' transport model. This way, the amount of car reductions in several zones of the 45*45 matrix, can be quickly implemented in the transport model, and the results on the network can be analysed.

Because the job used, transfigures the 45*45 matrix in a 5612*5612 matrix, the outcomes of the job did not show consistent results (100 trips for one OD pair in the 45*45 matrix can result in 81 trips for the resembling OD pairs of the 5612*5612 matrix. A parking price increase of 25% did not show the double amount of car reductions if the price elasticity was two times as high. The results of table 59-62 are adjusted in a way that two times as many car reductions in the 45*45 matrix results in two times as many car reductions in the 5612*5612 matrix.

Inside Rotterdam areas are defined by neighbourhood, where areas on the other side of The Netherlands are combinations of large surfaces, with the size of several provinces. This way more detailed information is used for the city of Rotterdam and the surrounding region. This is modelled this way, because the closer the area is to Rotterdam, the more this area will influence the transportation system of Rotterdam. The percentages determined by the price elasticity for different OD pairs of the 45*45 matrix are entered in the job.

```
# script BB_SB  beter benutten en  Slim Bereikbaar
# tbv rvmk3.1
# Benno vd Griendt, Goudappel Coffeng
# Aanpassingen: JRI 20140925


#raise "LET OP DEZE JOB BEWERKT MATRICES EN VERANDERD ZELFDE BESTAND ALS HET INPUT BESTAND. NIET MEERDERE KEREN DRAAIEN"

writeln " * inlezen parameters... "

load $Ot.dirJob+'Simjobs\parameters_rvmk3_rtd2010.rb'
include Parameters_rtd

dagdelen = [Ochtend,Avond,Restdag]



# DEZE ALLEEN VOOR AVOND GEBRUIKEN #
#

#BB en SB instellingen
begin
        gebied1 =[[1651..1709,2738],"Centrum"]
        gebied2 =[[1801..1808, 1813..1879],"Delfshaven"]
        gebied3 =[[1723..1782],"Noord"]
        gebied4 =[[2211..2302],"Kralingen"]
        gebied5 =[[2551..2562, 2567, 2576..2670],"IJsselmonde (bi)"]
        gebied6 =[[1711..1714,2732..2737, 2739..2803],"Feyenoord"]
        gebied7 =[[2831..2936],"Charlois"]
        gebied8 =[[2937..2954, 2991..3010, 3021..3032, 3041..3061],"Eemhaven/Waalhaven"]
        gebied9 =[[1906..1914, 1921..1938, 1951..2040],"Overschie"]
        gebied10=[[2062..2175],"Hillegersberg/Schiebroek"]
        gebied11=[[2331..2471, 2511..2536],"Prins Alexander"]
        gebied12=[[2563..2566, 2568..2575, 2671..2691],"IJsselmonde (bui)"]
        gebied13=[[3361..3431],"Hoek van Holland"]
        gebied14=[[3072, 3091..3186],"Hoogvliet"]
        gebied15=[[3071, 3073..3078],"Vondelingenplaat"]
        gebied16=[[3211..3230, 3232..3245, 3284],"Botlek"]
        gebied17=[[3231, 3246..3282],"Europoort"]
        gebied18=[[3283, 3285, 3312..3327, 3329..3330, 3339..3349],"Maasvlakte"]
        gebied19=[[9..21, 25..97, 128..131]  ,"Schiedam (bi)"]
        gebied20=[[1..8, 22..24, 98..127] ,"Schiedam (bui)"]
        gebied21=[[141..333]  ,"Spijkenisse"]
        gebied22=[[341..390, 408..410, 473..477],"Albrandswaard"]
        gebied23=[[334..335, 391..407, 411..472, 478..500]  ,"Barendrecht"]
        gebied24=[[501..629, 690..695],"Ridderkerk"]
        gebied25=[[631..658, 660..689] ,"Krimpen a/d IJssel"]
        gebied26=[[700..822]  ,"Capelle a/d IJssel"]
        gebied27=[[830..889, 891..893, 934, 939..947, 951, 983..986] ,"Berkel en Rodenrijs"]
        gebied28=[[890, 894..933, 935..938, 948..950, 987..989, 991..992]  ,"Bergschenhoek"]
        gebied29=[[952..982, 993..1000, 1030..1032, 1083..1090, 1134..1139],"Bleiswijk"]
        gebied30=[[1001..1029, 1033..1081, 4257..4258],"Maassluis"]
        gebied31=[[1291..1429],"Vlaardingen"]
        gebied32=[[1091..1133],"Rozenburg"]
        gebied33=[[1141..1196],"Brielle"]
        gebied34=[[1201..1279],"Westvoorne"]
        gebied35=[[1430..1437, 1501..1599],"Hellevoetsluis"]
        gebied36=[[1441..1497],"Bernisse"]
        gebied37=[[3988..4010, 4148..4162, 4169..4183, 4245..4256, 4259..4265, 4368..4370],"Westland Zuid-West"]
        gebied38=[[3798..3913, 3917, 3941..3943, 3945..3946, 3949..3956, 3958..3959, 3966..3987, 4011..4016, 4122..4123, 4126..4128, 4141..4147, 4184, 4244,
        gebied39=[[3701..3712, 3714..3796, 3914..3916, 3918..3919, 3944, 3947..3948, 4101..4106, 4531..4714, 4716..4728, 5582..5584, 5600..5618, 5622..5632]
        gebied40=[[3797, 3920..3940, 3957, 3960..3965, 4018, 4107..4109, 4113..4117, 4124..4125, 4129..4140, 4206..4207, 4231..4243],"Noordelijk B3hoek"]
        gebied41=[[4017, 4019..4045, 4047..4100, 4110..4112, 4118..4121, 4185..4189, 4195..4205, 4229..4230, 4383..4392, 4396..4406, 4412, 4715, 4729..4808,
        gebied42=[[4046, 4410..4411, 4413],"Oostelijk Krimpen a/d IJ"]
        gebied43=[[4416..4449, 4451..4462, 4465..4489, 4491..4522, 4809, 4852, 4882..4890, 4895..4899, 4907..4916, 4919..5262, 5270..5272, 5280..5282, 5633.
        gebied44=[[4163, 4165, 4190..4194, 4208..4228, 4366..4367, 4393..4395, 4463..4464, 4490, 4855..4881, 4891..4894, 4900..4906, 4917..4918],"Nederland
        gebied45=[[4164, 4166..4168, 4853..4854],"Zeeland West"]
        pr      =[[1600..1650, 3440, 3441, 3451..3650],"P+R-zones_specFuncties"]
        dum     =[[132..140, 336..340, 630, 659, 696..699, 823..829, 990, 1082, 1140, 1197..1200, 1280..1290, 1438..1440, 1498..1500, 1700, 1715..1722, 1783

        gebieden=[nil,gebied1[0],gebied2[0],gebied3[0],gebied4[0],gebied5[0],gebied6[0],gebied7[0],gebied8[0],gebied9[0],gebied10[0],gebied11[0],gebied12[0]
end


# [van gebied, naar gebied, factor auto]


# DIT ZIJN CORRECTIES VOOR 2015, HERKOMST WILL CLERX DD 25.09.2014


#OUD
mutaties_os = [ [1,2,0.824],    [1,3,0.824],    [1,4,0.824],    [1,5,0.824],    [1,6,0.824],    [1,7,0.824],    [1,8,0.824],    [1,9,0.824],    [1,10,0.824]
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############
mutaties_rd = [ [1,2,0.824],    [1,3,0.824],    [1,4,0.824],    [1,5,0.824],    [1,6,0.824],    [1,7,0.824],    [1,8,0.824],    [1,9,0.824],    [1,10,0.824]
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#/NIEUW!!!!

mutaties = [nil,mutaties_rd,mutaties_os,mutaties_as]

mc                      = OtMatrixCube.open
name    = mc.name
writeln " * Geopend: matrix ",name

name2 = name + "access_2000_avondspits"
begin
  writeln " * Maak matrix ",name2
  mc2      = OtMatrixCube.create(name2)
rescue
  mc2      = OtMatrixCube.open(name2)
  writeln " * Warning: Matrix ",name2, " bestond al. Nu geopend."
end

writeln " * BB en SB correcties"

dagdelen.each{|dd|
        if dd == Restdag
                u = Skimuser+1
        else
                u = Skimuser+3
        end

        mat = mc[Totaal,Auto,dd,u]
        matNieuw = mat.dup
        mutaties[dd].each{|mut|
                h = gebieden[mut[0]]
                b = gebieden[mut[1]]
                matNieuw[[h],[b]] = mat[[h],[b]].multiply(mut[2])
    #writeln dd,";",mut[0],";",mut[1],";",h.join(","), ";", b.join(","), ";" , mut[2]
        }
        writeln "  --- Verschil auto tgv BB en SB voor periode = #{dd}: #{(matNieuw.sum-mat.sum).to_i}"
        mc2[Totaal,Auto,dd,u] = matNieuw
        matNieuw = nil
        ObjectSpace.garbage_collect
}
writeln " * BB en SB correcties op auto gereed!"

writeln " * Nu vrachtmatrices 31 kopieren... "
  mc.move([1,31,1,3],name2,[1,31,1,3])
  mc.move([1,31,2,3],name2,[1,31,2,3])
  mc.move([1,31,3,3],name2,[1,31,3,3])
writeln " * Nu vrachtmatrices 32 kopieren... "
  mc.move([1,32,1,3],name2,[1,32,1,3])
  mc.move([1,32,2,3],name2,[1,32,2,3])
  mc.move([1,32,3,3],name2,[1,32,3,3])

writeln "Klaar!"
```

F. Modelling approach (RVMK, transportation Model):

This section elaborates on the model, used to analyse the network effects of different MM measures and strategies. The goal of this model study is to research how different measures and packages of measures reduce congestion problems on the road system of the Rotterdam' transportation system. The model used is the Rotterdam' RVMK (regional verkeer en milieu kaart). This model is developed using the software OmniTRANS. The characteristics of the transport model, input data and output data are discussed.

Model characteristics

'*OmniTRANS is a genuine multimodal and multi temporal system, which is extremely suitable for modelling the interactions between the various means of transport within an urban context. It supports both aggregated and disaggregated methods for modelling the mobility demand. OmniTRANS draws a clear distinction between static and dynamic allocation methods while at the same time offering a flexible transition between the two methods. StreamLine's dynamic allocation algorithm (DTA in Dutch) uses a proven methodology and models the effect of the distribution of traffic in time on traffic resolution, and the build-up and dispersal of tailbacks and queues.* (DAT, 2015)'

- A static assignment is used. By using a dynamic assignment, the effect on the network over time would be modelled. This would provide more detailed information about when congestion problems arise, and the level of congestion at different time periods.
- Traffic flows are used on an aggregated level. The use of aggregated traffic flows, results in less detailed information about the traffic interaction. The interaction between individual cars is lost. The aggregated data, result in output, which can be used to determine to what extent congestion is reduced
- For trucks an all or nothing assignment (AON) is used. Trucks are assigned to the network based on the shortest path based on costs between the origin and the destination. Congestion is not considered, and truck drivers are perceived to have perfect knowledge about the cost attributes of all route alternatives.
- For cars a deterministic user equilibrium assignment (DUE) is used. This traffic assignment considers congestion. Using 20 iterations the traffic is assigned to the network, trying to optimize the routes for all individual drivers. There is no random component in route costs considered. During every iteration car users are perceived to have perfect knowledge about the route costs of the route alternatives.
- For all scenarios, the network variant is based on the normal transportation network supply lay out of Rotterdam. The eight physical measures, which are part of the entire strategy to manage the transportation system during the renovation project, are included in this network variant, as is the closing of The Maastunnel, in North-South direction. Included in these matrices are the effect of 'Beter benutten' till 2017.

Limitations

The model used for this case does not contain a trip generation, trip distribution, mode choice assignment and time period choice assignment. The problem of these limitations are, that it is only possible to adjust the OD matrices per mode per time period and see how this affects the network assignment. The effects on mode choice, trip generation, trip distribution and departure time choice cannot be modelled. Which are essential in explaining the different impacts of MM measures.

Initially, the output data were supposed to provide information about a lot of goals and impacts, related to the renovation of The Maastunnel. Data regarding distribution effects (modal and spatial) and change in accessibility (access equity) are because of the exclusion of trip generation, trip distribution, mode choice and departure time choice, not obtainable from the model. Also, accurate indications of where and to what extend noise and air pollution affects part of the city cannot be obtained.

The assignment is based on a static assignment with aggregated data, this limits the possibilities to achieve accurate information about the travel time effects (vehicle loss hours) in the system. No interaction between individual vehicles is modelled (because of aggregated data), no interaction over time is modelled (due to static assignment) and no recoil over links is modelled.

Input data

The input data are based are adjusted OD-matrices per mode per time period. Different scenarios are run for alternative mobility management measures.

Output data

The model is used to observe where and to what extent congestion is reduced and what the traveller benefits are in different scenarios compared to the reference scenario (without mobility management). This is done using two type of output data:

1. Demand reduction on important congested links. After the traffic assignment to the network, the traffic intensity (total amount of motor vehicles/hour) on all links can be displayed using a bandwidth plot. This is done for the evening peak, to illustrate what the effects of the different measures are on the important links in the transportation network.
2. The total reduction of vehicle km. This type of output data is used to determine the effects of different impacts, like air and noise pollution.

G. Results quick scan CBA of The municipality of Rotterdam, TNO and TU Delft.

This annex shows the relevant results of the quick scan cost benefit analysis performed on 17-4-2015 by experts of The Municipality of Rotterdam, TNO and TU Delft.

Confidential