The next smart move

A decision support system for urban implementation of smart mobility solutions

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The next smart move: a decision support system for urban implementation of smart mobility solutions

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Preface

Unfortunately, a few weeks after officially starting my thesis project, both the university and Witteveen+Bos office had to close down because of the measures by the Dutch government in combatting COVID-19. It was not always easy to do all work from home, host my interviews over Skype and not be able to sit down with my company and university supervisors. It did, however, force me to learn to motivate myself, even when in an environment that is not necessarily motivational.

I really enjoyed writing my master thesis at a company, as it provided me with a very dynamic environment, teaching me way more about transport and planning than solely what was relevant for my thesis. The mobility team at Witteveen+Bos was diverse and helpful, and the colleagues were always willing to share their expertise with me. I would like to thank Hilke van Strijp-Harms and Elise Zuurbier in specific, who always made time for me to sit down and discuss my thesis work, and involved me in the team from the beginning.

I would also like to thank Jan-Anne Annema, as first supervisor at the TU Delft, for his fast and valuable feedback whenever I would reach out to him with questions. And lastly, Bert van Wee and Els van Daalen, as part of my graduation committee, for their flexibility in meeting virtually, and their helpful feedback at my kick-off and greenlight meeting.

In the end, this thesis was an opportunity to further develop my programming skills, and get a deeper understanding of interviewing techniques, design methods and quantification of societal factors. But most of all, I learnt about policy making and transport and planning, the developments in the sector and the challenges ahead of us. I would like to thank the respondents of my interviews for providing me with interesting insights in local, regional and national mobility policy.

This thesis got me interested in the future of mobility, as it is something all of us deal with every day, when traveling to school, work or abroad. I am very excited to see which of the smart mobility applications I have researched will become part of our day-to-day street scene the coming years.

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Summary

The urban mobility sector is developing at a fast pace and is demanding transportation systems to be resilient and sustainable. Policy makers deal with an extensive offer of new technologies but lack an overview of the contribution of these mobility solutions to their urban planning ambitions. Uncertainty exists regarding both the technological advancements and the future of the mobility sector in a more general sense.

Hence, there still seems to be a challenge to overcome for policy makers to transform the mobility system and adapt to the developments. The applications are clear and literature on implementation is present, but no specific guidance in terms of trade-offs is available to governmental organizations working on urban infrastructure. This is also shown by a lack of literature on decision support systems for smart mobility. On top of that, there is a more practical motivation for a tool that provides an overview on the possibilities in smart mobility applications and their effects. Engineering and consultancy firm Witteveen+Bos requested a design for such a tool, to be able to provide more insightful advice on smart mobility solutions to their clients.

The present study concerns the development of a tool that gives insight in the (expected) effects of investments in different smart mobility solutions The research question is formulated as:

What is a useful tool for policymakers to quickly assess effectiveness and efficiency of smart mobility applications?

The tool designed assesses the mobility situation in a municipality, suggests smart mobility applications that are relevant in regards to specific mobility ambitions, and has set the first steps for a framework to assess the effects of smart mobility applications. On top of that, the tool is verified by testing for all user and system requirements that were set by consulting policy makers and experts, evaluated by means of a walk-through of all the units in the tool, and validated with the envisioned users to evaluate if the tool is relevant and supports their decision-making process.

The methodology of this study is based on a V-process model, that consists of the following steps of research:

1. Determining the functional requirements, which are the requirements regarding the objectives of the tool;
2. Determining the non-functional requirements, which relate to the performance of the tool rather than the content;
3. Architecture design, or the overall conceptual design;
4. Module or unit design, describing all units of the conceptual design more specifically;
5. Development of the tool, translating the conceptual design into a usable tool;
6. Unit testing, to test if all units function as supposed independently;

7. Integration testing, to test if all units are well integrated;
8. System testing, to test if the systems works as expected, also in case of extreme inputs;
9. User acceptance, to evaluate if the developed tool satisfies the expectations of the users.

The user requirements for the tool were collected through informal interviews with policy makers and experts in the mobility sector. Additional requirements for the system were deduced from literature and sector reports. Based on these requirements, a conceptual design consisting of three separate units was created. This conceptual design includes the determination of the most important concepts for decision support on smart mobility, which are applications, ambitions, themes and effects, as well as the relations between these concepts. Each unit of the conceptual design focuses on one relation between two different concept, and hence, serves a separate objective.

The most important finding from the interviews conducted was the need of the policy makers for the tool to focus on the mobility challenge in a city, rather than only on the potential of the applications. According to the respondents, this would contribute to the inclusion of smaller municipalities in the trend of smart mobility implementation, because the focus would be more on solving mobility problems in their city, instead of technological innovation. The first unit of the tool focuses on this challenge, by assessing different mobility variables for a city and determining the challenge: the variable the municipality scores worst on. The second unit relates qualitative mobility ambitions to the smart mobility applications that could contribute to that ambition. These relations are all imported through an Excel reference sheet. In this way, municipalities are encouraged to consider smart mobility as a possibility in their mobility policies. The third and last unit gives the effects of various smart mobility applications on indicators within five determined themes.

The conceptual design was then translated to an interactive dashboard. The tool was developed in dashboard format through Python Dash. This dashboard was evaluated; a user test with two of the interview respondents was conducted to validate the tool. Validating the tool with respondents from the earlier interviews resulted in generally positive feedback for this initial version of the tool, but a need for further expansion of the functionalities and content. The most important suggestions were to include the effects of more smart mobility applications, and to add the negative effects as well. In general, the tool could eventually become a useful quick-scan to stimulate interest in smart mobility among policy makers.

In the discussion, three main subjects were focused on. First, the design and development of the tool was discussed, including the induced subjectivity of the lists of applications, applications and themes, and a critical reflection on the relevance of the indicators. The second part of the discussion concerns the methodology of the study. Alternative models could be considered instead of the V-process model, such as the incremental build model. The interview process was perhaps too informal, but provided very valuable insights. The framework to design a DSS knows some disadvantages, which can mainly be prevented if policy makers always use the tool together with an expert. The last point on the methodology was the evaluation process, which could have been improved by verifying the requirements set in Chapter 4 with all respondents afterwards. The last section of the discussion elaborates on the challenges and opportunities when the tool would be implemented. When integrating the tool with existing transport models and assessment methods such as Cost-Benefit Analysis, these existing methods would have to be reviewed and potentially adapted to work well together. The part on commercial implementation mainly discusses maintenance, public accessibility and knowledge sharing, which are all to be considered for implementation.

In conclusion, the design from this study could be a good start for a tool contributing to the insights of policy makers on the opportunities with smart mobility applications. Further completion of the tool as well as regular updates are required for the relevance of the tool. The main limitation of the development of the tool is the difficulty with determining the effects of smart mobility measures. 11 different recommendations are given for further development of the tool:

1. Add extra units
2. Review indicators for the city profile
3. Review the indicators for the effects
4. Same units for the effects and the city profile
5. Add factsheets or calculations
6. Provide follow up options
7. Expand the city profile
8. Review the challenge in the first unit
9. Increase the amount of applications in the effects unit
10. Improve rules of thumb
11. Automate conversion to indicators

Further descriptions of these recommendations can be found in Chapter 10. The further development of the tool regards to the practical suggestions that can be made. On top of that, there are three most important suggestions for future research. It would be recommended to conduct studies on the following topics:

1. Effect measurements of smart mobility implementation
2. Difference between smart mobility and normal transport projects
3. Effectivity of pilots

Key words: smart mobility, urban mobility, traffic management, transportation systems, impact measurement, transport policy

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1 Introduction

Population growth and climate change may be the biggest challenges of the upcoming century. At the same time, the possibilities of the use of data are endless and new applications are emerging at a rapid pace. These developments have large impact on urban areas as well. The amount of vehicles in possession has been increasing for years in the Netherlands, largely due to the increase in passenger vehicles. To be specific, the amount of Dutch passenger cars has risen by 6 percent in the period 2008-2018 (Centraal Bureau voor de Statistiek (CBS), 2019). This has led to 17 percent increase in congestion in 2019, that is difficult to solve, even though many new roads are being built (ANWB, 2019). Obviously, vehicles require space in urban areas as well, whether they are parked or driving. Although the amount of cars in the country keeps increasing, the study by CBS investigates the reasons one would consider giving up a personal car. It shows that, for example, among elderly, young people (18-30 years old) and citizens moving inside cities, cars were more often given up in comparison to other population groups. According to CBS, these groups that would give up a car may also be most interested in alternative mobility solutions.

CBS research shows that the amount of fuel used for mobility has again increased by a few percentage in the period of a year (Centraal Bureau voor de Statistiek (CBS), 2018). While cars have become more fuel efficient, improvement of the economy has led to more driven kilometres and hence more fuel used. The financial stimulation for electric cars and vehicles driving on natural gas proves to be effective: both more sustainable methods have experienced growth. For instance, in the period 2015-2018, the amount of plug-in vehicles has increased by 170 percent.

In short, cities are evolving in a direction that may yield environmental and spatial challenges. On top of that, new technologies as well as developments of the mobility sector are highly uncertain. Cities are required to become more resilient and future-proof in order to be able to adapt to these changes (Pellicer et al., 2013). When discussing urban sustainable development and cities of the future, many researchers use the framework for ‘smart cities’ (e.g. Hall, Bowerman, Braverman, Taylor, & Todosow, 2000; Nam & Pardo, 2011). Smart cities constitute different dimensions, smart mobility being one of them. The different dimensions identified besides smart mobility are smart economy, smart people, smart government, smart environment and smart living (Albino, Berardi, & Dangelico, 2013). These six categories relate to the traditional axes of urban development, however, now all indicating the ambition to make them ‘smart’. The notion ‘smart’ has been defined in many different ways, but generally entails the optimal use of technology and resources for coordinated urban planning. The variety of interpretations of the concept of smart cities and smart mobility, and consequently the possible solutions, confirms the complexity of the challenge this study concerns (Lyons, 2018).

Adaptive policies may lead to smart, energy efficient solutions for mobility in urban areas. Various mobility applications using innovative technology have been researched and will possibly be implemented, ranging from autonomous driving to traffic management measures. An overview of the research is provided in the next chapter. These mobility measures could benefit for example energy efficiency, road safety and accessibility. Whether the policy objectives are financial, environmental or otherwise, the most effective way to reach these objectives could be investing in one specific technology, but it could also be a combination of different technologies. The current study examines the relation between the urban applications of smart mobility and the ambitions of policy makers.

A general literature search on Google Scholar with search term *smart mobility* yields 1,830,000 results, of which more than 600,000 were published in the last 10 years. *Mobility as a service* gives 1,610,000 results on Google Scholar. These numbers prove the interest and topicality of the field. Smart mobility literature could be put into three different categories: development of technologies, mobility policy and the impact of smart mobility. Formulated differently, research discusses the what, the how and the why. This research is discussed in the first two sections of the literature chapter (section 3.1, 3.2); firstly by means of review papers, to give an overview of the variety of studies, and secondly, by distilling and exploring the relevant segments of the literature for the present study. The knowledge on these topics has been of essential need for the current research, but also shows a significant gap in angle.

1.1 Problem statement

There still seems to be a challenge to overcome for policy makers to actually transform the mobility system. The applications are clear and literature on implementation is present, but no specific guidance in terms of trade-offs is available to governmental organizations working on urban mobility. This is also shown by a lack of literature on decision support systems for smart mobility: a search in Google Scholar on *"smart mobility" "decision support system"* only gives 415 results, including many studies that are either more specifically looking at a certain smart mobility application or more broadly looking at smart cities as a whole. When searching for *smart mobility decision support system* or *smart mobility trade-off* only in the title, Google Scholar yields 0 results. 15 results are given for studies with *smart mobility tool* in the title. The advanced search for the terms in titles only was considered more accurate than a regular search, because occurrence in the title generally means it concerns the overall subject of the study.

Hence, there is a knowledge gap regarding decision support systems on smart mobility. This gaps fits with the more practical motivation for this research as asked by the engineering consultancy firm Witteveen+Bos. The role of Witteveen+Bos as engineering consultancy firm is to advice governments on specific smart mobility projects based on their individual needs. What they also miss is guidance on coupling the what, the how and the why, and helping the client to realize the most optimal smart mobility solution. This means there is also a practical need for a tool that provides an overview on the possibilities with smart mobility applications and on the effects of implementing smart mobility. On top of that, the tool shall ease the trade-off between these different options.

1.2 Research objective

At the moment, policy makers experience a broad offer of smart mobility solutions that is constantly under development. In order to assess the possibilities for implementation of these solutions, an overview of available applications and policy ambitions is needed.

The present study explores design possibilities for a decision support system (DSS) that can be used by engineers in the mobility sector to advice policy makers. The term tool and DSS are used interchangeably, as the theoretical framework deduced from literature for developing a DSS is used to develop the tool for this study. This tool shall require input from the policy makers on their ambitions and type of city they are working on. It shall yield insight on the positive and negative effects of different mobility applications, helping the user to choose a smart mobility solution based on the trade-off of advantages and disadvantages. The main research question is formulated as follows:

What is a useful tool for policymakers to quickly assess effectiveness and efficiency of smart mobility applications?

Before further exploring the development of the tool, more knowledge is required on the applications and ambitions at the present moment, and the expected developments. On top of that, a tool can be developed with various goals and in various forms. The sub-questions are formulated as follows:

- What are the user requirements of the tool?
- Which smart mobility applications should be included in the tool (and at which level of detail)?
- What are the effects of existing and future smart mobility applications?
- How do experts and policy makers assess the tool?

1.3 Relevance

The present study has been written by assignment of Witteveen+Bos and as partial fulfilment of the Master of Science Engineering & Policy Analysis at the Delft University of Technology. The relevance of this study from academic, societal and master program perspective is explained in the next subsections.

1.3.1 Academic relevance

Whereas regular transport projects are mostly focused on improving traffic flow, the implementation of smart mobility could have effects on many societal factors, such as the environment, health and comfort. These dynamics, however, complicate the measurements and quantification of the effects of smart mobility. As explained in Mangiaracina, Perego, Salvadori, & Tumino (2017), this results in a lack of quantitative models to assess smart mobility solutions. The present study aims to contribute to the quantification of the effects of smart mobility by exploring indicators and rules of thumb to assess the implementation of solutions. Next to literature review, experts and policy makers are consulted on the possibilities to quantify the impact of smart mobility, and on the relevance of pilots and the importance of knowledge sharing among stakeholders. This collection of knowledge and insights by experts and policy makers is combined into requirements for a decision support system that could assess smart mobility solutions.

1.3.2 Societal relevance

As an engineering consultancy firm, Witteveen+Bos aims to provide policy makers with advice on improvements on infrastructure and traffic systems. The developments in the mobility sector also affect their project and advice given to their clients. The tool designed serves as a sort of quick scan that can be used by engineers of Witteveen+Bos together with municipality officials, in order to determine potential smart mobility applications that would be worth starting further investigation on.

The eventual tool hopefully provides policy makers with more insight on the possibilities for their municipality regarding smart mobility. More specifically, hopefully it shows smaller municipalities that smart mobility is not only a relevant solution for larger municipalities, but could also be worth investigating for smaller and medium sized cities.

For Witteveen+Bos, the tool could facilitate dialogue about the topic of smart mobility among the engineers and clients, and in this way, encourage knowledge sharing and collaboration. By starting the conversations on a low-key level through this tool, the engineers hopefully get a more thorough understanding of the mobility challenges in the city the client is working for, and this way, they could formulate more accurate advice.

1.3.3 MSc Engineering & Policy Analysis

The current study is written as final part of the graduation requirements for the Master of Science Engineering and Policy Analysis at the Delft University of Technology. The master programme is focused at solving socio-technical challenges, and is therefore set up around both modelling and policy courses. In the present study, various techniques learnt in these courses have been used in formulating and answering the research questions. Just like the master programme, the present study focuses on the use of data analysis for decision-making; by structuring, analysing and visualizing smart mobility data and relations in a comprehensible way, the present study contributes to policy decisions in the mobility field.

1.4 Structure

The main research question and sub-questions formulated above are answered in the chapters that follow. First, the methodology applied to structure the process of finding the answers is explained in Chapter 2. The consequent chapters are based on the described methodology. This includes a literature review to set a theoretical framework for the study as a whole, followed by tool requirements, tool design, tool development, and tool evaluation. These topics are discussing in Chapters 3-8 respectively. After that, the discussion on the tool, the used methodology and the implementation possibilities follows in Chapter 9. The final chapter is Chapter 10, containing the conclusion and recommendations.

2 Methodology

As the previous section argues, there is a lack of understanding about the effects of smart mobility applications. Providing more insight on these effects through a tool could help decision makers in their policies on implementing or facilitating smart mobility in urban areas. The current thesis explores the design possibilities for a decision support system that includes various smart mobility applications and yield visual insight into the effects of these smart mobility applications. In order to explore the design possibilities for a tool, various steps are required beforehand to investigate the initial content of the tool, according to the sub-questions formulated in the previous section. These sub-questions relate to the requirements of the envisioned users that have to be determined before looking into the design of the tool, the conceptualisation of the design and an evaluation of the state of completion of the tool.

These steps can be structured according to existing systems engineering models. The two models considered for this research were the V-process model and the waterfall model, described in e.g. Sage & Armstrong (2000) as appropriate models for systems engineering. Both models follow roughly the same steps - requirements, design, implementation, verification - and are followed from left to right. The V-process model is presented visually in a V-shape, emphasizing the relation between the specification and the testing stream of the model. The V-process model also has a larger focus on testing the system developed, which suits the exploratory approach of the present study. Hence, the chosen model to structure this research is the V-process model.

In short, the V-process model is a framework for systems engineering that includes the caption of all conceptual and design requirements in an early phase of the systems engineering process (Sage & Armstrong, 2000). It follows the entire life-cycle of developing a system that meets the needs of the user and, therefore, very well fits as methodology for the present study. The steps are based on the V-process model as described in Sage & Armstrong (2000) but the visualization in Figure 1 is tailored to this specific study. The rest of this chapter describes the steps in more detail.

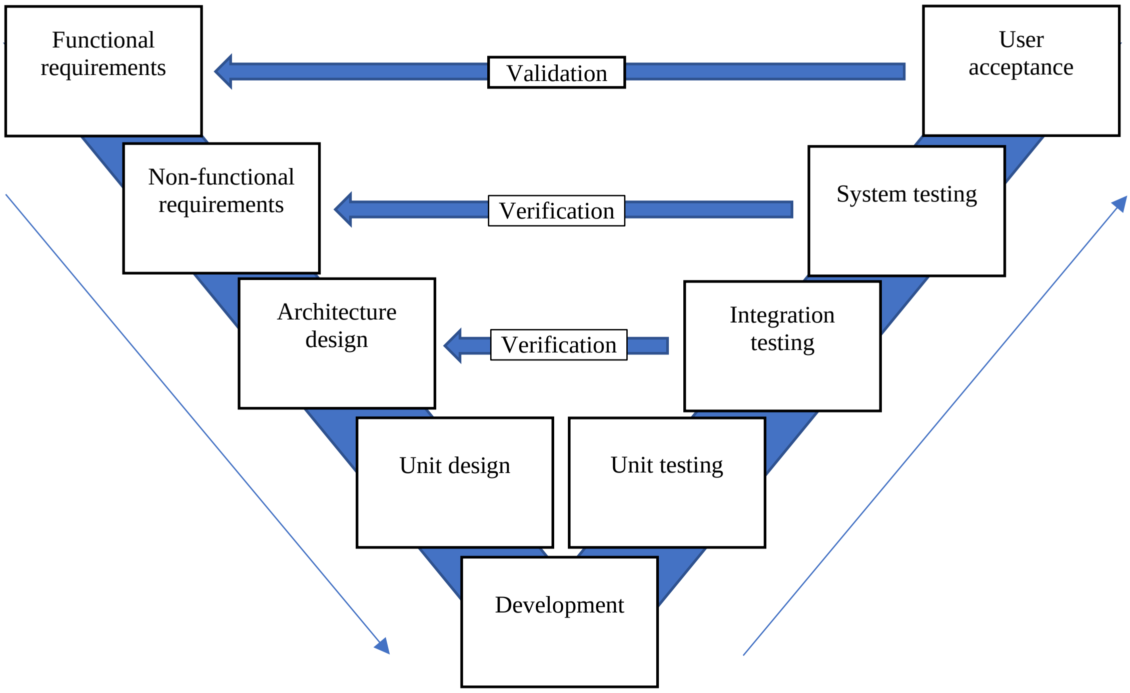


Figure 1 V-Process model

2.1 Requirements

The current study is mostly an exploratory design study. This entails designing the set-up of a decision support system that both satisfies the needs of the users of the tool, and at the same time, is a well-functioning system on its own. Prior to the design itself, the requirements for the design on these two topics have to be set, as functional and non-functional requirements respectively.

2.1.1 Functional requirements

In order to develop a tool that serves its purpose, the envisioned users of the tool shall be consulted on their demands (Zopounidis & Doumpos, 2000). This part of the research is conducted based on informal interviews with experts and policy makers in the sector. The reason to use interviews as main source of information on the user requirements is that it provides the option to tailor the conversation to the respondent's answers and experiences with smart mobility. Different respondents may have either more knowledge regarding technology or policy, and may also differ in the level of detail of their involvement with smart mobility projects.

The experts that were included in the interview are project managers and engineers working at various departments of Witteveen+Bos. The policy makers consulted are municipality officials, some of which are among the clients of Witteveen+Bos, and interested in the possibilities of smart mobility. All respondents are first contacted through email to schedule a one hour time slot. Although it may have been more informative to conduct all interviews physically, circumstances required most interviews with policy makers to be held virtually. The consultations are meant to provide insights on the format of the tool, by collecting preferences on types of input and output. The interviews have not been conducted in a completely formal manner, but are rather meant as source of inspiration and information. The municipalities of the Hague and Almere are among the clients of Witteveen+Bos and are working on smart mobility. These municipalities are therefore relevant stakeholders to include for defining the user requirements. On top of municipal policy makers, one of the engineers at Witteveen+Bos suggested to consult the metropole regions as well, since most mobility policy is made on regional levels. Therefore, similar interviews are held with representatives of the metropole region of Amsterdam. To get a more integral view of smart mobility policy in the Netherlands and by reference of one of the municipality respondents, an informal interview has also been conducted with a policy maker of the Ministry of Infrastructure and Water Management.

The interview questions are enclosed in Appendix A1. The first set of interview questions examines the knowledge and interest on the topic of smart mobility in a relatively broad sense, including definitions and ambitions. The second set of questions concerns the tool itself by posing questions on the format, input and output factors, and usability. In practice, both sets of questions are posed in the same conversation. A clear distinction between the two sets of questions is however relevant, as the first list of questions relates to objectives and ambitions, while the second set relates to the functional and non-functional requirements of the system. If there is a clear line of preferences among the interviewees, the user requirements is set as the answer given by all. If the interviewees do not agree in their preferences, a more thorough analysis of options is required as well as potentially settling for an option that is in-between their preferences. If a specific question is only posed to some of the respondents, but countered by none, it can still be considered a user requirement. The answers by the respondents are described qualitatively in the text, naming all respondents by a reference letter, e.g. Respondent A. A table with all reference letters and the corresponding function and organisation of the interviewees is included - Table 1.

Table 1 Interview respondents

Respondent	Organisation	Job position
A	Witteveen+Bos	Project engineer mobility
B	Witteveen+Bos	Project manager mobility
C	Witteveen+Bos	Advisor integral planning and environmental impact assessment
D	Witteveen+Bos	Project manager traffic management
E	Witteveen+Bos	Manager urban development
F	Witteveen+Bos	Urban data scientist
G	Witeveen+Bos	Project engineer urban mobility
H	Municipality The Hague	Policy advisor mobility, innovation and strategy
I	Municipality Almere	Policy advisor mobility
J	Ministry of Infrastructure & Water Management	Senior advisor innovation, strategy & concept development in smart mobility
K	Smart Mobility platform MRA	Leader theme Digital & physical infrastructure
L	Vervoerregio Amsterdam & Smart Mobility platform MRA	Program manager Smart Mobility
M	Witteveen+Bos	Project manager infrastructure

2.1.2 Non-functional requirements

The development of a tool can be interpreted in many ways and has to be restricted by requirements. While the user needs regarding the content of the tool can for a large extent be translated to functional requirements, a list of non-functional requirements is collected as well. Everything not directly relating to the purpose of the tool, but relevant for its development, is considered a non-functional requirement.

For example, the software used brings along some restrictions as well. Not everything is possible with a certain type of software, and the conceptual design has to complement the chosen software in order to actually realize it.

Most non-functional requirements are deduced from the interviews as well, in combination with the literature on creating tools and decision support systems. For this, Google Scholar and the TU Delft Library are consulted, using key words such as *decision support system requirements*, *dashboard design requirements, non-functional requirements*. The book by Sage and Armstrong (2000) also provides valuable context for the requirements.

2.2 Design

The conceptual design of the tool has been created based on the requirements and literature insights. Through flowcharts, tables and in words, the relations between all different concepts is explained. The design of the tool could be divided into two parts, the model architecture and the units.

2.2.1 Model architecture design

The model architecture design concerns the conceptual design of the system, meaning that it broadly describes the different parts of the tool and its main purpose. It really focuses on the overall concept, does not give many details, but rather describes the general operations. For the present tool, that means the most important concepts of the tool and the relations between those have to be determined.

Based on the literature, a clear focus on both the technology side and the policy side of smart mobility could be noticed. For this study, these concepts are called **applications** and **ambitions**. On top of that, to discuss the impact of applications, the concept of **effects** is introduced. The last important concept is **themes**, used to split the other concepts into broader categories. These concepts have been defined, and both literature review and consultations have been conducted to determine the content of these concepts. Based on the information gathered, lists of applications, ambitions and themes could be composed. These concepts are needed to analyse the potential of smart mobility.

The literature review is conducted through Google Scholar and the TU Delft library, by using key words such as *smart mobility, intelligent transport systems, effect smart mobility*, and *goals smart mobility*. It is important to consider that this analysis is never complete, due to unexpected developments and new insights that may happen in the sector. The goal of the literature review on applications is to get an overview as complete as possible on the existing applications and expected developments. It would be useful to concatenate different applications in broader categories, to minimize the effect of transitions and developments on the suitability of the tool. These themes shall be relatable to smart mobility applications and policy ambitions, and are mainly useful for creating more structure in these two sets.

2.2.2 Unit design

The unit design phase determines the design in more detail compared to the model architecture. Whereas the model architecture determined the concepts and the relations between the concepts, the unit design further studies the methods to demonstrate and analyse those. The model consists of various units, all operationalizing a part of the objective of the tool. That means that each unit focuses on a specific relation between two different concepts, and requires its own input and gives its own output.

The section Unit design describes every unit separately, including input and output factors, conversion and calculation techniques. While the design of the model architecture includes the relation between the different concepts, the unit design describes the way of gathering user input and visualizing outputs.

An important part of this being setting the indicators to quantify the effects of smart mobility. In order to do this, the different methods used in literature to quantify the effects of smart mobility and define indicators are reviewed. Based on all this literature, a limited set of both themes and indicators quantifying those themes has been chosen for the present study. The indicators are meant to quantify the themes, but due to the ambiguity of a theme, there could be multiple indicators for one theme. The most important requirement is for the indicator to come with a clear definition and unit.

2.3 Development

The development of the tool itself translates the conceptual model and its units to a physical tool. A distinction is made between the model behind the tool, the *back-end*, and the tool shown to the users of the tool, the *front-end*.

2.3.1 Back-end

The back-end of the tool was built through a combination of Excel sheets and Python scripts. The Excel sheets were used for all data input, while the Python scripts process the Excel sheets and translate them to the front-end of the tool.

One Excel sheet is needed to determine all the lists of concepts, and the relations between these lists. The choices made for these connections all have to be documented, for the sake of the present study, but also for reproducibility. Another Excel sheet is used to import external data on mobility situations in cities. The Python scripts read in the Excel sheets, transform the data and execute the calculations.

The Excel sheets could be filled mostly with the lists defined in the design phase. The city-specific data was subtracted from databases and downloaded in Excel format. In Python, the data were imported as pandas data frames, and standard functions within the pandas package were applied to transform the data into the desired format. Separate functions were written for the more project-specific type of operations.

2.3.2 Front-end

The front end of the tool is built in dashboard form through Python Dash. It aims at visualizing the information from the back-end in an easily assessable manner. The aim of the present study is not necessarily to fill the tool with a complete set of identified applications, as long as sufficient applications are run through the tool to demonstrate its operation. A partial fulfilment of the tool is necessary to show the calculations and relevance of the design; the feasibility to include all identified applications in the tool is restricted by time.

The Python scripts were written on the foundation of the Dash package, including the core components and bootstrap components. These components enable the organisation of the layout of the dashboard as well as standard buttons, charts and menus. In combination with some html integration, the Dash package provides a simple set-up for dashboard building.

A dashboard typically consist of relatively much information compared to the amount of decorative elements on the web page. It is also not meant to be static; the information in the dashboard shall be updated on a regular basis to ensure recency of the. The main purpose of a dashboard is to apply visualization techniques to improve comprehension of the users of the situation analysed.

The advantage of choosing a dashboard format for the tool built is that it provides high-level insight and overview of the available information. At the same time, this is also the downside of choosing a dashboard format. A dashboard does not allow for users to understand the complexity of the topic and pose follow up questions. Therefore, the dashboard is meant to be used in combination with expert advice (Abd-Elfattah, Alghamdi, & Amer, 2014).

2.4 Evaluation

The evaluation of the tool relates to the right part of the V model in Figure 1 and includes the verification ("does the tool function as designed?") and validation ("does the tool function effectively?"). It also includes a sensitivity analysis for the quantitative parts of the tool.

2.4.1 Verification

Verification relates to the unit testing and integration testing as denoted in Figure 1. The verification of the tool includes the following steps:

- Unit testing, to test if all modules of the tool independently function correctly;
- Integration testing, to see if the units of the tool are well connected to each other;
- Consistency testing, to test if the tool gives expected output to input proportionate to each other.

Normally, a tool would have to be checked on extreme cases and fault injection as well. However, as the front-end of the tool only allows limited freedom for the input factors, these two types of testing are at the moment not executed. This would, however, be relevant when the back-end of the tool, and especially the cross-reference input Excel file, would be accessible to any user as well.

On top of these parts of testing, the tool is designed to satisfy the functional and non-functional requirements that have been set. The verification therefore also includes a check on these requirements and the level of fulfilment.

2.4.2 Validation

The last step, concluding the design, has been validation of the tool by applying it to one or more case studies with the clients of Witteveen+Bos. Verbally evaluating the cases with potential users is a good opportunity to test the effectivity and user-friendliness of the tool and possibly make some final adaptations. As it may be difficult to sometimes validate the outcomes of the tool by comparing them to the real world situation, assessing face validity by consulting experts may sometimes be all that is possible (Qureshi, Harrison, & Wegener, 1999).

This validation was roughly conducted by the list of questions in Appendix A1.3. these questions supported the user test in a way that these could be exemplary questions to pose, but in practice, walking through the tool and requesting feedback proved more informative.

3 Literature

The present chapter reviews the literature on three important topics: smart mobility technologies, smart mobility indicators and decision support systems. The review of literature on technologies and ambitions is meant to gather an overview by analysing review papers, and consequently, using the literature, categorize the technologies and indicators in a comprehensive manner for the rest of the study. In this Chapter, the literature is only reviewed, but it will be processed in Chapter 5. The review of existing mobility indicators is valuable, because it provides ideas on quantifying the efficacy of smart mobility applications, and inspires the determination of indicators for each ambition for this study. Lastly, the literature on decision support systems helps to identify pitfalls and opportunities in the design of a decision support system, which are important to consider in later chapters. Hence, this literature chapter does not relate to one specific part of the methodology framework, but rather contributes to all that are following this chapter.

3.1 Technologies

Technological innovations for the mobility sector are emerging rapidly, especially due to the wide range of possible applications of data. This is also visible in the amount of research conduction on traffic technology. Google Scholar finds approximately 407,000 results for *smart mobility technologies*, 410,000 results for *intelligent transport systems*, 516,000 for *autonomous driving* and 970,000 for *driving assistance*. Two important fields of investigation can be distinguished for technological innovations, traffic management and vehicle related technologies.

In traffic management, a division can be made between users and infrastructure. Both users and infrastructure connectivity can be used for data acquisition. Data of users is collected through their mobile phones or vehicles. Infrastructure is connected through sensors for speed control and road lightning, but also traffic lights. Traffic lights are constantly monitored and improved, and academic researchers investigate the options for using data to further develop the systems. Bravo, Ferrer, Luque and Alba (2016) are among the literature, suggesting the use of bio-inspired techniques and micro-simulations to improve traffic flow.

Olaverri-Monreal (2016) also explains the use of data for mobile phone applications, that could provide personal route suggestions, preventing congestion or saving fuel. This is all possible because of the communication between the user’s smartphone and other entities participating in traffic. Parking management could also benefit from this connectivity and guide users to available parking spots (Mangiaracina et al., 2017).

Vehicle use is the second important topic of investigation for technological innovations. Autonomous vehicles and other technologies for mobility applications are discussed in the paper by Olaverri-Monreal (2016). Autonomous driving is mainly interesting from a safety perspective, as it could decrease the part of accidents caused by human error. However, it would also have a positive impact on accessibility, capacity use and energy consumption. For instance, autonomous vehicles allow less distance between them and hence increased road capacity, as the distance is regulated by pre-programmed systems. This concept is called platooning (Vinel, Lan, & Lyamin, 2015).

As the aim of the present study is, in the first place, to relate smart mobility technologies to their effects and policy ambitions, a more comprehensive view on existing and emerging smart mobility solutions is offered in this chapter. On top of that, the applicability in urban areas are evaluated, as the present study focuses primarily on urban transport. Lastly, the technologies are structured and classified for the purpose of the rest of the study.

3.1.1 Existing smart mobility technologies

The level of detail of smart mobility solutions differs per study. For now, an overview as complete as possible is provided, and any way of structuring and categorizing is left for later sections. Categorizations used in literature are partly be included, however no analysis or deductions follows yet in this section.

Benevolo, Dameri and D'Auria (2016) provide an extensive list of smart mobility applications. The study also indicates the extent of use of ICT per application and to which effect the application relates. The applications have been listed in Table 2, while the ICT use and related effect have been left out, but are available in the study by Benevolo et al. itself. This table still includes EUR 5, which is the European norm on emissions, and has been replaced by EUR 6.

Table 2 Smart mobility applications (Benevolo et al., 2016)

1. Public mobility: vehicles and innovative transport solutions
Vehicles EUR 5 Use of alternative fuels (LPG, methane, hydrogen, bio-diesel, fuel cell) Vehicles with automated driving Integrated management of public transport vehicles Collective taxis Integrated ticketing system
2. Private and commercial mobility: vehicles and innovative transport solutions
Electric vehicles Vehicles EUR 5 Use of alternative fuels (LPG, methane, hydrogen, bio-diesel, fuel cell) Vehicles with automated driving Car sharing (with georeferencing and geotagging) Car pooling Hire and ridesharing services Bike sharing (with georeferencing and geotagging) Piedibus Automotive navigation system Eco-driving

3. Infrastructure and policies to support mobility
Infrastructure, changes and addressing mobility
Parking Park and ride Bicycle lanes Columns recharge electric vehicles Message signs about mobility Integrated traffic lights Pedestrian zones or auto-free zones Restricted (or limited) traffic zones Bus lane or bus only lane Parking guidance system Systems for speed control and management Mobility management based on the level of pollutant emissions
Integrated policies to support smart mobility initiatives
Traffic flows division (private, public, commercial) Integrated ticketing Tariff integration between public and private transport Incentives for the use of less polluting fuels Control of emissions Speed limit sign Economic incentives and/or higher taxation measures (congestion pricing, ecopass, cordon pricing, road pricing, park pricing) Tax incentives and/or measures such as higher taxation on polluting fuels Regulation of access (pedestrian areas, time bands, ZSL, STL) Redesign of city times (public schedules, school schedule etc.) Redesign of the city and its spaces (residential and industrial areas, integrated neighborhoods etc.
4. Systems for collecting, storing and processing data, information and knowledge aimed to design, implement and evaluate policies and integrated initiatives of Smart Mobility
Demand control systems for access to reserved areas (cordon pricing, congestion pricing, electronic tolling, electronic tolling with GPS, pay as you drive) Integrated parking guidance systems Variable Message Signs (VMS) Urban Traffic Control (UTC) Video surveillance systems for area and environment security Integrated systems for mobility management Traffic data collection systems (section control, variable speed limit control, ramp metering etc.) Expert systems for the correlation and filtering of events (Automatic Incident Detection—AID) addressing and control systems of urban and suburban traffic (section control, ramp metering, variable speed limit, activation of the emergency lane for congestion) Systems for the management of fleets and logistic Systems for managing fleets of vehicles of public transport adapted to UTC (system of planning, monitoring and reporting of public transport service, integrated electronic ticketing system, information system for users of public transport)

Hence, Benevolo et al. use the four categories public mobility, private mobility, infrastructure and policies, and systems for collecting, storing and processing data, information and knowledge. The third category, infrastructure and policies, is split up into two subcategories, infrastructure and policies.

The study by Cledou, Estevez & Soares Barbosa (2018) aims to design a taxonomy for smart mobility applications and has defined eight dimensions to achieve this: types of services, level of maturity, users, technology, channels, benefits, beneficiaries and common functionality. For the present section, most useful is the first dimension because it includes their analysis of categorizing the existing smart mobility into a limited set of types of services. In the specific case of their study, they have categorized 42 identified smart mobility applications into 12 types of services. The types of services and their descriptions used by Cledou et al. (2018) is listed in Table 3.

Table 3 Types of smart mobility services (Cledou et al., 2018)

Category	**Description**
Driving guidance	It provides guidance to drivers about the best route for moving from one place to another, including fixed or real time information of issues affecting mobility. Routes can be selected based on different criteria, such as the shortest or fastest route
Improving transport resources	It refers to enhanced functionality included in transport resources, usually related to a specific goal, such as energy savings, enhancing the travel experience, and reducing CO_2 emissions
Improving transport infrastructure	It refers to enhanced functionality delivered to transport infrastructure such as parking places, roads, traffic lights, etc., including devices to detect empty parking places, or dynamic message signs to inform about traffic
Journey planners	It provides instructions for moving from one place to another using one or multiple types of transport for a single journey. Instructions include types of transport available, travel and arrival times, and guidance for commuting between them. Guidance can be personalized with different criteria such as the cheapest, fastest or most environmentally friendly journey, and support for transporting wheelchairs or bicycles, among others
Locating objects	It enables to locate, usually in real time, vehicles in the city such as cars, public bicycles or public buses
Monitoring traffic	It enables authorities to monitor, analyse, and get insights about traffic and pedestrians, such as detecting congestions, estimating traveling times, and detecting cars' illegal behaviour. It can rely on monitoring of simulated data, e.g., to evaluate the impact of events on traffic, such as, weather, road closure, and adjustments in traffic lights patterns. Recorded data can serve as evidence of incidents for authorities
Monitoring transport	It enables transport authorities to monitor public transport vehicles to get insights about onboard events, vehicles' performance based on current and expected traveling times, number of passengers, and incidents, among others
Parking	It enables users to search, book, and pay for parking places. It can also include functionality for managing the parking facilities, offering parking places and managing interactions between the parking provider and the users
Payment	It enables to seamlessly pay transport-related services, such as tickets for single or multi-modal journeys, parking places, energy for electric vehicles, road tolls, and use of public bicycles, among others
Reporting mobility	It provides various stakeholders with information about events affecting mobility such as planned events, incidents, alternative routes, and current traveling times, among others
Sharing transport	It enables to share vehicles (car-sharing) and journeys (car-pooling), including, announcing, searching, booking, and paying for cars and shared journeys, and accessing to vehicles
Traffic light optimization	It allows adjusting traffic light patterns based on different factors including current traffic flow, historical and simulated data, and approaching of special types of vehicles such as emergency vehicles and public buses. The main aim of this type of service is to respond to the changing demands in traffic flow and to prioritize the moving of special vehicles

These twelve services are all distinct, but could in some way be categorized in fewer categories. Driving guidance and parking relate to in-car assistance. Improving transport infrastructure and traffic light optimization both relate to traffic infrastructure. Journey planners, locating objects, monitoring traffic, monitoring transport and reporting mobility are all types of data tools. Improving traffic resources and sharing transport concern vehicles. Payment is a service that is slightly different than the others, as it considers both infrastructure services and vehicle services.

In comparison, Garau, Masala & Pinna (2015) define six different categories, which are public transport, cycle lanes, car sharing, bike sharing, private mobility support system and public mobility support system, and categorize all smart mobility applications accordingly.

As the variety of classifications proves, there is no predetermined method to classify the smart mobility applications. Seeking common ground between the studies analysed is therefore the preferred method to come up with the most efficient classification method for the present study. When doing this, applications are put in the category that fits best, but some overlap is inevitable. Especially cross-domain solutions have proved successful, including technical progression, smart governance and adapted infrastructure.

3.1.2 Expected developments in mobility

An extensive amount of literature on existing and implemented smart mobility applications has been broadly analysed above. Smart mobility is, however, a field that is developing very quickly. New technologies improving or adding to the current applications are constantly emerging. It is therefore relevant to develop understanding of the expected developments in the mobility sector by analysing some review papers. These developments may not directly be applicable for the present study, but rather sketch the context of the sector and demonstrate the pace of development.

According to Flügge (2017), technological developments, such as the Internet of Things and Augmented Reality may influence the mobility sector. Augmented reality, for example, would decrease the complexity of assessing situations on the road by rendering important information in the driver's line of sight (Mahmood, Butler, & Jennings, 2018). Augmented reality could be implemented for in-vehicle driver assistance, e.g. for parking cameras.

On top of that, the shared economy is predicted to grow by 3000% (Flügge, 2017). This would mean that sharing platforms for vehicles would gain in popularity as well, which would have a large effect on the sector as a whole, for example in terms of space use and car possession numbers. However, it is not just sharing platforms that are expected to arise. Mobility as a service is the term that is used to describe the envisioned shift around mobility; users would not be limited to one type of vehicle, but could use an app that includes various modalities and provides the opportunity to travel by the mode that is most optimal for the travel objective. This way, using public transport alternatives become more user-centred and hence more appealing (Deloitte, 2017).

In general, cities tend to aim for a reduction of cars in urban areas. The trends described in Chapter 1, climate change and population growth, play an important role. Population growth and increase density of cities increase the amount of cars per area, while the negative effects of emissions on the environment become more important to citizens and government officials. Transforming to a car-free city centre would therefore be healthier for citizens, more comfortable and spatial, and less harmful for the environment (Nieuwenhuijsen & Khreis, 2016).

Lastly, in order to facilitate these developments, the rapidly changing traffic environment in cities requires policy measures that are adaptable. Predictive analysis could support decisions to be made by providing insight into potential developments of technologies.

3.2 Indicators

Smart mobility measures can be designed and implemented with various envisioned effects. For this study, it is important to know what policy makers are aiming to achieve when implementing smart mobility measures, and whether or not these ambitions are similar among policy makers or differ significantly. While there is a lot of research conducted on specific effects of certain applications, the literature on the effects of smart mobility in more general terms is also extensive. A Google Scholar search gives 372,000 results for *smart mobility effects*, 270,000 for *smart mobility impact* and 226,000 *for smart mobility benefits*. In literature , the words effects, impacts, themes and ambitions are often used interchangeable as policy ambitions regarding mobility are equal to the envisioned effects or impacts of implemented measures. In section 5.1, a clear distinction between these sets is made for the tool development.

Objectives of mobility policy are described on all levels of detail in literature. A distinction can be made between overall areas of impact, and the actual factor an application impacts. The first relates to the themes that are considered important by the municipality, while the second is a measurable factor that changes because of the implementation of smart mobility. The review on the qualitative terms, themes, can be found in 3.2.1, while the literature on quantification can be found in section 3.2.2.

3.2.1 Themes

Among the literature is Benevolo, Dameri and D'Auria (2016), who list the following effects of smart mobility: reducing pollution, reducing traffic congestion, increasing people safety, reducing noise pollution, improving transfer speed, reducing transfer costs.

In comparison, Mangiaracina, Perego, Salvadori, & Tumino (2017) name for example improved travel time, reduced emissions and economic returns as benefits of intelligent transport systems and express the need for a model quantifying all induced effects, while Djahel et al. (2015) highlight the importance of improved response time to incidents and a better travel experience. Combining these studies, a comprehensive classification would be to distinguish among the effects on accessibility, environment, finances, safety and comfort. Most other research on the effects of smart mobility reasons or the objectives for implementation can be categorized under these five effects.

The European Commission introduced the concept Sustainable Urban Mobility Plans, stimulating the member states to attach importance to more sustainable and integral policy making (Arsenio, Martens, & Di Ciommo, 2016). The core objectives of this proposed approach to urban mobility planning are defined to be: accessibility and quality of life, sustainability, economic viability, social equity, health and environment quality.

Banister (2008) rightfully points out the paradox between the ambitions of accessibility and comfort versus safety and environmental quality. While the first would ask for lowering travel time and increasing transport possibilities, the last would provide arguments against that rationale. With respect to the implementation of smart mobility applications, it should be considered that an application may contribute to a larger extent to part of the ambitions, but shall not harm the others.

Taking all these studies into account, the best covering ambitions would be accessibility, environment, comfort, health and safety. In section 5.3.3, the outcome from this part of the literature review is evaluated by assessing the results of the interviews with policy makers.

3.2.2 Quantification

Not only the ambitions of policy makers are relevant for this study, but perhaps even more so, the methods of measuring and quantifying these ambitions. Hence, the present section investigates literature on the indicators that have been determined to measure or quantify the impact of mobility applications.

As discussed earlier in the present chapter, Garau, Masala & Pinna (2015) have defined six different categories of applications. They have set a couple of indicators per variable category and defined the unit per indicator, which are also noted in Table 2.

Table 4 Variable indicators (Garau et al., 2015)

Variables	Indicators	Specific indicators		Unit
Public transport	$\mathbf{I_{PT}}$	$\mathbf{I_{BND}}$ $\mathbf{I_{DPT}}$ $\mathbf{I_{TLC}}$	Bus network density Demand for public transport Traffic lights centralized	km/100km² passengers per year/inhabitants n°/total
Cycle lanes	$\mathbf{I_{CL}}$	$\mathbf{I_{CLD}}$ $\mathbf{I_{CLI}}$	Cycle lane density Cycle lanes for ten thousand inhabitants	km/km² km/10000 inhabitants
Bike sharing	$\mathbf{I_{BS}}$	$\mathbf{I_{BSD}}$ $\mathbf{I_{BPI}}$	Bicycle station density Bicycle per thousand inhabitants	n°/km² n°/1.000 inhabitants
Car sharing	$\mathbf{I_{CS}}$	$\mathbf{I_{CI}}$ $\mathbf{I_{SI}}$	Car for ten thousand inhabitants Station for ten thousand inhabitants	n°/10000 inhabitants n°/10000 inhabitants
Private mobility support system	$\mathbf{I_{PMSS}}$	$\mathbf{I_{VMS}}$ $\mathbf{I_{STA}}$ $\mathbf{I_{EPPS}}$ $\mathbf{I_{AMD}}$	Variable message sign SMS service for traffic alerts Electronic payment park service Applications for mobile devices	yes=1.00; no=0.00 yes=1.00; no=0.00 yes=1.00; no=0.00 yes=1.00; no=0.00
Public transport support system	$\mathbf{I_{PTSS}}$	$\mathbf{I_{EBSS}}$ $\mathbf{I_{ETPS}}$ $\mathbf{I_{RSWT}}$ $\mathbf{I_{TPC}}$ $\mathbf{I_{TTO}}$	Electronic bus stop signs Electronic ticket pay systems Information on routes, schedules and waiting times Travel planner for the route calculation Travel tickets online	yes=1.00; no=0.00 yes=1.00; no=0.00 yes=1.00; no=0.00 yes=1.00; no=0.00 yes=1.00; no=0.00

These indicators, however, is more focused on quantifying the applications, rather than quantifying the effects they would have. The use of indicators is not only proposed by Garau, Massala & Pinna (2015), but also by, for example, Orlowski & Romanowska (2019). According to that study, using indicators helps to identifies the strengths and weaknesses of cities. On top of that, it allows for comparison between time periods for the same city as well as among cities. Comparing the indicator values of one city to another makes it possible to borrow solutions from better-ranking cities. A city that is already ranking well, can include the indicator in its marketing strategy and become more attractive to investors and residents (Orlowski & Romanowska, 2019).

The Smart Mobility Indicator designed by Orlowski & Romanowska (2019) is based on 4 domains, 17 categories, 29 composite elements, 12 elements and 108 different factors. The factors link to either an element, or directly to a composite element or category. All factors get a score based on filled out questionnaires among residents and city hall officials and are weighed on a score that adds up to 1.00 per category. The residents fill out questionnaires asking them to rank statements by the extent of agreement, while city hall officials can get either open-ended or close-ended questions. Open-ended questions require a numerical value and close-ended questions require the officials to pick the response that most accurately fits the city. The domains, categories, composite elements and elements are listed in Table 5 below. The factors and elements are left out for the sake of clarity but can be found in the annex of the study Orlowski & Romanowska (2019).

Table 5 Composition of the Smart Mobility Indicator (Orlowski & Romanowska, 2019)

Domains	**Weight**	**Categories**	**Weight**	**Composite elements**
Technical infrastructure	0.3	car parks	0.2	car parks at interchange nodes quality of parking spaces
		bicycle routes	0.2	amenities for bicycles bicycle route network condition of the road surface
		roads and intersections	0.4	number of roads road quality intersections
		external connections	0.2	
Information infrastructure	0.3	access to portable devices and the Internet	0.2	Internet access
		applications	0.2	cyclists public transport passengers passengers who use the services of private carriers drivers
		information gathering	0.2	examination of the current location of vehicles situation on the roads situation in the car parks
		resident information systems	0.2	information in public transport vehicles stationary information for passengers variable message traffic boards
		traffic management systems	0.2	traffic lights
Mobility methods and vehicles	0.25	public transport	0.2	connections vehicle fleet tickets
		travelling on foot	0.2	
		traveling by bicycle	0.2	time of transit penetration rental
		private carriers	0.2	car sharing car pooling

Domains	Weight	Categories	Weight	Composite elements
		traveling in one's own private car	0.2	automation
Legislation	0.15	types of vehicles	0.35	
		forms of transportation	0.35	
		other aspects	0.3	

This SMI is composed of a combination of availability of smart mobility application as well as more effect-like factors, such as time of transit. However, this way of structuring one indicator may be very relevant once applications are implemented, but would not work optimally for a predictive type of analysis. The SMI is also a more integral indicator that tries to capture all elements of smart mobility in one indicator. That may eventually be useful, but at this point, this approach is not expected to be very comprehensive yet.

In short, the two studies analysed do not provide the perfect method for quantifying the effects of smart mobility. They do, however, provide insight in the type of variables that can be used as indicator for quantification. The idea of using weights to calculate one integral indicator is also considered to be very interesting to assess a mobility situation rather than quantifying the expected effects.

3.3 Decision Support Systems

Lastly, a more thorough review of the design of decision support systems (DSS) is conducted to gain knowledge on its limits, pitfalls and capabilities. The key words used on Google Scholar are *decision support systems mobility*, *decision support system development*, *decision support system pitfall*. The results of this review support the design requirements for the tool.

A DSS is a framework for a tool that supports decision makers in assessing complex problems. More specifically, DSS ease the interpretation of data by structuring and visualizing it in such a way that it meets the demands of the user of the DSS (Martinsons & Davison, 2007). The method of DSS has been present in research since the 1980s and has for example been defined by Sprague (1980) and Carlson (1978b). Since then, the field of DSS has expanded and evolved by technologies such as data-warehousing (D. J. Power & Kaparthi, 1998). It could benefit both the efficiency of the decision making process and the effectiveness of the resulting decision (Pearson & Shim, 1995). This does not mean, however, that DSS fully take over the decision making process. It is merely a tool to advice and complement the decision maker, and on top of that, save the user of the DSS time and money, and reduce cognitive load (Burstein, W. Holsapple, Beemer, & Gregg, 2008) (Burstein & W. Holsapple, 2008).

In short, DSS improve the capabilities of decision makers with regards to knowledge processing and guide them in formulating solutions for complex problems. Most importantly, it can help decision makers to make a trade-off between alternatives and collective factual arguments in favour of the eventual decision (Carlson, 1978a).

The field of research and applications is characterized by a wide variety of approaches, ranging from mathematical models to rules or decision trees. The appropriate approach is dependent on the user requirements and scope of the DSS.

3.3.1 Different types of DSS

Five different types of DSS can be distinguished based on their primary driver of the system, which would be knowledge-driven, data-driven, model-driven, communications-driven and document-driven DSS (D. Power, 2001). On top of that, Power distinguished two sub-types, based on the envisioned users and purpose of the DSS. These are phrased as interorganizational DSS and intra-organizational DSS.

3.3.2 Attributes of DSS

According to Turban, Aronson & Liang (2007), the attributes of a DSS include the following:

- Adaptability and flexibility
- High level of interactivity
- Easy user interface
- Incorporation of insights of decision-makers
- Iterative process
- Use of data and modelling
- Standalone, integrated, and Web-based

All these attributes relate to the performance, accessibility and usage of the tool. These attributes will be used to set the non-functional requirements of the tool.

3.3.3 Advantages of DSS

The advantages of using a DSS could be of two sorts: first, a DSS could improve the decision making process by for example saving time or money, second, a DSS could actually contribute to coming to a better decision by improving the breakdown of the problem and the different alternative solutions (Burstein, W. Holsapple, & Pick, 2008).

Chichernea (2014) list various advantages of using DSS for smart city planning, most of which are included in the other mentioned studies as well. The list below serves as overview of the most important advantages.

1. Time savings, by increasing time of decision cycle, employee productivity and information provision;
2. Enhance effectiveness;
3. Improve interpersonal communication and collaboration;

4. Competitive advantage for business intelligence, performance management systems and web-based DSS;
5. Promote learning of new concepts and development of better understanding of the organization;
6. Increase organizational control by making data available for performance monitoring.

For the tool designed in this study, these advantages confirm the usefulness of a quick scan to improve understanding. On top of that, the tool is expected to improve the relationship between experts from Witteveen+Bos and their clients, on the basis of the third advantage.

3.3.4 Disadvantages of DSS

According to Chichernea (2014), the disadvantages of DSS for smart city planning are the following:

1. Overemphasized decision making, when the chosen type of DSS is not appropriate for the decision situation;
2. Assumption of relevance, when using the DSS inappropriately;
3. Unanticipated effects, when the skill needed to perform a decision task is reduced by the implementation of a DSS;
4. False belief in objectivity.

These disadvantages are important to keep in mind when designing the DSS for the present research objective and shall be communicated to the envisioned users of the DSS as well. A reflection on these disadvantages is included in the discussion chapter (section 9.2.3).

3.3.5 Development of DSS

The DSS developed in the present study is meant to be an effective and efficient method for assessing smart mobility solutions, as stated in the research objective in section 1.2 . Using that definition, the smart mobility applications, as analysed in 3.1, are input values to the tool. Some kind of assessment of these smart mobility solutions is the output. For this assessment, the quantification methods from section 3.2.2 could serve as examples.

Looking at the objective of the research, a knowledge-driven DSS would be most suitable; the DSS is supposed to gather knowledge from mobility experts and simplify the assessment of the effectiveness of smart mobility solutions for policy makers. Hence, the operation of the tool is knowledge-driven. This would mean, however, that the DSS is built based on existing information, and would therefore not be fitted to deal with unknown, new situations. It always requires the knowledge from previous pilots or studies to support decisions. The DSS developed also uses data to present insightful information, and could therefore be argued to be a data-driven DSS, but the knowledge of expertise and effectiveness assessment are more directly serving the tool. As the DSS targets both policy makers and the mobility experts within Witteveen+Bos, the DSS developed is considered inter-organizational.

Combining the insights on the smart mobility applications, the measurement methods and the theory on Decision Support Systems, an initial concept of DSS for smart mobility has been designed. This rough concept is shown in Figure 2.

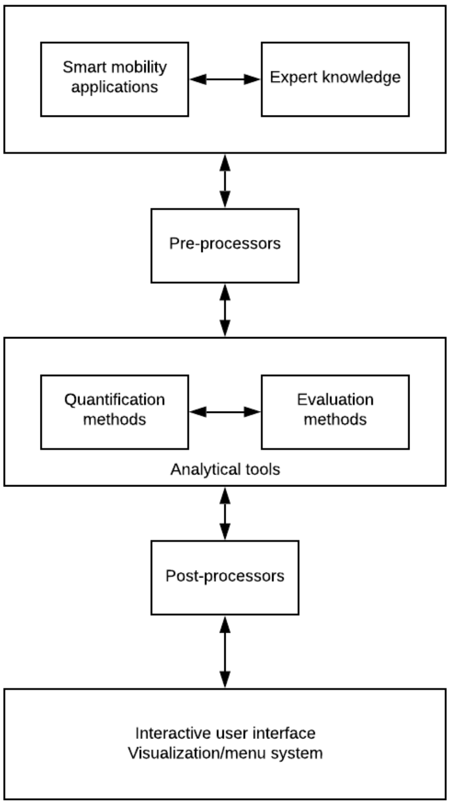
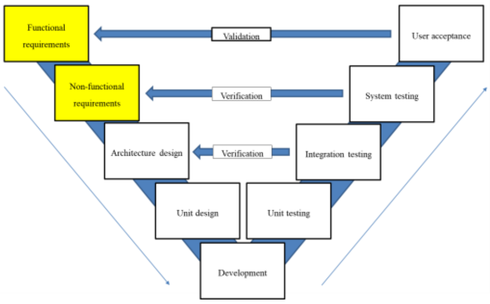


Figure 2 Outline Decision Support System

As explained in Abd-Elfattah et al. (2014), a decision support system consists roughly four steps: the input, the processing, the output and the interpretation. These first three steps shall take place within the DSS, roughly corresponding to the structure of Figure 2. The input factors are the databases used for the DSS. The processing phase concerns choosing and calculating indicators. The outcomes of those indicators are visualized in the output phase. After that, the interpretation of those visualization can support decision making (Abd-Elfattah et al., 2014).

Interviews with policy makers determine the requirements of the users, which are used to design a more detailed model for the tool. Already in 1987, Keen identified the importance of relating to the users' perspective and the tool supporting the users' key operational processes (Keen, 1987). Hence, it is important to not just develop a new tool, but actually consult the users on their needs and their policy ambitions, and aim for complementing that with the developed tool.

4 Requirements



The previous example set the first outline on a concept for a decision support system; the content of the tool was supposed to complement the needs of the users. Therefore, the present section discusses the functional (user) requirements and the non-functional requirements. Hence, this chapter relates to the first two parts of the methodology framework.

The function requirements are directly relatable to the purpose of the tool, while the non-functional requirements includes for example usability, scalability and performance. The requirements of the system to be used were set by the literature on best practices for decision support systems as well as by formal and informal conversations with experts and policy makers. The requirements have been split up in functional requirements and non-functional requirements (Chung, Nixon, Yu, & Mylopoulos, 2000).

4.1 Functional requirements

The functional requirements are set in order to ensure the tool is designed for its purpose and fulfils the needs of the users. The functional requirements shall all be satisfied and are therefore formulated in a measurable way; the requirements are either true or false.

The questions from Appendices A1.1 and A1.2 were used to determine the functional requirements.

Table 6 User requirements

Respondent	Requirement	Line nr
C.1	Include regional differences regarding smart mobility implementation.	2-3
E.1	Include at least relative effects of applications.	9-10
E.2	Combine data with knowledge.	11
E.3	Include location-specific data.	12
E.4	Ensure comprehensibility of the tool.	13
E.5	Provide insight on the current mobility situation in a city.	15-16
E.6	Start with a simple model.	18
E.7	The tool shall be developed in close coordination with policy makers.	19
E.8	The tool shall be expandable based on consultations of users.	20
G.1	Effects shall be specified by rule of thumb.	1
I.1	The tool shall lower the boundary for considering smart mobility.	2
I.2	The tool shall show what happens in other municipalities.	3
J.1	Mobility as a Service shall be included as application.	22
J.2	Autonomous cars shall be included as application.	24
J.3	The tool shall focus on the challenge in a city.	30
J.4	The tool shall include the prerequisite of a good data infrastructure.	32
J.5	Both a city profile and effects shall be included in the tool.	34-35
J.6	The effect shall be formulated less abstract than accessibility, livability, sustainability.	41-42
J.7	Focus on the cause of the effects rather than the size of the effect.	45-46
K.1	Start at the challenge of the city.	15
K.2	Provide a practical perspective.	17
K.3	Provide only a quick scan, and the option for a more elaborate assignment.	23-24
K.4	Include best practices of smart mobility throughout the country.	27

K.5	Facilitate knowledge exchange.	31-32
K.6	Combine a dashboard with expert knowledge.	55-56
K.7	Facilitate easy maintenance to stay up to date.	57-59
L.1	Work with grouping by city or region sizes.	1-2
L.2	Start advising based on the challenge in a city.	18-19
L.3	Make it practical and easily applicable.	22-23
L.4	Work with a dashboard format.	24-25
L.5	Include referrals to further information.	25-26
L.6	Include best practices on smart mobility.	35-36

The requirements in Table 6 are directly withdrawn from the notes of the interviews in Appendix A1.4. The table includes the Respondent reference letter in the left column, as well as the number of the requirement by that respondent. The second column is the requirement itself. The third column refers to the line number of the notes in the Appendix.

Almost all requirements relate to functional requirements rather than non-functional requirements; in other words, they require something on the content of the tool, not on its functioning. Requirement E.4, E.8, K.7 and L.4 are the only ones that has been included as non-functional rather than functional requirements.

Not satisfied in the tool are requirements I.2, J.7, K.4, and L.6. All of these requirements, however, would be considered suggestions for further development of the tool. I.2, K.4, L.6 relates to best practices of smart mobility implementation in other municipalities. J.7 is considered to be improvements that may still be made, but were not suggested by other respondents. The cause of effects rather than the size of effects demands both more and different data, which is currently available to only a limited extent.

The requirements that are selected and satisfied in the tool are listed in Table 7. On the left, the requirement is formulated; on the right the respondent that serves as a source for this requirement is noted.

Table 7 Functional requirements

Reference	Functional requirement	Source
F.1	The tool shall account for regional differences regarding smart mobility implementation.	C.1
F.2	The tool shall include effects of smart mobility applications.	E.1, J.5
F.3	The tool shall combine data with knowledge.	E.2, K.6
F.4	The tool shall include location-specific data.	E.3
F.5	The tool shall provide insight on the current mobility situation in a city.	E.5, J.5
F.6	The tool shall be designed by a simple model.	E.6
F.7	The tool shall be developed in close coordination with policy makers.	E.7
F.8	The tool shall include the prerequisite of a good data infrastructure.	J.4
F.9	The tool shall calculate effects by rule of thumb.	G.1
F.10	The tool shall lower the boundary for implementing smart mobility	I.1
F.11	The tool shall include at least the applications MaaS and autonomous cars.	J.1, J.2
F.12	The tool shall start at the challenge in a city.	J.3, K.1, L.2
F.13	The effects shall be formulated less abstract than accessibility, livability, sustainability.	J.6

F.14	The tool shall provide only a quick scan.	K.3
F.15	The tool shall facilitate knowledge exchange.	K.5
F.16	The tool shall work with grouping by city or region sizes.	L.1
F.17	The tool shall be practical and easily applicable.	K.2, L.3
F.18	The tool shall include referrals to further information.	L.5

These 18 functional requirements can be split up into 5 different categories. All requirements concern the functional aspect of the tool, but among these, the focus of the requirements differ. F.1, F.3, F.4 and F.11 focus on the input of the tool, while F.2, F.5, F.12 and F.18 focus on the output of the tool. F.7, F.8, F.9, and F.16 are about the approach taken in the development, F.10 and F.15 set requirements on the objective of the tool and, lastly, F.6, F.13, F.14 and F.17 concern the level of complexity of the tool. The satisfaction of the functional requirements of the tool is evaluated in section 8.2.

4.2 Non-functional requirements

The non-functional requirements ensure the functionality of the system itself. Hence, they do not set boundaries on the content of the tool, but set the minimum requirements for a well-functioning system.

The non-functional requirements are mostly deduced from the literature on decision support systems in section 3.3. Some of the non-functional requirements, however, were set by Respondent A as main contact person at Witteveen+Bos through an iterative feedback process. Requirements E.4 and K.7 are also included in the non-functional requirements. The entire list of non-functional requirements can be found in Table 8. The left column of the table contains the requirement itself; the right column contains the source, whether that is a respondent or an academic source.

Table 8 Non-functional requirements

Reference	Non-functional requirement	Source
N.1	The tool shall be interactive.	A, (Turban et al., 2007)
N.2	The tool shall provide the option to save or export selected options	A
N.3	The user shall be provided with references of the data used.	A
N.4	The tool should function in any regular use browser, such as Edge, Chrome, Firefox, Safari.	A
N.5	The tool should always show at which date information was subtracted.	A
N.6	The tool should start up in less than 1 minute.	(QRA Team, 2019)
N.7	The tool shall be user-friendly.	(QRA Team, 2019), E.4, (Turban et al., 2007)
N.8	The information in the tool should be editable by someone without programming experience	A, K.7, (Turban et al., 2007)
N.9	The tool architecture should be editable by someone with programming experience.	A
N.10	The tool shall use data for calculations from reliable sources.	A, (Turban et al., 2007)
N.11	Data used in the tool should always be up to date, data should not be older than 5 years.	A
N.12	The tool shall load a new tab or new information within a maximum of 3 seconds after each click.	A
N.13	The tool shall be expandable.	E.8
N.14	The tool shall be in a dashboard format.	K.6, L.4

The non-functional requirements can be split up into requirements that focus on data quality, usage, information, performance and adaptability. N.10 and N.11 concern data quality, N.1, N.2 and N.14 focus on the usage of the tool. The requirement on information are set by N.3 and N.5, and the ones on performance by N.4, N.6 and N.12. Lastly, non-functional requirements N.8, N.9 and N.13 concern the adaptability of the tool. The developed tool is verified on the non-functional requirements in section 8.1.

4.3 Processing the requirements

In total, there are 19 functional requirements and 13 non-functional requirements. These requirements serve as the basis for the design and give direction for the design of the tool. Some of the functional requirements relate to the input and the output of the tool, so a definition of these concepts as well as determining the relations between them would be a good start for the design. The satisfaction of these requirements by the developed tool is described in the evaluation (Chapter 8).

5 Model architecture design

In the previous section, the requirements for the tool were defined. These are taken along into the present chapter exploring the most important aspects to consider for the conceptual design of the tool, starting with the design of the model architecture. The model architecture design is the conceptual, or overall, design of the tool that describes the relations between the input and the output.

5.1 Definitions

As came up in earlier sections, the terms ambitions, effects, themes, applications and technologies are important when discussing smart mobility policy. Sometimes these terms have been used interchangeably in literature or interivews, or, at least, not with a clear, distinct meaning. To avoid confusion, all terms are defined here and from now on, only used with this meaning.

A smart mobility **application** is a mobility technology that can be implemented by a municipality, either permanently or temporarily. An example would be car sharing or DRIP (dynamic route information panels). Other examples can be found in the list in Appendix A2.2.

A mobility **ambition** is a policy ambitions by a governmental organisation regarding mobility, e.g. Become CO2 neutral city. The full list of ambitions used for the present study can be found in Appendix A2.3.

An **effect** of smart mobility is a quantitative impact, that can be either negative, positive or neutral, of a smart mobility application. An example would be a certain reduction in CO2 emissions.

A **theme** is an overarching term for broad objectives of mobility measures. Ambitions and effects can both be categorized by themes. An example is Sustainability & energy. All themes are listed in Appendix A2.1.

As the definitions already indicate, these four terms relate to each other. The relations between the terms are visualized in Figure 3.

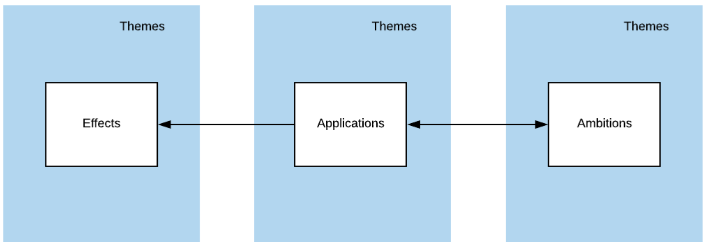
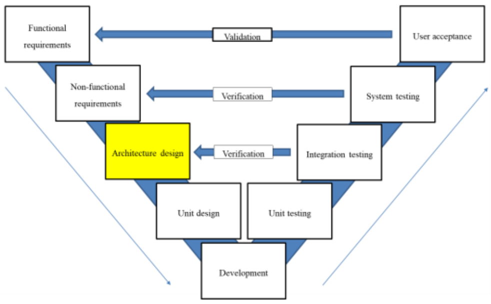


Figure 3 Relation between terms

In words, the graph shows that all smart mobility applications have some effect. Each smart mobility ambition can be achieved by implementing one or multiple smart mobility applications. Each smart mobility application, in turn, can contribute to several smart mobility ambitions. These three terms, effects, applications, and ambitions, can all be categorized in themes. An example of this would be that an application on electrification of transport, the ambition to become CO2 neutral and the effect of reduced CO2 emissions can all be categorized under a theme that includes sustainability.

Next to these four most important definitions, the term indicator is used throughout the research as well. For this study, an **indicator** is a measurable variable, which is used to quantify mobility. Whereas an effect is a reduction or increase in emissions, the indicator would set the unit to kilograms of CO2, and hence, make it possible to express values in absolute numbers.

5.2 Design



As stated in the research question, the overall objective of the tool is to provide insight in the effectiveness of implementing smart mobility applications. The envisioned clients of the tool are policy makers, on a local, regional and national level. These clients will be guided through the tool by an expert in the mobility sector. In order to develop the tool at the right level of detail, it important to analyse the level of knowledge of the policy makers, as this determines the approach to be taken. To do this, the five representation levels from Burstein et al. (2008) as well as the three different decision support approaches are used. The policy makers consulted are most of the time experts in the policy field, but have limited technical knowledge. Some of the respondents indicated clearly that they were most interested in a quick scan type of tool, that provides insight on a higher level. The policy makers are estimated to be on the second representation level, which is defined as:

> *"At this level, the representations become explicit and the problem can be broken down into a number of sub-problems, some of which can be formalized. The structuration of the problems is still partial rather than detailed and managers refer to 'the marketing function' or 'the marketing process' without being able to formalize processes in greater detail. Data mining may be used at this level as a way to help formalize ideas to a greater extent and to test hypotheses. Some pre-models may be developed in broad terms by managers, but it is still difficult for them to discuss these with analysts."* (Burstein, W. Holsapple, Adam, et al., 2008)

Although this definition relates to business context rather than public sector context, it is also applicable to policy makers instead of managers. Based on this definition of the second representation level, the most suitable decision support approach would be discovering, rather than the other two approaches defined, scrutinizing or reporting. That would mean the decision support system could focus on activities such as data mining, meaning that it shall focus on relations between concepts and demonstrate valuable information from large datasets (Burstein, W. Holsapple, Adam, et al., 2008).

In Chapter 4, the requirement was set for the tool to follow a challenge-centred approach, meaning that the tool shall relate to the mobility challenge a city a deals with, to ensure relevancy of the tool for that particular city. Hence, the tool shall identify the challenge of a city as well as provide insight on the effects. Considering the definitions in section 5.1, that would mean that one would start with identified the theme that is the biggest challenge for the city, and end with the effects of applications. In order to link these parts to each other, the more specific ambitions are used as well. Themes do not directly relate to applications, hence, ambitions are used to connect the two.

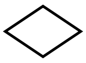
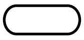
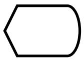
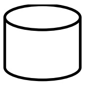
The tool starts by identifying challenges of the municipality regarding mobility policy, and based on that, suggest mobility ambitions and consequently, smart mobility applications. After that, the user can assess smart mobility applications This workflow is divided into three units, all covering the interrelation between two of the defined concepts, e.g. from mobility ambition to relevant smart mobility application. The three units of the tool, in short, will be referenced to either by their unit number, or as follows:

1. City profile;
2. Applications;
3. Effects.

The first unit defines the profile of the city selected, by scoring the city on various indicators, and relate this to the ambitions complementing the largest mobility challenge. The second unit establishes the connection between mobility ambitions and smart mobility applications contributing to those ambitions. The third unit provides an assessment of the effects of a smart mobility application, serving as an example for the impact it could have. It is important to note that problem-solving can be considered two-folded: the tool shall provide information on the identified problem (unit 1) as well as potential solutions for the decision-making question (unit 2 and 3). Both of this output requires data processing to support those insights (Abd-Elfattah et al., 2014)

The three steps, all appended in the separate units, are visualized in Figure 4. The flowchart in Figure 4 is designed with standard flowchart symbols. The meaning of all symbols can be found in Table 9. Except for the database symbol, all meanings have been deduced from Rossheim (1963). In Figure 4, the decision nodes indicate new user input, hence also the start of a new unit.

Table 9 Meaning of flowchart symbols

	Decision symbol
	Process symbol
	Terminal symbol
	Display symbol
	Database symbol

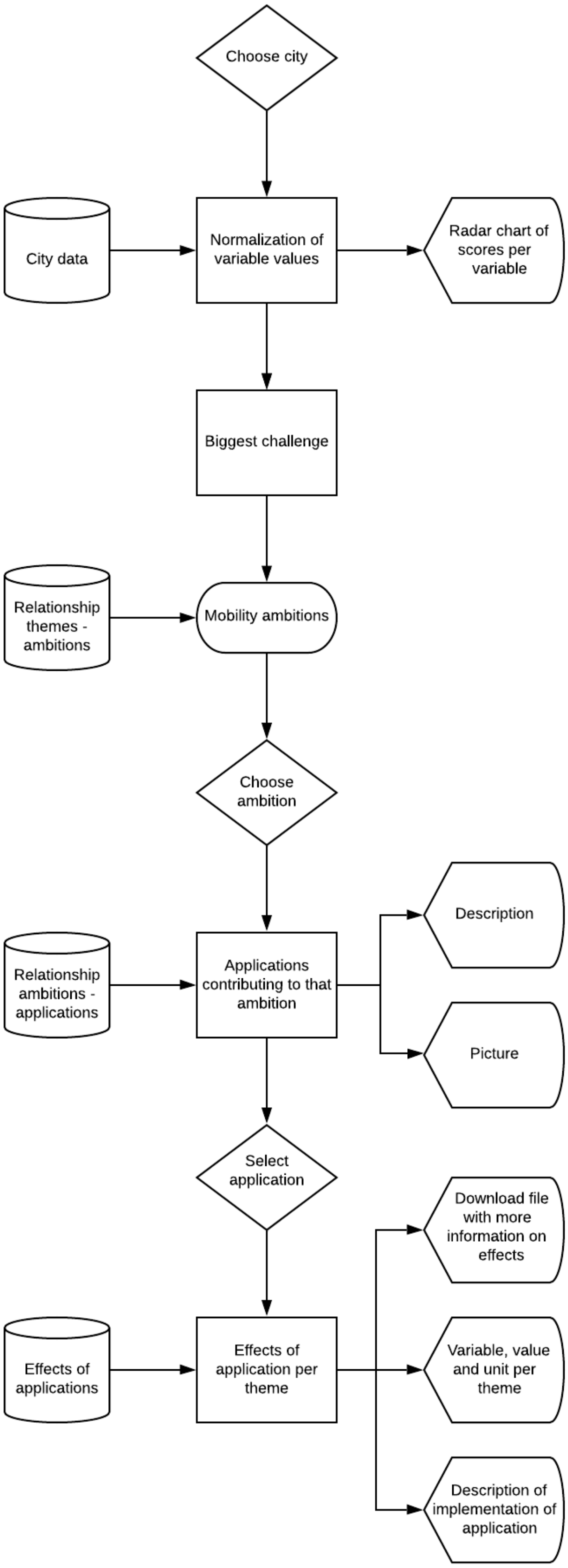


Figure 4 Flowchart architecture design

5.3 Concepts and relations

The architecture design includes the terms introduced in section 5.1. The applications, ambitions, themes and effects have all been preliminary determined through a combination of consultations and literature review. The exact lists can be found in the Appendix, and the rest of this chapter will include an explanation on the composition of these lists.

5.3.1 Applications

Various sources on smart mobility applications have been reviewed in section 3.1. This review already exposed the variety of applications itself, but also the range of categorizations possible. Based on this literature review, a combination of suggested categorizations was made to use for the present study. The list defined for the present research can be found in Appendix A2.2. All applications are listed by name, but are also split into categories and sub-categories. The five categories used are data tool, infrastructure, policy measure, traffic management or vehicle use. The sub-categories per category are listed in Table 10. For traffic management, no subcategory is listed, as these include various separate technologies that could not be split reasonably into subsets.

Table 10 Application categories

Category	Subcategories
Data tool	Consumer application; data collection; driving assistance
Infrastructure	Lanes; parking & charging; surroundings; zones
Policy measure	Restructuring; subsidy; tax
Traffic management	-
Vehicle use	Sharing

These applications have been verified with Respondents A, B, D, M. They considered the list to be sufficiently complete for the present study.

5.3.2 Ambitions

Based on conversations with policy makers and engineers of Witteveen+Bos, and analysis of policy documents (e.g. Gemeente Den Haag (2019)), an initial list of policy ambitions for the mobility sectors has been comprised. The exact list, as can be found in Appendix A2.3, was determined together with Respondent A, and verified with Respondents B, D, M. These ambitions are an important, qualitative source of information. Both the themes and the smart mobility applications relate to these ambitions.

The ambitions are formulated from the perspective of the municipality. That means that the ambitions concern the ambition in terms of what the municipality wants to become, earn, or do.

5.3.3 Themes

The policy makers consulted were also asked about their views on smart mobility and their policy ambitions. The exact questions asked can be found in Appendix A1. The present section aims to gather all shared views on this topic and comprise a list that includes those themes most relevant for the present study. These themes serve as overall category for mobility ambitions and applications.

Respondent H referred to the mobility transition letter where the municipality of the Hague lists following ambitions for 2040:

- Safe - with the ambition of zero traffic victims per year;
- Efficient - in using space and infrastructure;
- Clean - to meet the environmental and climate ambitions;
- Tailor-made - so everyone can reach their destination;
- Affordable - with a mobility solution for every budget;
- Connected - with the region and other metropole regions in the Netherlands and abroad.

Respondent J, on the other hand, mentioned the following ambitions for national mobility policy:

- Accessibility;
- Safety;
- Sustainability.

Lastly, Respondent L shared four mobility ambitions for (the metropole region of) Amsterdam:

- Safety;
- Sustainability;
- Liveability;
- Accessibility.

Comparing these among each other shows a large overlap. The list of the municipality of the Hague is mostly more elaborate. As suggested, these ambitions can also be compared with those reviewed from literature:

- Accessibility;
- Environment;
- Comfort;
- Health;
- Safety.

Assuming liveability constitutes comfort and health, the list derived from literature captures the lists by Respondents J and L. Regarding the list of Respondent H, there are some substantial differences. However, connected is considered to be part of accessibility, and tailor-made part of comfort. Affordability is significantly distinct. The present study, however, relates to a tool aimed at the government perspective, rather than the consumer perspective; affordability is not explicitly included in the list of themes for now, but formulated in a broader sense as ethics. These lists from respondents and from literature have been combined, but are phrased more specifically to indicate wat exactly is meant with the themes listed:

- Efficient spatial use & infrastructure;
- Sustainability & energy;
- Efficient mobility & accessibility;
- Comfort, health, safety & ethics.

In this list, ethics includes for example affordability and inclusivity. As Respondent K indicated, smart mobility applications do not necessarily directly contribute to a goal. Building up a data infrastructure is sometimes a prerequisite for the implementation of other smart mobility applications. Measuring an existing system could improve it, by for example small adaptations in green-light time. Providing citizens with information could also change their travel behaviour. Therefore, the theme Knowledge & data collection is added to the list of themes. This results in the following final list:

- Efficient spatial use & infrastructure;
- Sustainability & energy;
- Efficient mobility & accessibility;
- Comfort, health, safety & ethics;
- Knowledge & data collection.

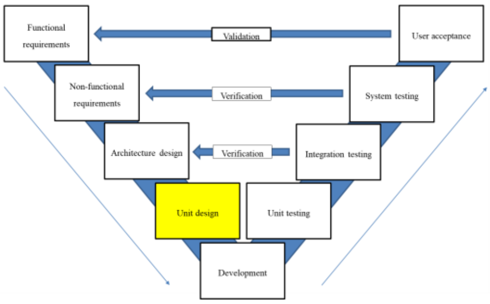
This list can also be found in Appendix A2.1.

5.3.4 Effects

Smart mobility applications affect the themes listed in the previous section. The themes, however, are formulated in quite a broad sense. The applications have effect on a more specific aspect of the theme. Therefore, indicators are set for each theme, on which smart mobility applications could have an effect. An example of this is that the indicator for the theme Sustainability & energy is set to CO2 emissions, with unit kilograms of CO2 per year. For all these indicators, where possible, all effects are converted to the same unit. More details on these conversion are given in section 6.3. The actual calculations of the effects can be found in Appendix A2.4.

At this point, this study focuses only on the effects of smart mobility solutions, not on the financial impact. Of course, costs and financial benefits are an important aspect for policy makers when considering the implementation of smart mobility. Applying common financial assessment methods brings along challenges in the field of smart mobility study, which are explained in more detail in section 9.3.1. Taking into account this additional complexity, the financial aspect was not in the scope of the present study. More research on this matter would be recommended.

6 Unit design



The model architecture design described the conceptual design of the tool. This tool, however, is built up of various parts, or units. These units have briefly been described in the model architecture, but are worked out in more detail in the present section.

The chart in Figure 5 shows the relations between the three units, together composing the design. In this figure, each square is a separate unit. Each decision node indicates the user input, each database symbol indicates the Excel sheets with data used for the executed operations. The dotted lines between the units indicate the output factors from one unit that can be used as input factor for another unit.

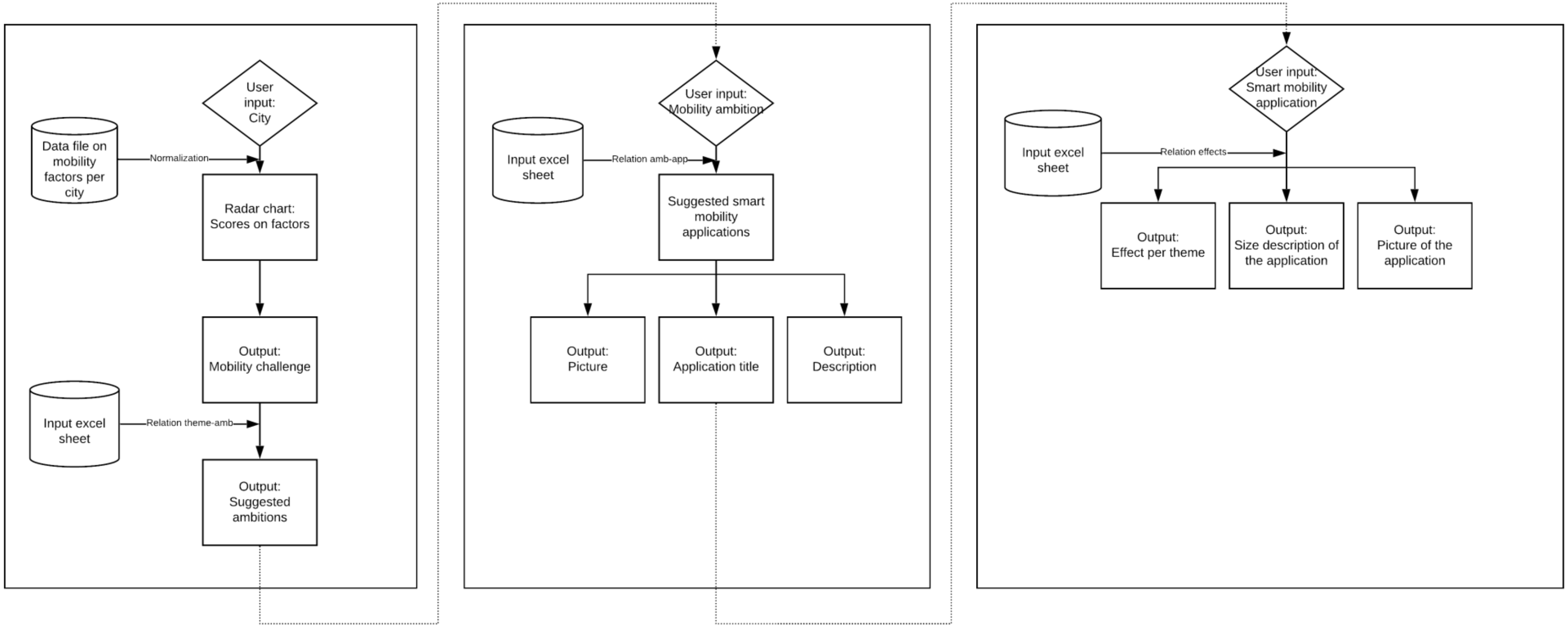


Figure 5 Relations between the three units

6.1 Unit 1: City profile

The first unit takes as input a city, to be chosen from a dropdown. As output, it gives the mobility profile of that city in a chart, together with suggested ambitions to work on the aspects of mobility the city does not score well on. The conceptual design of the first unit is depicted in Figure 6.

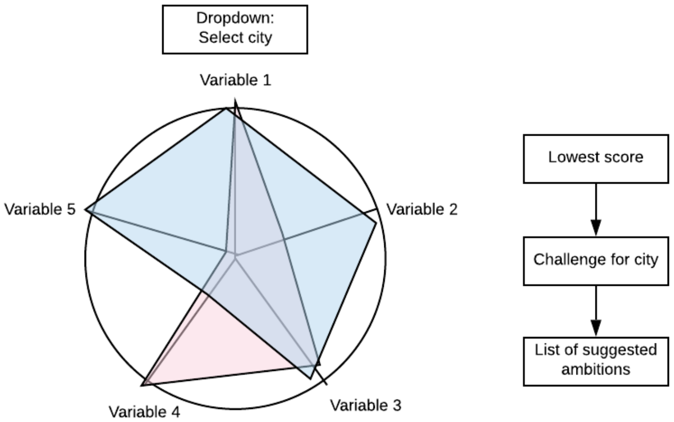


Figure 6 Conceptual design unit 1: city profile

The rest of this section will describe the subparts of the first unit in more detail, including the indicators the cities are scored on, the scoring method and the method of determining the challenge in the city.

6.1.1 Indicators

In previous chapters, the literature on mobility has been examined, leading to a list of those factors that most completely comprise mobility. These factors to keep in mind when designing mobility policy are called themes in the present study and are listed in Appendix A2.1. For all these themes, key performance indicators are used to proxy the effect factor. Although the themes are not perfectly capturable in one indicator, the indicators are chosen as such to proxy the theme as closely to reality as possible. The indicators determined as proxies for the theme can be found in Table 11. This table is not yet complete, but these five indicators were chosen, as they are suitable for the present study. Not all themes are connected to an indicator yet, or only partly; a reflection and suggestions for further elaboration of this list of indicators follows in Chapter 9.

These indicators were found on the website of VNG, waarstaatjegemeente.nl. A more elaborate description of the use of this database can be found in 7.1. This website is in Dutch, so all terms on the website are translated to English, including the variable names in Table 11. The website uses other categories compared to the present study; on the website, the most suitable categories are Energy transition, Mobility and Sustainable environment. The most important prerequisite in selecting variables was that they should be linkable to the theme either positively or negatively. For example, the variable selected on Efficient mobility & accessibility is Total average distance to train station (km), as it can be stated that a smaller distance means better accessibility. Another variable on waarstaatjegemeente.nl within the subcategory Accessibility (category Mobility) is the amount of displacements by cars, but this variable does not have a positive or negative connotation.

Table 11 Theme and indicator

Themes	**Indicators**
Efficient mobility & accessibility	Total average distance to train station [km]
Comfort, health, safety & ethics	Traffic accidents [per 1000 inhabitants]
Comfort, health, safety & ethics	Registred traffic deaths (5 years cumulative) [per 100,000 inhabitants]
Sustainability & energy	CO_2-emissions car traffic excluding highways [tonnes per 1000 inhabitants]
Comfort, health, safety & ethics	Exposure NO_2+PM10 [µg/m³]

At the moment, no indicator is defined to score Efficient spatial use & infrastructure. A sensible indicator could for example be number of cars per square meter. However, waarstaatjegemeente.nl does not provide data on such indicators. In Chapters 9 and 10, reflection follows on this missing data as well as suggestions to include these indicators in the future.

As the municipalities shall be scored on these themes, for all indicators, datasets have to be linked that provide this information. The actual collection of the data for these variables is described in more detail in section 7.1.

6.1.2 Scoring and normalization

Consequently, municipalities all score in a certain way on the indicators defined. For example, in Amsterdam, the average distance to a train station is 2,5 kilometer. The values on the different indicators for a municipality are plotted on a so-called spider or radar chart. A radar chart plots multivariate data on a spider web-like graph, and connects the points of all variables, creating a figure with as many corners as variables. This type of graph enables the comparison of scores on various variables at first glance. An example of a radar chart is depicted in Figure 6.

In order to optimize comprehensibility of the chart, all values are normalized to a value between 0 and 1, by applying the following formula to the data:

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}}$$

The minimum and maximum value used are grouped by city size. The following boundaries are used for the city size grouping:

- <25,000 inhabitants
- 25,000-50,000 inhabitants
- 50,000-100,000 inhabitants
- 100,000-300,000 inhabitants

- >300,000 inhabitants

Larger cities, including for example Amsterdam or Utrecht, are hence only compared with other larger cities. This conversion to values between 0 and 1 makes the comparison among different variables sensible; all scores are based on the normalization per group and can in this way be compared to the scores of other cities with comparable city size. The normalization is done in such a way that 1 means a positive score, while 0 means a negative score. For example, a high amount of traffic accidents would therefore give a low score.

6.1.3 Challenge

The city profile yields a theme the city scores worst on, based on the chosen indicator. This could mean, for example, that a city scores badly on environment by having a high value of CO2 emissions. An ambitions that could be assigned to improve that score that is ‘Become a CO2 neutral city’, or ‘Reduce CO2 emissions’. Surely, these ambitions could be formulated on various levels of specification and could overlap to some extent. The link to the mobility challenge identified in the city is however most important. Hence, based on the mobility challenge, several mobility ambitions associated to this challenge are suggested. In order to do this, all themes - Appendix A2.1 - have been cross-referenced with the ambitions - Appendix A2.3.

6.2 Unit 2: Applications

The first unit visualized the city profile, the largest mobility challenge for the city and the policy ambitions relating to that challenge. The tool, however, has been built to explore the possibilities with smart mobility. The link from the policy ambitions to smart mobility applications is therefore important. The approach taken is to suggest for each mobility ambitions a few smart mobility applications that could contribute to the ambition. The visualization of the design of this second unit can be found in Figure 7.

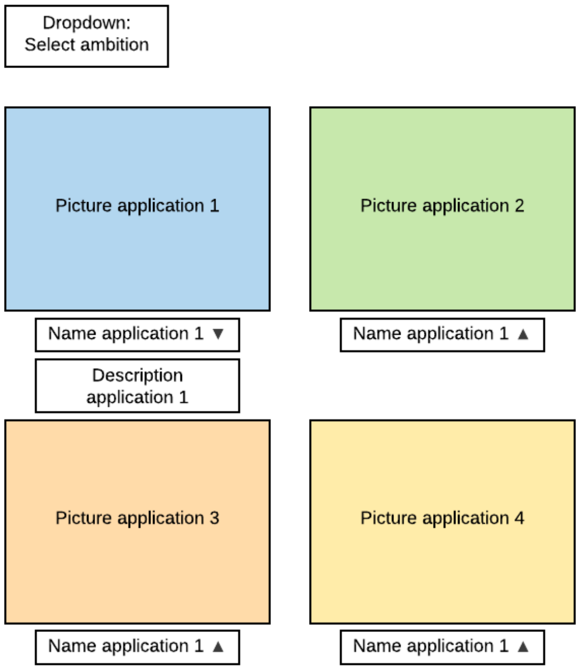


Figure 7 Conceptual design unit 2

As explained and shown in the figure, the second unit considers ambitions and applications. The present section will therefore discuss both separately.

6.2.1 Ambitions

Ambitions are more specific objectives that can be achieved or aimed for by a municipality, as explained in section 5.1. All ambitions fall within at least one theme. The ambitions Become a CO2 neutral city could for example be categorized in Sustainability & energy. An exemplary table of how to cross-reference ambitions with themes has been annexed in Appendix A2.4. In the second unit, the user has to, first, pick a theme, and secondly, pick an ambition. Only the ambitions that fall under the theme chosen are shown and can be picked from.

6.2.2 Applications

All ambitions in the list in Appendix A2.3 can be cross-referenced with four smart mobility applications from the list in Appendix A2.2. In this way, the user of the tool gains insight in the applications that could potentially be a solution to the mobility challenge in the city and are worth investigating in more detail. These cross-references are based on a few assumptions:

- More cars means more CO2 emissions;
- Electrical cars emit less or no CO2;
- Sharing transport means less cars on the road;
- Getting information on traffic causes changed behaviour;
- Passenger experience is related to travel time, among other factors.

Based on these assumptions, the ambitions Become CO2 neutral city could for example be related to the applications Charging stations electrical cars, Environmental zone, Kilometer-based charge, Stimulate working from home. More examples of cross-referencing one ambition with multiple applications can be found in Appendix A2.4.

The second unit gives as output the four smart mobility applications that could contribute to achieving the mobility ambition selected. For all these four applications, a picture and description are added to improve understanding of the objectives and varieties of the application.

6.3 Unit 3: Effects

The last unit of the design concerns the determination and quantification of the effects of the smart mobility applications. The user selects an application from a pre-defined list and gets as output the effects of that application on indicators that are determined to quantify the themes. The design of this third unit is visualized in Figure 8.

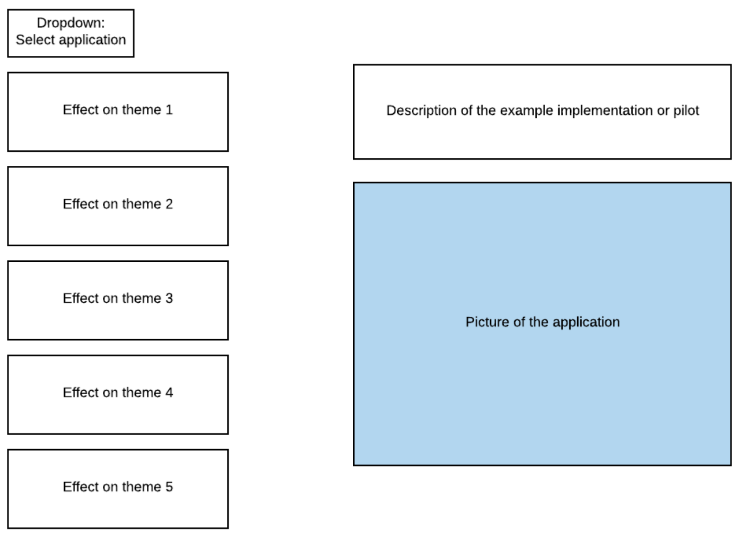


Figure 8 Conceptual design unit 3: effects

The present section will discuss the selection of the applications included in the third unit, as well as the method used to quantify the effects of these applications.

6.3.1 Limited set of applications

As determining the effects of all applications in this unit is not within the scope of the present study, a limited amount of applications have to be selected.

It seems most useful to select those applications that are considered most important or promising by policy makers and experts. The selection would have to be limited to 5-10 applications to ensure enough applications for a reasonable idea of the functioning of the tool but still optimize effectivity of the study. The following applications were chosen to include in the third unit at this point:

- Park and ride;
- Shared cars;
- Congestion avoidance;
- Bicycle highway;
- iVRI - intelligent traffic lights;
- Realtime information supply;
- Shared bicycle.

A more detailed description of the type of implementation envisioned with this application is included in Appendix A3 on the effects of applications. This list of applications can be extended in the future, by simply adding a new application and its effects to the input data for the tool. These chosen applications do not only include smart mobility applications applicable in urban settings, but rather those smart mobility applications that are at the moment most relevant for municipal policy makers.

6.3.2 Indicators

In order to determine the effects of smart mobility solutions, the impact has to be measured or estimated, and quantified. To do that, it is important to select a set of factors the applications have an effect on. For this study, the effects of the applications are determined on the themes used throughout the study (Appendix A2.1).

Within these themes, the effects are mostly converted to the same unit for the sake of comparability. Not for all applications, however, that conversion is possible. Including effects in other units is considered still valuable, hence, still added to the tool. That could for example mean that qualitative rather than quantitative effects are sometimes included as well. The unit also includes a description of the example. For car sharing, that means that the description would denote the size of implementation, e.g. 10 cars, which is used to calculate the numbers in the effect boxes.

When calculating effects of smart mobility, indicators have to be defined to determine these effects on. The themes that are listed in Appendix A2.1 are the most important factors to score smart mobility applications on, but do not yet set the exact indicators. Throughout literature, these indicators differ as well. The current section, therefore, aims at setting a few standard indicators, and consequently, convert all available information per application to these standard indicators.

For the effects on the theme **Efficient mobility & accessibility**, the most appropriate indicators would be travel time or travel distance (Niedzielski & Eric Boschmann, 2014). As travel time does not only take into account distance, but also traffic flow, that indicators is considered most appropriate for this theme. Travel time can be quantified by calculating the savings on lost vehicle hours (*voertuigverliesuren*, *VVU* - in Dutch). One lost vehicle hour means that one vehicle experiences a 60 minute delay or, for example, that 60 vehicles experience a 1 minute delay (Ministerie van Infrastructuur

& Waterstaat, 2015). Another option would have been to use congestion avoidances as standard indicator to quantify travel time, as in e.g. Ministerie van Infrastructuur & Waterstaat (2018). A congestion avoidance is a person preventing their participation in congestion, i.e. one less car participating in the traffic jam. However, as lost vehicle hours are expressed in time, this unit is considered more appropriate.

On the theme **Sustainability & energy**, the most important negative impact by transport is in terms of emissions. In general, environmental impact is measured in terms of global warming potential in equivalent kg CO2 , e.g. Marwah et al. (2010). Smart mobility solutions would, most of the time, reduce emissions and hence, save CO2.

The theme **Comfort, health, safety & ethics** consists of four different factors, all relating to societal effects. Although it would be desirable to translate all these factors into quantifiable indicators, at this moment, it is most important to show the idea rather than fully capture the theme. Health, as part of Comfort, health, safety & ethics, is therefore converted to kg PM10 and kg NOx, which could cause for example lung damage (Pénard-Morand & Annesi-Maesano, 2004). NOx and PM10 also impact Sustainability & energy, for example by NOx oxidizing in the atmosphere to become nitric acid, a major component of acid rain. However, for this research, their impact on human health is considered most important.

Efficient spatial use & infrastructure can be defined in terms of space available for specific purposes, but for this study, it is meant in more general sense. As explained in Bloemmen & Lüdtke (2002), efficient spatial use can be expressed in terms of savings per m2. In total, that could be converted to total meters squared saved by implementing a smart mobility solution. This indicator shall be measured as average over the period of a year, rather than summed over a year.

The last theme, **Knowledge & data collection** is for now not proxied by an indicator. This theme is a bit different than the others, as it is a prerequisite for successful implementation of smart mobility solutions as well. In case of further development, an indicator for this theme could be for example amount of users of applications.

As some themes are formulated in a broader sense than others, and can, hence, not be captured by one indicator, some themes could include more than one indicator. The standard indicators for determining the effects of smart mobility applications are listed in Table 12.

Table 12 Standard indicators

Theme	Standard indicator	Unit
Efficient mobility & accessibility	Travel time	lost vehicle hours (VVU)
Sustainability & energy	Emissions	kg CO_2
Comfort, health, safety & ethics	Air pollution	kg NOx
Comfort, health, safety & ethics	Air pollution	kg PM10
Efficient spatial use & infrastructure	Spatial use	m2
Comfort, health, safety & ethics	Traffic safety	amount of injured victims
Comfort, health, safety & ethics	Traffic safety	amount of deathly or hospitalized victims

6.3.3 Conversion

In order to get to the standard indicators, sometimes values are converted by using rules of thumb. These rules of thumb convert values from one unit to the other, enabling the comparison of information available on different smart mobility applications among each other.

Rijkswaterstaat has created a toolbox on smart mobility that includes various factsheets and rules of thumb for costs and effects of smart mobility. These factsheets are set up per applications and merge the information from a variety of sources. By combining the factsheets on different applications and verifying if the information can be matched among the factsheets, general rules of thumb for all smart mobility applications can be defined. The factsheet on car sharing, for example, states one car sharer drives approximately 1600 kilometres less per year. 1600 kilometres equals around 90 kg CO_2 per year, and for one household, car sharing saves approximately 175-265 kg CO_2 per year (Rijkswaterstaat, 2019). As general rule, one shared car replaces four to eight private cars. The factsheet on shared bicycles analyses the different types of sharing platforms, but also includes the general rule of 0.1-0.6 congestion avoidances per shared bicycle per day. On sustainability effects, according to the factsheet, each congestion avoidance leads to a reduction of 3.7 kg CO_2. The factsheet on bicycle highways, however, claims a reduction of 1.1-2.1 kg CO_2 per congestion avoidance. On NOx and PM10, this same factsheet says that one congestion avoidance saves 0.0013-0.0026 kg and 0.00015-0.00030 kg respectively (Rijkswaterstaat, 2019). All other factsheets on the toolbox are compliant with the information from these three factsheets discussed.

Other sources include rules of thumb for smart mobility as well. The report Handreiking Beter Benutten by the Ministry of Infrastructure and Water Management (2018) claims that one congestion avoidance saves 1.1-3.7 kg CO_2, which just the entire bandwidth of the information in the Rijkswaterstaat toolbox. Each congestion avoidance equals a reduction of 0.2 lost vehicle hours, as argued in Goudappel Coffeng (2018). The factor 0.2 was confirmed by KiM (2018), specifically for urban context. This conversion enables the calculation of accessibility effect.

Some sources give accessibility effects in units of kilometers. Using the estimations in Decisio (2012) of 36 lost vehicle seconds per kilometer, that data can also be converted from seconds to hours: one driven kilometer yields 0.01 VVU.

The spatial effects of smart mobility applications depend on the type of changing behavior that is stimulated by the application. In the mobility transition nota from Gemeente Den Haag (2019), the spatial use by one person travelling with different vehicle types is visualized (Figure 9). This figure shows that a driving car uses most space, around 7 times as much as a parked car. As it is very dependent on the transport mode composition of a traveler, which can differ from time to time, setting rules of thumb for this indicator is difficult. A distinction is made between a measure impacting vehicle possession and a measure impacting vehicle usage.

Replacing a driving car by a parked car reduced the spatial use from 140 m2 while driving, to 20 m2 while parked. That would mean that a reduction of one VVU per day equals a car being parked rather than driving one hour per day more, hence saving 120 m2 over the period of an hour. Hence, a reduction of 1 VVU on a day saves 5m2 on average over a day. This calculation concerns vehicle usage and traveling time. When looking at vehicle possession, some measure may lead to replacement of possession of cars. Taking the conservative assumption that a car is always parked, replacing a private car saves 20m2.

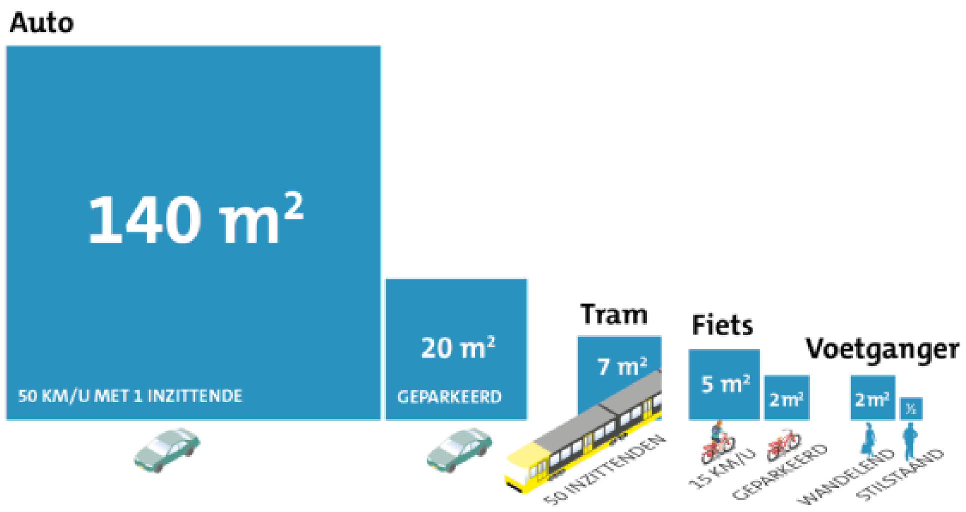


Figure 9 Spatial use per vehicle type (in Dutch) (Gemeente Den Haag, 2019)

Finding an indicator on traffic safety proved a bit more difficult. Most studies focused on accessibility and sustainability effects and did not include projected or measured effects on safety. Metz (2014) uses the Sumo effect calculator to estimate the effects of less kilometers being driven. By first verifying if the results of this study are consistent with the other rules of thumb, the legitimacy of the estimated effect on safety can be tested. The study by Metz states that a reduction of 5,000,000 car kilometers would save 600,000 kg CO2 , which is within the bandwidth of 275,000-925,000 kg CO2 that results from the defined rules of thumb. Therefore, the estimation of 6.5 fewer injured victims and 1.6 fewer deaths or hospitalized victims for those 6,000,000 kilometres is assumed to be reasonable (Metz, 2014).

Table 13 includes all rules of thumb that are used for conversion of the information available to standard units, relevant for all applications. Information from the sources mentioned above that is only relevant for one specific application is used in section 6.3.4 and the corresponding appendix (A2.4).

Table 13 Rules of thumb

Rule nr	Rule of thumb	Source
1	0.2 lost vehicle hour (VVU) equals 1 congestion avoidance.	(Goudappel Coffeng, 2018) (KIM Kennisinstituut, 2018)
2	A reduction of 1 car equals saved space of approximately 20 m2 .	(Gemeente Den Haag, 2019)
3	1 congestion avoidance saves between 1.1 and 3.7 kg CO2.	(Ministerie van Infrastructuur & Waterstaat, 2018)
4	1 lost vehicle hour (VVU) equals between 5.5 and 18.5 kg CO2.	Rule 1+3
5	Driving 1 kilometre yields 0.01 VVU.	(Decisio, 2012)
6	1 congestion avoidance saves 0.0013-0.0026 kg NOx.	(Rijkswaterstaat, 2019)
7	1 lost vehicle hour (VVU) equals 0.0065-0.0130 kg NOx.	Rule 1+6
8	1 congestion avoidance saves 0.00015-0.00030 kg PM10.	(Rijkswaterstaat, 2019)
9	1 lost vehicle hour (VVU) equals 0.00075-0.00150 kg PM10.	Rule 1+8
10	1 kilometre driven yields 0.0000013 injured victims.	(Metz, 2014)
11	1 VVU yields 0.00013 injured victims.	Rule 5+10
12	1 kilometre driven yields 0.00000032 deathly or hospitalized victims.	(Metz, 2014)
13	1 VVU yields 0.000032 deathly or hospitalized victims.	Rule 5+12
14	1 VVU per day equals 5 additional m2 of spatial use.	(Gemeente Den Haag, 2019)

Putting all this data together, the information from these sources can be verified. Using the information on the Rijkswaterstaat toolbox, one car sharer would save around 90 kg CO2 per year. However, calculating the sustainability effects of car sharing differently also gives a different result. By combining that one car sharer drives 1600 km less per year and rule number 5, one car sharer saves 16 VVU per year. Using rule 4, one car sharer saves 88-296 kg CO2 per year. These bounds are a bit wider, but the information from both sources does match with each other. Note that for this verification, the effects used are per car sharer, not per shared car. As one shared car is used by multiple people, these numbers differ.

In Table 13, only the rules of thumb are included that are relevant for the applications as defined in 6.3.1. The sources used, however, include rules of thumb that can be used to calculate the effects of other applications as well, may they be included at a later point.

6.3.4 Effects per application

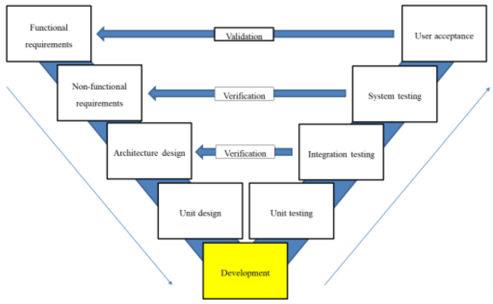
For all applications defined in section 6.3.1, the effects on the indicators set in Table 12 are calculated. The exact calculations for all applications can be found in Appendix A2.4. The sources used are indicated in the appendix as well. The results of these calculations are summarized in Table 14.

All values are calculated on the basis of one year, except for the project Congestion Avoidance as that can only last for a limited period. The effects are relevant for the implementation size that is noted in the descriptions. More information on the exemplary information that was used can also be found in the Appendix with calculations. It is important to consider that the information used was taken from an exemplary effect measurement source and is not necessarily scalable. In other words, implementing 1000 shared cars does not inherently have 1000 times as much as effect as implementing one shared car. There is always a certain threshold for optimal impact.

Table 14 Results of effects calculations

Application	Description	Traffic safety (deathly or hospitalized)	Traffic safety (injured)	Spatial use (m2)	Emissions (kg CO2)	Air pollution (kg NOx)	Air pollution (kg PM10)	Travel time (VVU)
Park and ride	150 parking spots, per year	0.1869	0.7592	1600	400,040	283	17.5	5840
Shared cars	1 shared car, per year	0.01	0.03	120	3300	1.56-3.12	0.18-0.36	240
Congestion avoidance	160 days	3.79	15.39	3700	1,243,200	1420.8	159.84	118,400
Bicycle highway	10 km, per year	0.35	1.42	150	60,225	71.2	8.,2	10,950
iVRI - intelligent traffic lights	1 crossing per year	0.05	0.19	20	7,865-26,455	9.30-18.59	1.07-2.15	1430
Realtime information supply	System: ITS Reisinformatie-diensten, per year	11.68	47.45	5000	5,500-18,500	2372.5-4745	273.75-547.5	1000
Shared bicycle	1 shared bicycle, per year	0.00023-0.00140	0.00095-0.00569	-	0.11-2,22	0.0475-0.5694	0.0055-0.0657	0.02-0.12

7 Development



The conceptual design, both on architecture and on unit level, has been the basis for the development of the tool. The present chapter explains the practical side of the design of the tool as well as its implementation.

Based on the user and system requirements, a suitable type of tool would be one in dashboard format (Burstein, W. Holsapple, Adam, et al., 2008; Kourtit & Nijkamp, 2018). The preference for choosing software for developing a web-based application is also argued by Hewitt & Macleod (2017). Without having seen visual examples, Respondent H also indicated to prefer a tool in the form of a dashboard.

The tool has three tabs, corresponding to the three units designed. The user can switch between these three tabs. The first tab is the tab that takes as input the city and based on that, visualizes the city profile. On the right side of the screen, a text is shown explaining the mobility challenge for the city as well as the policy ambitions related to that. The second tab takes as input a mobility ambition, and subsequently, shows the four smart mobility applications contributing to that ambition most. The third tab requires a smart mobility application the user is interested in and visualizes the effects for this application, as found in academic or experimental reports.

7.1 External data

In order to create meaningful visualizations of smart mobility opportunities and challenges in cities, it is very important to work with reliable databases. These databases may be used for various parts of the design of the tool and their availability is therefore discussed here, in more general sense. More specific use of the databases is described in the relevant sections.

Respondent F gave input on the databases often used for data engineering projects at Witteveen+Bos. Statistics Netherlands/Centraal Bureau voor de Statistiek (CBS) could be used for general demographic data, including population density numbers but also numbers on for example car possession. Open Street Map and National Road Database/Nationaal Wegenbestand could, after applying some GIS, give data on amount of crossings, which may proxy walkability. Registration addresses and buildings/Basisregistratie adressen en gebouwen (BAG) could be used for commuting data, by identifying buildings that are offices and buildings that are residential. Lastly, Research on Movements in the Netherlands/Onderzoek Verplaatsingen in Nederland (OVIN) is very useful for data on traffic behavior.

The tool uses data on various indicators, which are listed in section 6.1.1. At the moment, all data used for the first unit is downloaded from waarstaatjegemeente.nl by VNG (Vereniging Nederlandse Gemeenten - Association of Dutch Municipalities). The data available on this website is a combination of various existing datasets, from organisations including CBS, Ministry of Interior Affairs and RIVM.

At the moment, the data on the variables selected is downloaded manually from the website waarstaatjegemeente.nl/jive as xlsx file. If a user would want to include additional or different variables, a new input Excel file would have to be downloaded this way as well. By replacing the downloaded file in workspace but keeping the same file name for the new file, using Thema's.xlsx as standard file name, the Python scripts will automatically replace the data on the dashboard as well.

The data from VNG does not update automatically and hence, has to be replaced manually at least every year to ensure the latest available data is used. Ideally, of course, the tool would automatically refresh the data. This could not yet be implemented as there is no API for the data source used. When using only CBS data, this real time updating would be possible. CBS, however, does not include all necessary or desired variables. CO2 emissions on municipal level, for example, are not available through CBS but through RIVM.

7.2 Reference sheet

Next to the Excel sheet that contains the external data, the tool also makes use of an Excel file that consists the most important cross-references and information, contained in various sheets. First, there are sheets for the themes, ambitions and applications used. The themes relate to more general aspects or objectives of mobility, including efficient spatial use and infrastructure, and sustainability and energy. The ambitions include the most important policy ambitions for mobility in urban setting, for example becoming a CO2 neutral city, reducing traffic accidents or encouraging cycling. The applications include the most important smart mobility applications at the moment of writing and are categorized into five categories: data tool, infrastructure, policy measure, traffic management or vehicle use. The themes, ambitions and applications as included in the reference sheet can also be found in Appendices A2.1, A2.3, A2.2 respectively.

On top of the sheets listing the themes, ambitions and applications, additional sheets were added to document the relationship between them. The sheet *amb_app* cross-references each ambition with a maximum of four smart mobility applications. An example of how this sheet can be filled in has been added in Appendix A2.5. Ambitions and themes are linked in the sheet *amb_the*, by having all ambitions listed vertically and all themes horizontally; an X in the cell means the ambition of that row could be categorized under the theme of that column. An example of this can be found in Appendix A2.4. The sheet named *the_var* defines the indicators for each theme; these are equal to the indicators as set in section 6.3. The indicators for unit 1, as defined in section 6.1, are noted in the sheet *the_wsjg* in the reference sheet. Lastly and most importantly, sheet *effects* relates the smart mobility applications to their impact on the indicators. This sheet is basically equal to Table 14.

7.3 Scripts

The tool is programmed using Dash, a Python framework to create dashboards for the purpose of data analytics. Dash uses the Python library Plotly to create data visualizations and easily enables interactivity by various components, such as dropdown menus. The dashboard uses two different Excel files as input, one on qualitative relations between different factors and one on city data. These two Excel sheets are described later in this chapter. The tool is launched by running server.py and opening the local server. This could eventually put on for example the Witteveen+Bos website, for internal or external usage.

The Python scripts operate all calculations and mechanisms that are necessary to translate the input to the visualizations in the tool. The Python files as listed in Table 15 are required to run the dashboard. These Python files have not been added in the Appendix, as it concerns around 650 lines of code. While 650 lines is not much for coding a dashboard, it is quite much to include in the present text. To give an idea of the objectives of the files, descriptions are added to the table.

Table 15 Description of Python files

File name	**Description**
server.py	Launches the app built in app.py on the local host server.
app.py	The general file that contains the layout and callbacks for the app. It sets the CSS stylesheets, background colours, header and footer. It also creates the tabs for the different units. It includes the callbacks for all interactivity on all tabs.
tab_1.py	Contains the layout for tab 1.
tab_2.py	Contains the layout for tab 2.
tab_3.py	Contains the layout for tab 3, as well as the functions needed for the visualization of tab 3.
calc_data.py	Takes the sheet.xlsx file as input and converts all sheets to dataframes. Also includes functions to relate the different dataframes to each other and subtract information from the dataframes.
wsjg.py	Takes the data downloaded from waarstaatjegemeente.nl. Reads it in as pandas dataframe, executes some general operations to remove empty values and convert all values to the right datatypes. Converts the data to the normalized values as explained in section 6.1. Exports an Excel file with the dataframe created.

7.4 Dashboard

The units described in section 5.3.4 are developed as tabs on the dashboard. The dashboard automatically opens at the first tab. The user can switch tabs by using the bar at the top of the page and clicking the tab. The user is expected to start at the first tab, go to the second tab and end at the third tab; another sequence, though, is also possible. All tabs function separately and do not require input from the other two tabs.

The three tabs of the dashboard are shown in Figure 10, Figure 11 and Figure 12. The url to access to local host for the laptop used is l611018.wbad.witteveenbos.com:8080. By default, the dashboard runs on localhost, port 8050; this means that on a laptop for personal use, the dashboard can be accessed through http://127.0.0.1:8050.

On each tab, the dashboard shows the title, the logo of Witteveen+Bos and the bar to switch between the three tabs.

The first tab is shown in Figure 10. The tab starts with a brief explanation of the themes and that the chosen municipality will be scored on those themes. Below that is the dropdown to select the city. All Dutch municipalities can be chosen. Below the dropdown, the radar chart is shown with scores between

0 and 1 for the five variables. On the right of the radar chart, there is again a block of text. This indicates the variable the city scores worst on, relates that to the theme it belongs to and suggests the list of ambitions that match this theme.

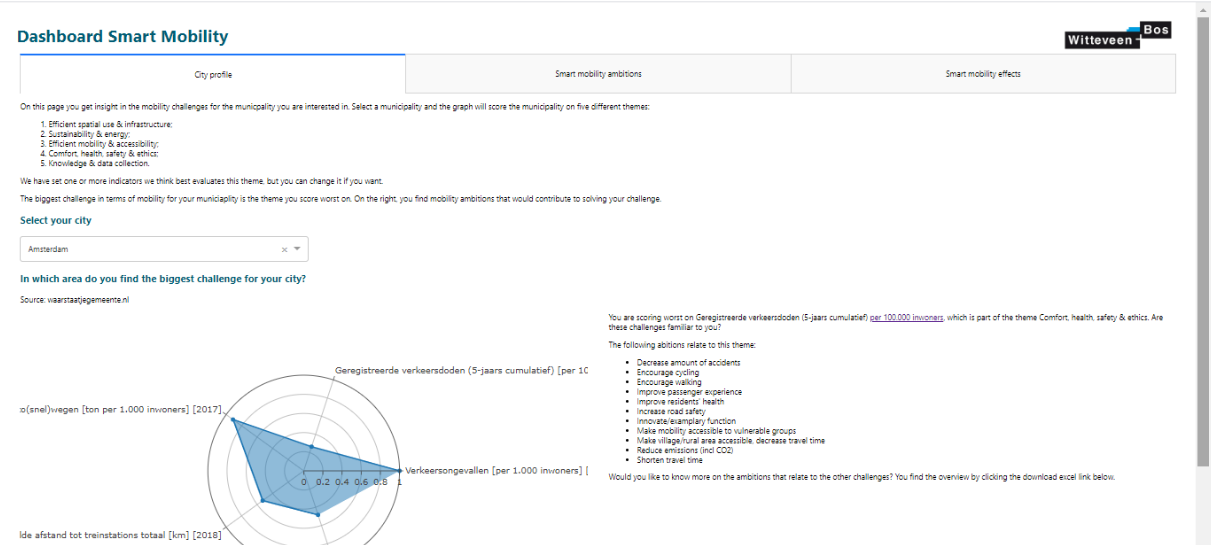


Figure 10 Dashboard - tab 1

The second tab (Figure 11), starts with a brief explanation of the objective of the tab. Right below that, it shows to dropdowns next to each other. The first dropdown lets the user select a theme; the second dropdown shows the ambitions within that theme. Based on the ambition chosen, four smart mobility applications are suggested. These applications are visualized by picture, name and description. The description is not visible right away but can be opened through a toggle arrow next to the application name.

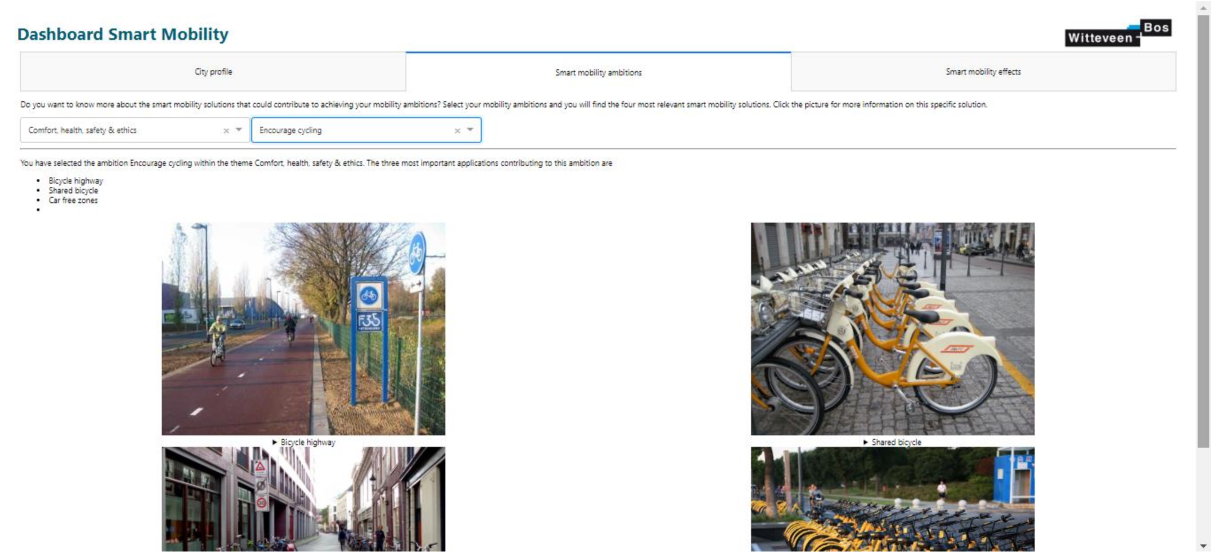


Figure 11 Dashboard - tab 2

The third and last tab is shown in Figure 12. This tab also starts with a brief explanation of the tab, followed by a dropdown to select a smart mobility application. This list of smart mobility applications is not yet complete, as explained earlier. On the right, one finds a description of the implementation used as example for the effects calculated, as well as a picture of the application. On the left, there is a box for each theme, with a small table of the known effects within this theme.

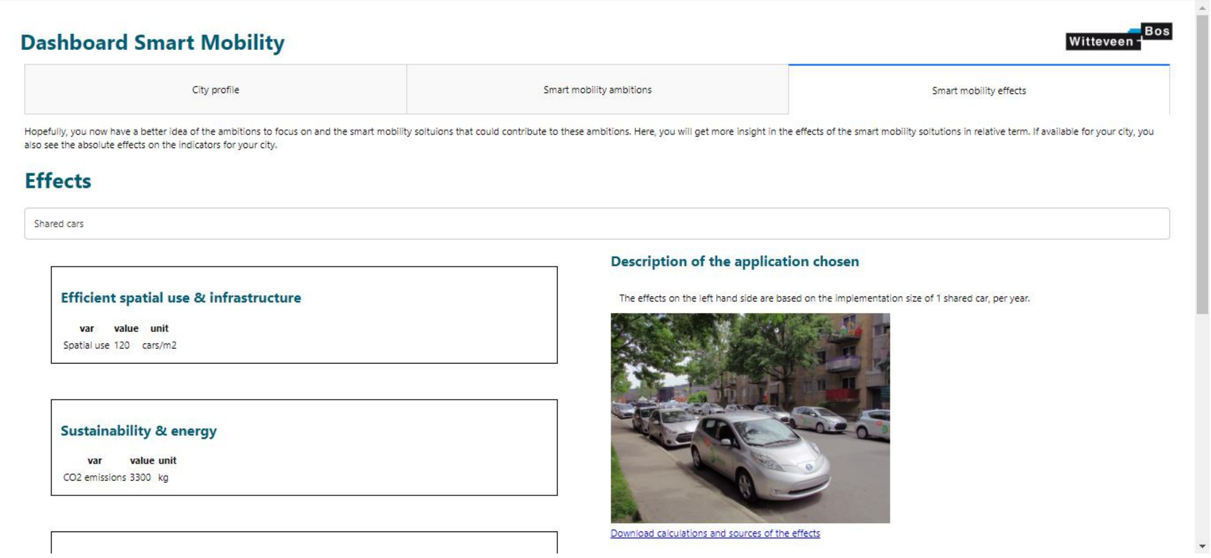


Figure 12 Dashboard - tab 3

A more critical reflection on the contents of these tabs follows in the next chapter, in section 8.1.1. In that section, all outcomes are reflected upon to verify whether or not they are valid, relevant and comprehensible.

8 Evaluation

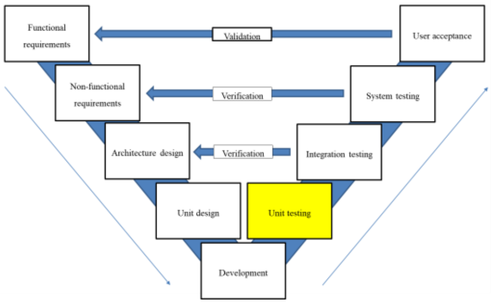
The tool developed aims to provide users with a better insight into the applicability of smart mobility. This chapter verifies the extent to which that goal has been achieved as well as the functional operation of the tool. The requirements set in Chapter 4 are used to analyse where the tool stands, and what still has to be done to fully satisfy those requirements. The evaluation in this Chapter in on a relatively detailed level; the broader and more reflective discussion follows in Chapter 9.

8.1 Verification

As explained in the methodology section, verification is meant to evaluate the accurate operation of the decision support system. The verification consists of three parts: verification of the units, verification of the integration of the units into the model architecture and verification of the system by testing if the system requirements have been successfully implemented.

One important observation on the tool is that, at the moment, it is partly in Dutch and partly in English. The reason for this is the use of Dutch data sources. It would be recommended to either translate the data variables or translate the entire tool to Dutch. This discrepancy does not harm the efficacy of the tool.

8.1.1 Unit testing



To test all separate units, the dashboard has been opened and the outputs given have been verified by comparing the output to the reference sheet.

For the first unit, the input used to test is Amsterdam. Choosing Amsterdam in the dropdown menu gives the radar chart depicted in Figure 13. At first sight, it can be noticed that the variable names are not depicted correctly. Rather than using multiple lines, the names are on one line and cut off at the edge of the page.

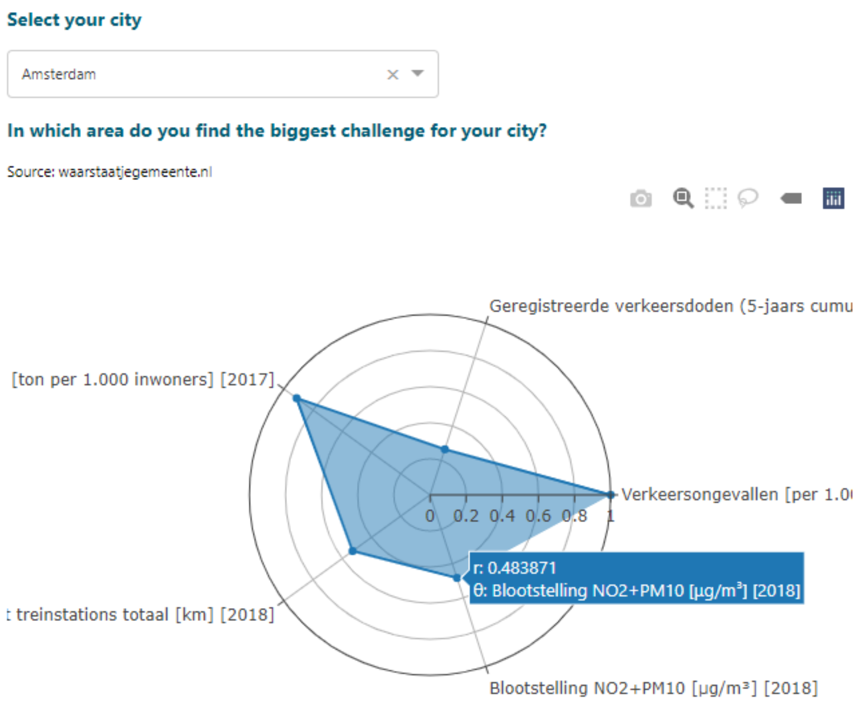


Figure 13 Radar chart, Amsterdam

As explained, the radar chart shows the scores of Amsterdam on five pre-defined variables. For Amsterdam, these scores are listed in Table 16.

Table 16 Scores on variables, Amsterdam

Dutch variable name	English translation	Score
Geregistreerde verkeersdoden (5 jaar cumulatief) [2017]	Registered traffic deaths (5 years cumulative) [2017]	0.27
Verkeersongevallen [2018]	Traffic accidents [2018]	1
Blootstelling NO2+PM10 [2018]	Exposure NO2+PM10 (2018]	0.48
Gemiddelde afstand tot treinstations totaal [2018]	Total average distance to train stations [2018]	0.53
CO2-uitstoot autoverkeer exclusief auto(snel)wegen [2017]	CO2 emissions car traffic excluding highways [2017]	0.91

The units of the variables have been left out in Table 16, as all values were converted to a unit-less score between 0 and 1. The scores are based on a normalization per city size group, meaning that Amsterdam is compared to other cities with more than 300,000 inhabitants, which are Den Haag, Rotterdam and Utrecht. Looking at the input data on these variables, Amsterdam and Den Haag both show an equally low value on traffic accident, lower than the value for Rotterdam and Utrecht. That means that Amsterdam scores best on this variable, hence the score of 1.

At the moment, a high value of a negative variable (such as traffic accidents) is converted to a low score. Whether or not that is intuitive is up for discussion; it may be better to convert the variable names used now to positive variable names, e.g. traffic safety.

At the moment, the tool takes the lowest score, and relates this variable to the challenge this belongs to. That means, for Amsterdam, that, although the score on traffic accidents is 1, the largest challenge is identified to be Comfort, health, safety & ethics, due to the low score on traffic deaths. As this is quite a broad theme, the suggested ambitions do not only relate to safety, but also to comfort, health and ethics. That may sometimes be inaccurate.

For Amsterdam, one of the suggested ambitions is Decrease amount of accidents. Using this ambitions as input for the second unit, suggests to the following applications contributing to decreasing the amount of accidents:

- Automatic Incident Detection - AID
- Systems for speed control and management
- Autonomous shuttles
- ITS - intelligent transport systems

The second unit for this ambition gives the output as visualized in Figure 14

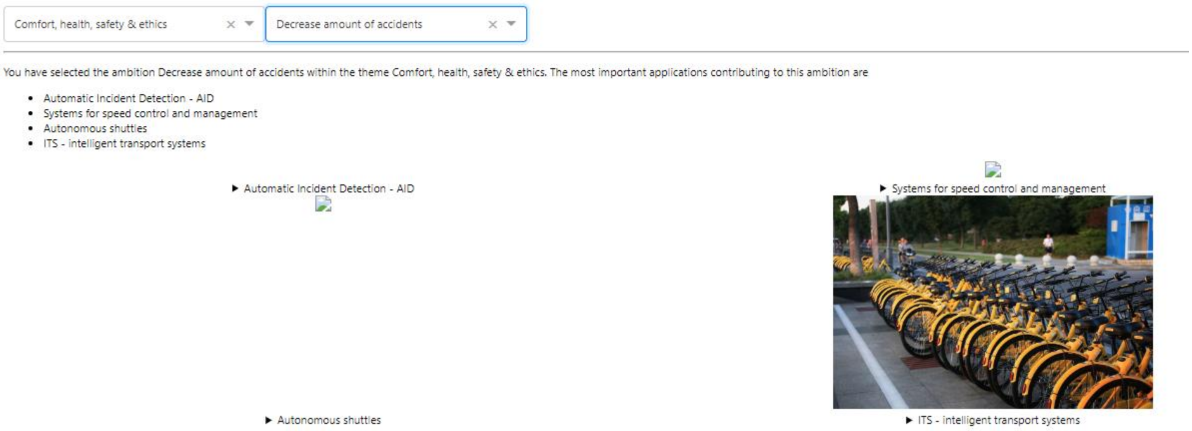


Figure 14 Suggested applications, Decrease amount of accidents

The pictures for the applications do not seem to work; three applications give no picture and one application gives the default picture. This is not a coding error, but rather an error in the picture URL in the reference sheet. Only Autonomous shuttles gives a description, which is correct, as the description has not been filled out in the reference sheet yet for the other applications.

The third unit shows a dropdown to pick an application. The choices are limited, Shared cars is for now used as example. This gives the effects as shown in Figure 15, as well as on the right of the window, the picture and description of implementation size for shared cars.

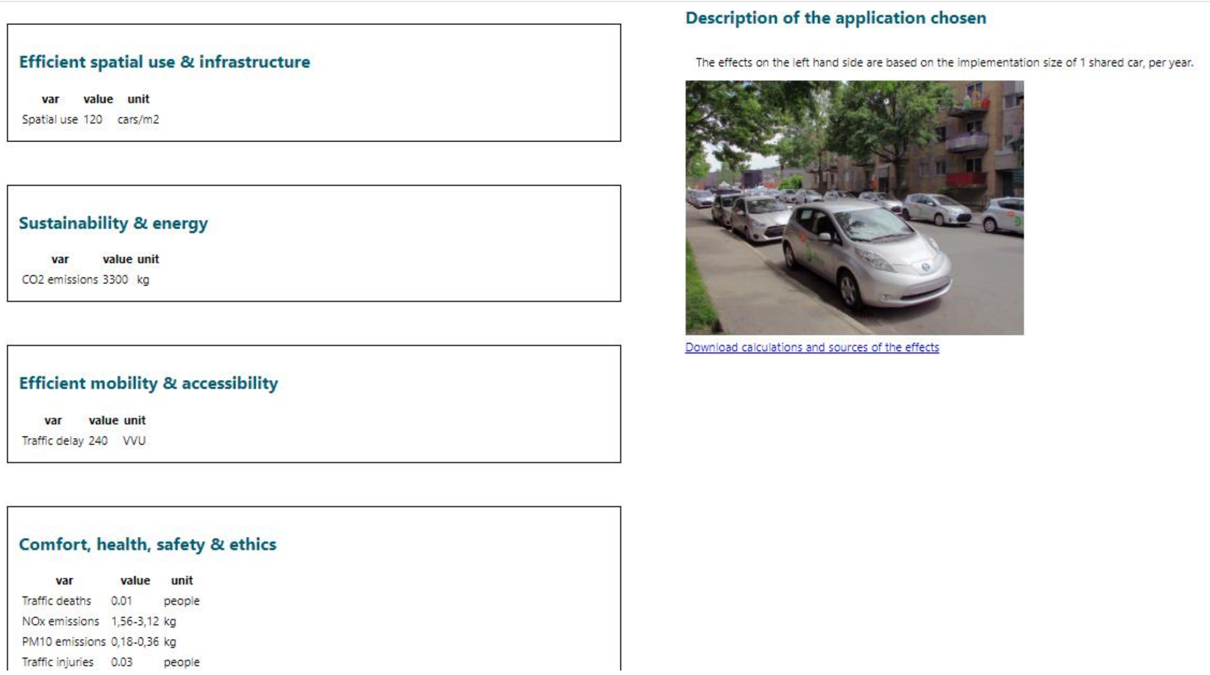
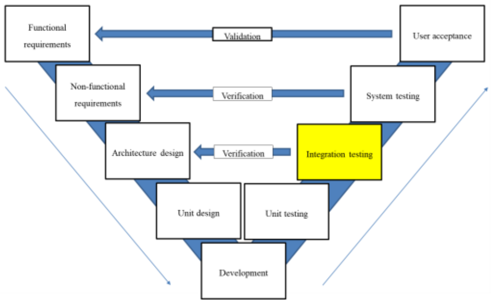


Figure 15 Effects for application Shared cars

Below the dropdown, the tool shows a block per theme. Within those blocks, the variables are listed underneath each other with the values and units. Those effects correspond to the ones in Table 14 Results of effects calculations, which means the data is correctly imported, transformed and visualized. What may not be intuitive is that the blocks are also shown if no effects for variables within that theme are known; the block on Knowledge & data collection is empty - see Figure 16. On the other hand, showing them immediately clarifies the possible themes an application could have had effects on.

Figure 16 Empty effects block, Amsterdam

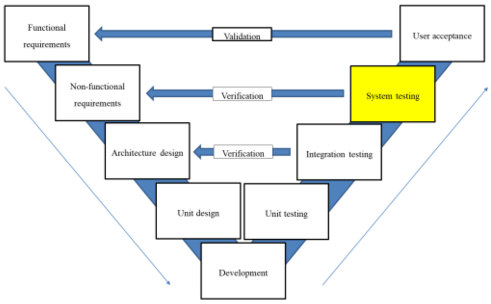
8.1.2 Integration testing



As briefly reported, the integration between the units is not optimal. The main reason for this is the incompletion of the third unit, which only includes a limited set of applications. Because of that, a user may not be able to gain insight in the effects of applications that have been recommended to look into in earlier units.

On top of that, the connection from one unit to the other, at the moment, still has to be made by the user. When a user gets the suggestion of an ambition in the first unit, the user still has to select that ambition in the second unit manually. This makes it a semi-integrated flow rather than a fully automated or integrated one.

8.1.3 System testing



In this section, the non-functional requirements are evaluated. These requirements do not directly relate to the content but rather to the operationality of the tool.

The non-functional requirements are listed below, including an evaluation of the level of sufficient implementation.

- The tool shall be interactive.

The tool requests input from the user, outputs information that is based on that input, and can hence be considered interactive. The level of interactivity, however, is relatively low when the user only has access to the dashboard. The dashboard is meant for usage by policy makers and experts, while experts at Witteveen+Bos can also alter the information in the reference sheet. The reference sheet contains a lot of information, some of which could have been added to changeable information in the dashboard, to improve interactivity.

- The tool shall be user-friendly.

Respondent H considered the tool to be user-friendly. Giving input is fairly easy and does not ask detailed knowledge or many actions. This is, however, an objective rather than a requirement, and shall therefore, always be subject to improvement. One aspect of user-friendliness is accessibility. The dashboard is accessible by opening and running the file server.py. That means the tool, in principle, can be accessed through 2 actions. When the user wants to open any input files or more coding files, however, more actions are required.

- The tool should start up in less than 1 minute.

The tool has been timed to startup in 2,5 seconds, which is faster than was prescribed by the requirements. This is dependent on internet connection and computer specifications, but no computer is expected to take longer than 1 minute to start up the tool. When elaborating on the tool, it is important to keep the run time in mind. A longer startup time than 1 minute would reduce user-friendliness.

- The tool shall provide the option to save or export selected options

At the moment, saving the selected options is not possible. The user can, of course, always use the print function of the browser to convert the dashboard to pdf.

- The user shall be provided with references of the data used.

The references of the effects and rules of thumb that have been used to calculate the effects have been included in the downloadable file on the third tab. This file includes the calculations of the effects as well. The database of waarstaatjegemeente.nl was used for the data on the first tab, and is referenced there in-text.

- The tool should function in any regular use browser, such as Edge, Chrome, Firefox, Safari.

The tool has been tested in both Edge and Chrome. In those two browsers no issues were noticed. A quick search tells that no problems are known for running Dash in other browsers.

- The tool should always show at which date information was subtracted.

The tool itself does not show a date at the moment. When the user would want to save the output and chooses to export the information to pdf through the print function, the header of the file includes both the date and the title of the dashboard.

- The information in the tool should be editable by someone without programming experience.

The tool has been designed to be accessed by users without programming experience. That is, as long as the user only runs the dashboard or would like to make adaptations in the input file. The moment the user would like to change the visualizations or change the infrastructure the tool is built on, programming experience is needed to change the coding files. The input Excel file can be changed in terms on content by someone without programming experience. The moment the structure is changed, the scripts would have to be changed as well.

- The tool architecture should be editable by someone with programming experience.

The scripts for the dashboard have been written in Python and are relatively simple. Anyone familiar with pandas and a bit of HTML should be able to edit the tool architecture. That means that for example, additional tools could be added or other information could be subtracted from used data frames.

- The tool shall use data for calculations from reliable sources.

All sources for the calculations are included in this study as well. The main sources used are governmental institutions, such as planning bureaus, and external research agencies conducting their research by assignment of a governmental institution.

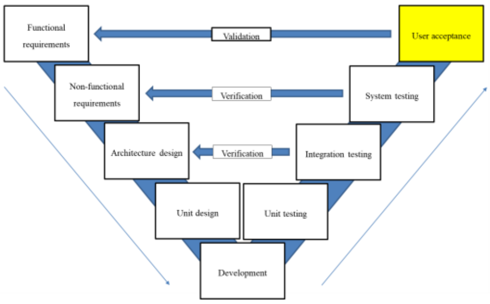
- Data used in the tool should always be up to date, data should not be older than 5 years.

The data currently used for the first unit, the city profile, is from 2017 and 2018, as that was the most recent data available. It is important to keep the data in the tool up-to-date in the future as well. The variable names for the city profile include the year of recency of the data as well. The variable names, however, are too long to be visualized well, and are hence sometimes cut off. For the data used in the third tab, the recency is not available to the user in the unit itself. The file that can be downloaded does include references and therefore also the publication dates of the information.

- The tool shall load a new tab or new information within a maximum of 3 seconds after each click.

Once the tool has started up, each operation executes directly, taking very little time. The loading time of new information is therefore not expected to cause problems.

8.2 Validation



In this section, the tool will be validated. By evaluating the satisfaction of the functional requirements and conducting user tests, it can be validated if the tool serves the objectives it was designed for.

8.2.1 Functional requirements

All functional requirements set in Chapter 4 are listed below. For each functional requirement, the partial or full satisfaction of this requirement explained.

- The tool shall account for regional differences regarding smart mobility implementation.

The tool accounts for regional differences by letting the user select a city. Cities are only compared with cities of similar size, and suggestions on ambitions are based on the score of the city on a number of variables.

- The tool shall include effects of smart mobility applications.

The tool includes effects of a limited set of variables. It includes effects on the five themes defined in A2.1 by standard indicators. Hence, it does include some effects of a few smart mobility applications but does not include all effects of every application.

- The tool shall combine data with knowledge.

The tool combines both external data and expert knowledge. The data comes from external databases (see 7.1), while most expert knowledge is processed through the reference sheet (7.2). In order to combine data and knowledge to a further extent, the tool shall always be used by an expert and a policy maker collectively, to integrate the outcomes of the tool in a more integral advice.

- The tool shall include location-specific data.

The external data from waarstaatjegemeente.nl is municipality-specific is used to create a city profile. It includes data on five different variables that are related to mobility and scores each municipality on these variables.

- The tool shall provide insight on the current mobility situation in a city.

The city profile created in the first unit scores a city on five variables that relate to the mobility situation. These five variables all provide some insight in the mobility situation, but do not comprise all aspects of mobility as a group.

- The tool shall be designed by a simple model.

The conceptual model of the tool is relatively simple, as visualized in Figure 4. At the moment, however, the tool may be a bit too simple. The subject is complex and may therefore require a more elaborate model to capture the versatility of smart mobility.

- The tool shall be developed in close coordination with policy makers.

The requirements of the tool have been set through consultations with five policy makers. Two of the policy makers have again been consulted for the user test. Ideally, the policy makers would also have been consulted to verify the requirements that were set based on the conversations.

- The tool shall be expandable.

The tool is expandable by increasing the amount of inputs in the reference sheet. For example, the third unit only includes the effects of seven smart mobility applications. By just adding the effects of other applications in the same format in the reference sheet, these are automatically added to the tool. The same goes for the applications sheet and the ambitions sheet. That is, as long as the framework of the sheets does not change, applications can easily be added in the tool. When the tool would have to be expanded in terms of units, that would only be possible by adapting the framework programmed in Python.

- The tool shall calculate effects by rule of thumb.

The effects are calculated by converting existing information to the same units, using rules of thumb. These rules of thumb were listed in Table 13. These rules of thumb convert most information to a ratio among a variable and travel time (in VVU). Other rules of thumb could be added to be able to add even more information to the tool.

- The tool shall lower the boundary for considering smart mobility.

The tool does not focus on the technological side of smart mobility, but rather on the added value for a city. This hopefully contributes to the accessibility of smart mobility applications for municipalities that are still in an early phase of implementation. The objective of the tool shall not be to only provide the positive effects of smart mobility, the downsides of implementing smart mobility solutions shall also be included.

- The tool shall include at least the applications MaaS and autonomous cars.

Mobility as a Service and autonomous cars are among the applications included, see A2.2. These were considered important by the respondents as they are subject to increasing societal support and interest.

- The tool shall start at the challenge in a city.

The tool determines the mobility challenge of a city by scoring it on five different indicators and comparing that score to municipalities of similar size. In this way, the challenge is determined in the first unit of the tool. At the moment, the challenge is defined to be a theme. A more critical reflection on whether this challenge shall be defined on the detail level of a theme or an indicator can be found in section 9.1.

- The effects shall be formulated less abstract than accessibility, liveability, sustainability.

The tool works with themes, ambitions and indicators. While the themes are formulated in an abstract manner, the ambitions and indicators further specify them. Thus, an objective of a municipality to make its city more sustainable is for instance formulated as Reduce CO2 emissions. The effects of smart mobility are expressed as indicators, e.g. reductions in CO2 emissions in kg per year.

- The tool shall provide only a quick scan.

The tool provides a quick scan for municipalities interested in knowing which smart mobility applications would be interested to further investigate. The tool, at the moment, does not provide the option to request a follow-up with an expert, as the tool is meant to be used by a policy maker and expert together. The expert could guide the policy maker in determining which applications would be interest for further study and explain the possibilities.

- The tool shall facilitate knowledge exchange.

The tool includes the effects of some implemented smart mobility projects. The calculations of these effects can be downloaded and include references to information sources. In this way, it facilitates the knowledge exchange of pilot results among municipalities. By adding for example best practices to the tool, knowledge exchange could be facilitated even more.

- The tool shall work with grouping by city or region sizes.

In the first unit, all cities are grouped by city size. When determining the score of a city on the five different indicators, cities are compared with other cities of similar size.

- The tool shall be practical and easily applicable.

The tool is easily usable and gives an idea of feasible implementations in a short period of time.

- The tool shall be in a dashboard format.

The tool is programmed in Python Dash to create a dashboard-format tool. That means that its main objective is to comprehensibly visualize information. This information shall be interpreted by policy makers and experts together, to integrate it in a more integral analysis of the interesting smart mobility applications for a specific city.

- The tool shall include referrals to further information.

The tool includes the effects of some implemented smart mobility projects. The calculations of these effects can be downloaded, as well as the reports that contain more information on the numbers used. Actual referrals, in terms of contact information, is at the moment not included, but may be suggested for further development.

- The tool shall include the prerequisite of a good data infrastructure.

The tool addresses the five themes that are important for smart mobility. One of these themes is Knowledge & data collection. While the current use of this theme in the tool is limited, it is mentioned multiple times as theme. As described earlier, this theme is a bit different from the others. The theme Knowledge & data collection focuses on the applications in smart mobility that improve the data infrastructure and hence, enable monitoring and information provision. These data infrastructures would have to be built up over time and may provide additional challenges for smaller municipalities in terms of investment.

8.2.2 User tests

The tool has been validated with two of the policy makers consulted in the first round of interviews. The first validation interview was conducted with **Respondent H** of the municipality of The Hague. Due to the circumstances at the time of conducting the present research, the consumer test was conducted virtually. The exact date of the consumer test was **13/05/2020**.

Respondent H was walked through all units of the tool, and asked to provide both negative and positive feedback on the elements of it.

Tab 1: Respondent H positively reviewed the radar chart as visualization technique for the city profile. H could even see the benefit of more factors being included. At this point of the study, the positive or negative effect of each factor was not yet visualized correctly, meaning that a high value on a variable was converted to a high score, regardless of the positive or negative connotation to that variable. Respondent H pointed out that this would still have to be changed to be able to compare the variable scores among each other. Respondent H also agreed that taking the challenge as starting point is the most effective and helpful way to build up the tool.

Tab 2: In The Hague, smart mobility is defined more narrow than in this list. Especially smart use of data and technology within the mobility fields are considered to be smart mobility solutions, as well including shared mobility, iVRI and parking sensors. Fast cycling lanes and car free zones would be considered part of regular mobility in the municipality of The Hague.

Here again, positive feedback was given on the challenge-perspective. Respondent H explained that this would also be beneficial for political support. An example of this would be that Amsterdam is experimenting with road pricing and kilometer taxes, while Rotterdam and The Hague are more reluctant. This willingness to experiment depends on political relations as well.

An effective way to get politicians on board would be to use the tool together with their political coalition agreement, and see which ambitions were written down in that agreement. Those could be used as input for the tool.

Tab 3: Respondent H commented on this tab that additional verbal explanation could be very helpful for explanation, including sources and a description of the application size. He argued that all users will straight-away be interested in the data that is behind the visualized information. According to Respondent H, it could help to use even more examples for the visualization.

Respondent H thinks that the tool could be expanded even more in the future, for example by answering the question: What is already being piloted or implemented in each municipality? Actually seeing which city is experienced would be beneficial for the bundling of forces between municipalities. That could be implemented by checking what happens already, combined with for example plans from coalition agreements. It could also be interesting to clarify by means of example; the application shared bicycles could, for instance, benefit spatial use, citizens, and reduce emissions.

In general, the tool is assessed as innovative and useful. According to Respondent H, demand for this tool definitely exists. Another suggestion from Respondent H would be to include negative effects as well. For example, regarding shared bicycles, previous implementation has shown that the bicycles were left chaotically around the city. A disadvantage for shared cars could be that users may prefer them mostly for short trips, which could mean they replace public transport rather than private cars.

The second validation test was conducted virtually on **03/06/2020** with **Respondent K.**

On Tab 1, Respondent K commented that, next to the normalized numbers, absolute numbers may be important to include as well. This could be in addition to the graph visualized.

Tab 2: Respondent K indicated that a more elaborate description would be useful. He argued that the moment a user starts investigating smart mobility, one would want answers to all questions as well. If all this information is not included in a tool, Respondent K would suggest a reference to an external source. Respondent K thinks this tab would have to include more detailed information to stay interesting. The tool itself could include a short description and link to an external page with more information.

Respondent K was very positive about Tab 3. He indicated that completing the information on that tab, would be very useful. Respondent K agreed that the possibilities with smart mobility are endless, and including all applications at this point was not feasible.

In general, Respondent K thinks the architecture of the tool is good. It makes sense that further development is needed. If applications can be quantified, especially if that can be done automatically in a tool, policy makers or company experts using the tool would really be one step ahead.

9 Discussion

This discussion chapter covers the content of the tool, the quantification of effects and the commercial implementation of the tool. The content of the tool is important to discuss as it relates to the decisions made for the design. The quantification of effects has proven to be very challenging and had to be executed pragmatically, which is explained in more detail in section 9.1.2. The expected difficulties for implementation are described to inform Witteveen+Bos on the prerequisites for successful use.

9.1 Design and development

The design consists of a conceptual design and a unit design. The second unit of the three units, however, is rather an auxiliary unit, as it only links the ambitions to the applications. The first and the third unit contain a specific choice of indicators, which requires some more discussion. This section therefore starts with the concepts and relations determined in the model architecture design, and then discusses the indicators set in the unit design.

9.1.1 Concepts

The content of the tool is not complete, yet captures a large part of the available information. The themes chosen are broad (e.g. Comfort, health, safety & ethics), which benefits the coverage, but on the other hand, decreases specificity. The theme Knowledge & data collection is a bit different from the other themes selected, as it is also a condition for a well-functioning smart system, rather than solely an application category. Improving data infrastructure can also contribute to efficiency and changing travel behaviour.

The applications included are considered to be complete and include all relevant applications important at the moment. Some, however, are at more level of detail than others. For example ITS entails rather an approach than one singular system, which led to some overlap with other applications described in more detail, such as Automatic Incident Detection - AID. On top of that, the term smart mobility and the range of applications that are included was considered very broadly; while some respondents in the interview considered this list to be right, others indicated that some of the applications included would be considered regular mobility measures rather than smart mobility solutions in their work environment. An example of that would be an infrastructure project such as Park and Ride or a policy measure such as Stimulate working from home. The definition used for the present study includes all applications that are part of the transition to a smarter mobility system.

The ambitions that were used for the study were a bit less objective than the themes and applications. Many of them had been mentioned by the interview respondents, but the final list has been composed only in coordination with the experts from Witteveen+Bos. The list includes at most 11 ambitions per theme, for Efficient spatial use & infrastructure and Comfort, health, safety & ethics. The theme Knowledge & data collection relates to only 5 ambitions.

Determining the effects of smart mobility applications has shown to be very difficult at the moment. The amount of pilot results and studies on this topic is limited, and where available, studies still contradict each other. The effects included in the present study are included ‘by example’, meaning that they should not be considered replicable, but could be used in an indicative manner. The effects are tried to be expressed in terms of equal and comparable units.

On a more detailed note, the effects currently included in the tool are implemented for the size of known previous projects. It is not necessarily the case that this data is scalable. The effects of shared cars, for example, are included for the implementation of 1 shared car. It has not been researched whether or not the effects of this application can be calculated linearly. Even if that would be possible, the effects of smart mobility applications are expected to have a limit. Hypothetically, implementing a million shared cars in a small municipality would not have one million times as much as effect as implementing one shared car. The same argumentation holds for the combination of different smart mobility applications, in that case, the effects are not necessarily summable. When implementing two applications, the effects may be larger or smaller than the sum of implementing each application separately. The tool does, at the moment, not account for this.

9.1.2 Indicators

The measurement and quantification of the effects of smart mobility has proven to still be difficult at this point. The early stage of development as well as its continuous progress results in a lot of uncertainty of the return on investment of smart mobility technologies. Effects on the environment and accessibility can be expected and estimated, but exact definitions are harder. The smart mobility sector is characterized by its high amount of private companies responsible for public transportation, which complicates the dynamics of effect measurement. The relationships between public and private sector as innovative as the technologies, leading to increased uncertainty on prices, tariffs, policies and regulations (van Winden & van den Buuse, 2017).

The current indicators used for the city profile only consider three of the five themes defined. The main reason for this was limited availability of variables on the database used. There are two indicators for Comfort, health, safety and ethics, but both only relate to safety. There are two indicators for Sustainability & energy, and one for Efficient mobility & accessibility. The indicators used for Sustainability & energy can be considered sufficient, as they capture the most important pollution measurements. The indicator on Efficient mobility & accessibility is now set to total average distance to the train, but could be replaced by one of the other accessibility indicators in the database, e.g. average distance to the hospital.

The indicators for the effects currently used relate to the theme but do not fully capture it. For some themes, it is therefore necessary to add more indicators to fully capture the theme. For example, for Comfort, health, safety and ethics, traffic accidents and pollution are used as indicators. These indicators, however, merely relate to safety and health, and not to health and ethics. On top of that, the indicators for the effects are calculated by using rules of thumb. Most of these rules of thumb use travel time in units of VVU as value to convert to, which makes all other indicators dependent on travel time. It could, however, be that the ratio of one indicator to travel time differs per application. It is now assumed that the ratio between travel time and emissions, for example, is equal for both shared cars and shared bicycles, which may not be the case at all. This simplification was necessary to formulate general rules of thumb, but because of this, the rules of thumb may need some additional cross-validation with other sources. Another simplification that was made was to assume VVU as one standard unit, while the effects on travel delays in VVU could be estimated differently in urban areas compared to highways. The same goes for the spatial use of a driving car: the 140 m2 from Figure 9 is based on driving 50 km per hour. For different speeds, these variables used would be different as well.

In short, the indicators chosen are all individually relevant, but not yet complete. All indicators relate significantly to one of the themes, but the other way, the themes are not fully captured by the indicators. Recommendations to improve this follow in Chapter 9.3. Literature argues for the importance of giving priority to the improvement of the indicators, as this determines the eventual successfulness of the dashboard. As Burstein et al. (2008) state, no matter the usability of the interface, if the indicators fail to capture the policy problem, the tool would fall into disuse.

9.2 Methodology

The research objective could have been approached from multiple angles. The chosen approach was a V-process model, consisting of 9 different phases. The chosen methodology, including its phases, is discussed in this section.

9.2.1 V-process model

For the present study, the methodology was structured by a V-process model. This meant a very clear division of phases. On the one hand, this clear division was a benefit, as it very well structured the research into 9 separate parts. On the other hand, the requirements for the design in this study were not as clear as may be necessary to use a V-process model (Adel & Abdullah, 2015). The V-model does not provide the flexibility to change the design throughout the process The complexity of the topic would have requested a more iterative approach to designing a tool on smart mobility. Therefore, it was not always possible to fully finish one step before starting the next. In that regard, other models that could be considered for a similar study would be incremental or prototype models. Prototyping would have been relevant only for this exploratory phase of the development of the tool, while the incremental build model concerns the combination of a waterfall-type model (like the V-process model) and prototyping (Pressman, 2009).

9.2.2 Interviews

The interviews to determine the user requirements were only conducted with a limited set of respondents. All municipalities consulted were relatively large (The Hague, Almere and Metropole region Amsterdam). It did prove useful to conduct interviews with policy makers on different levels, locally, regionally and nationally. For instance, while the tool may be most applicable to use for municipalities, the interview with the Ministry of Infrastructure and Water Management gave insight into the piloting procedures, challenges throughout the country, and national policy. Local municipalities were relevant to consult as they could provide input from their own, local experience in considering smart mobility solutions. Next to that, only being able to conduct interviews virtually limited the quality of interaction to some extent. The circumstances preventing the research from being conducted at the office prevented continuous iteration of the tool with experts in the mobility sector. Some virtual sessions were organised to gather feedback on the expert data used, but not as often as would otherwise have been the case. The content may therefore need some more revision after implementation of the tool.

The interviews were also not all conducted in the same period. By conducting the interviews over a period of three months, some respondents were consulted at a later stage of research than others. Instead of using a set list of questions, these questions were used indicative and the interviews were relatively informal. Because of this, the content of the interviews and hence, the level of information provided to the respondents differed.

The requirements were set afterwards, based on the informal interviews. These requirements have not been evaluated by the respondents of the interviews again. It may therefore be that one requirement now seems to be supported, but may have been rejected by others, if they would have been consulted on that requirement specifically.

9.2.3 Decision support system

The tool has been designed on the framework of a decision support system. Section 3.3.4 reviewed the literature on this framework and tailored it to the objective of this study. In this section, both advantages and disadvantages were discussed. This present study has taken the first steps in developing a well-functioning DSS for smart mobility effects. The advantages of using such a DSS are, in short, the efficiency of assessing different policy options and the improved communication with the client. The disadvantages could pose a greater risk and are therefore discussed here in a bit more detail. As reviewed in 3.3.4, the disadvantages of a decision support system could be:

1. Overemphasized decision making, when the chosen type of DSS is not appropriate for the decision situation;
2. Assumption of relevance, when using the DSS inappropriately;

3. Unanticipated effects, when the skill needed to perform a decision task is reduced by the implementation of a DSS;
4. False belief in objectivity.

The first disadvantage seems to have been covered by using the DSS as a quick-scan type of tool, rather than trying to include all aspects of mobility in one tool. In other words, the tool is and shall not be too complex, in order to simply guide the first assessment of feasible options and lower the threshold to investigate potentially feasible options in more details. The second and third disadvantage are not directly prevented by the tool as designed at the moment, but would be covered if the tool is used as envisioned; the tool shall be used by an mobility engineer together with a policy maker, to ensure the outputs of the tool are not interpreted as isolated results, but as part of an expert advice. The last disadvantage requires an important remark: at the moment, the tool helps to identify the smart mobility applications that are most suitable for implementation in a city, but it does not assess whether or not smart mobility at all would be beneficial. This assessment would have to be made by the engineering that is advising the policy maker.

9.2.4 Evaluation

The evaluation consists of verification and validation. The unit and integration testing was not executed with the presence of an external party, but mainly focusing on checking the correct operation. The system testing was also conducted without consultations, but reviewed all non-functional requirements, and could therefore be considered objective.

The validation of the tool was separated into two different parts. The first part concerns the satisfaction of the functional requirements, and the second part concerns the user tests. These two parts could potentially have been integrated to include the respondents in the validation of the functional requirements. Reminding the respondents of the requirements that were set before the design, may have guided them to be more critical on the tool.

9.3 Implementation

The tool has been designed to be implemented for commercial use. This implementation brings along a few challenges, with regards to the integration with existing methods (9.3.1) and the commercial implementation (9.3.2). The first subsection reviews the existing transport models and assessment methods commonly used in the sector and the potential integration of this study and tool into; the second subsection discusses the most important considerations with regard to public accessibility, maintenance and knowledge sharing.

9.3.1 Integration with existing methods

The present study aims to assess smart mobility solutions. Generally, the impact of mobility policy measures is estimated by using transport models and assessed through a Cost-Benefit Analysis (CBA).

Because smart mobility is still in the phase of pioneering and uncertainty, and knows different dynamics than regular infrastructure projects, these methods could be a bit more difficult to apply. However, the financial factor is as important to consider for smart mobility measures as it is for regular infrastructure projects. The integration of the present tool with existing transport models and CBA as assessment method is therefore import to discuss.

The two most important sources for this discussion are Rigo (2019) and Centraal Planbureau (2018). The findings from the present study, in combination with an analysis of these two reports, will consider the challenges regarding the dynamics between physical and smart measures and the applicability of transport models. The basis for this discussion for this discussion will be a comparison between quantification of effects in normal infrastructure project and quantification of effects to smart mobility projects.

Most traffic measures are implemented for the purpose of improving traffic flow. While physical measures are mainly increasing capacity, smart mobility would most often be removing intensity. The smart mobility measures that are aimed at removing traffic intensity on roads rely on the scarcity of the capacity in order to be effective. In other words, the moment capacity is increased, measures to divert travellers to avoid congestion would not be as effective anymore.

Past projects on temporary congestion avoidance have shown that the effect of the project largely fades when the incentive is taken out, i.e. when the rewards ends and/or the capacity is increased by physical measures. Only in very few cases, when the implementation of a temporary measure succeeds to serve as catalyser, a working business model could keep existing.

The conclusion that smart mobility measures to improve traffic flow are only effective in case of a capacity shortage suggests large regional differences in the applicability of smart measures. Whereas in some regions, capacity might be limited and hence, smart measures could have large impact, in other regions, smart measures may not improve traffic flow, as no or little capacity problems exist.

However, smart mobility measures are not solely focused on traffic bottlenecks, but could also be implemented to improve other factors, such as safety and sustainability. The present study focused on five different themes, of which traffic flow was only one. These themes could also interact with each other. For instance, safety measures implemented to prevent traffic incidents could at the same time affect traffic flow. Therefore, one shall not treat smart mobility as irrelevant when the effect on traffic flow seems insufficient (Rigo, 2019). Using ex-post analyses of case studies and experiments could improve the knowledge on these, potentially underestimated, effects on sustainability, space and safety and knowledge (Centraal Planbureau, 2018).

For smart mobility, using transport models is not always possible, as they can be affected by measures in many more ways. In general, macroscopic transport models work according to the 4-step model: ride generation (how many rides), distribution (origin and destination of rides), modal split (modality choice) and division (route choice). Smart mobility affects various inputs of those four steps, such as:

- New modalities: The introduction of for example the speed pedelec changes the alternatives a traveller can choose from. The higher speed improves traffic flow and comfort for the cyclist, hence becoming a more attractive option.
- Shared cars: One shared car replaces on average 4-8 possessed cars. The decreasing car possession does not only affect for example spatial use, but could, on the long term, also make travellers more conscient of their modality options per ride. This way, car use could be decreasing even more.
- Tailored advice: Mobile applications can provide tailored travel advice per day and per displacement. This will result in travellers having a more complex, diverse and dynamic set of modality options. A transport model such as the nationally used NRM stays behind in incorporating this development.
- Remote working is enabled by the improvements in IT communication technologies and the capabilities needed to use them. The option to work from home and host meetings online alters the necessity of transportation. This topic is more relevant than ever, as COVID-19 changed the perspective on working from home.

Because of these arguments, determining the effects of smart mobility had to be limited to a pragmatic approach. When no proven quantitative effect is available, it was necessary to revert to (argued) estimations and ambition levels (Rigo, 2019). The Dutch knowledge institution on mobility policy published a report arguing that existing transport models are too complex to be relevant. Using simpler models and rules of thumb rather than large, complex models could benefit the unilaterality and applicability of the models. Many difficult calculations are not always the most efficient approach to yield comprehensive outcomes (Kennisinstituut voor Mobiliteitsbeleid (KiM), 2010).

Even when the effects of smart mobility could be estimated, using CBA as assessment method still yields some difficulties. The costs of smart mobility projects, which would be compared to the positive effects of the projects, have to be estimated differently as well. When planning a project on physical infrastructure, there are multiple aspects to keep in mind. Project managers look at the construction timeline, the investment costs, the maintenance needed and the effects. The construction timeline for physical infrastructure is normally built up of different phases. The investment costs are large at the start of the project, while maintenance costs are periodically equal until the next big reinvestment is needed. The effects of a physical infrastructure projects are observable as soon as the adaptations have been fully implemented, and are equal over periods.

Smart mobility follows a different investment and effect pattern. First of all, it is important to realize that both private and public parties are often investing in a smart mobility project, collaborating to achieve stable new business models. Compared to physical infrastructure projects, the cost structure of smart mobility measures is different; while investment costs are lower, maintenance costs are higher and should be seen as facilitating continuous updates of the technologies used. The time-frame for the effects of smart mobility measures is different as well; the effects of the measures do not start from the moment of implementation and are not constant over time, but can increase by adaptation, increasing user amounts and interaction with other measures (Rigo, 2019).

According to CPB (2018), the difference in investment and effect pattern does not necessarily have to be a problem to assess smart mobility applications by means of a CBA. It does, however, require a more detailed timeframe, for example an estimation of the costs and benefits for the upcoming years on a yearly basis. The tool could become more relevant by expanding it to include a CBA as well rather than only the positive effects. A first analysis of the most important valuation numbers for the standard indicators set in this study as well as an investigation on the current 'null' scenario is included in Appendix A4.

9.3.2 Commercial implementation

The current tool has been developed in Python, using the package Dash for dashboard creation. The aim of this dashboard, is however, to be easily usable, interactive and adaptable. In order to facilitate that, all coding has been written to dynamically communicate with the Excel sheets and hence, facilitate easy adaptation of the inputs. In this way, all content can be configured by those who do not have programming experience. Editing the Python framework and design itself would be the only part of the tool that is only accessible to someone with more coding expertise.

As the maintenance and updating of the tool are considered essential for the relevance of the tool, it is helpful to discuss the expectations on time and manpower to facilitate this. The data from waarstaatjegemeente.nl has to be updated at least once a year, but preferably twice a year. Downloading a new dataset takes little time. A more thorough check of the tool on its content would be needed at least once a year, but again preferably more often. That would include potential new applications and the relations thereto, a review on pilot results and effect studies. Both are expected to consist of sharing developed expertise (~5 hours), desk research on reports (~25 hours) and literature and implementation time (~10 hours).

On top of that, potentially expansion of the tool would be interesting to consider in the near future. Recommendations on that follow in section 10.2. This would require Witteveen+Bos to dedicate labour to the expansion.

Another important factor to keep in mind for commercial implementation is the accessibility of the tool to external parties. As explained, the tool is built in Dash and yields an interactive html file. At the moment, the dashboard can only be accessed locally. The tool has been designed to support experts and policy makers in the comprehension of smart mobility effects, and shall therefore become available to those groups as well. The accessibility could, however, be arranged in different ways.

The tool has been designed as assignment for engineering and advisory firm Witteveen+Bos. Their expertise in the field of mobility measures is complementary to the usage of the tool. The consulted policy makers, however, indicated to be interested in using the tool internally as well. Eventually, in conversations with experts of Witteveen+Bos, the conclusion was that it would be most suitable to put a limited version of the frontend of the tool on the website of Witteveen+Bos, including a disclaimer to refer to the firm when reusing the material. This approach is recommended to be followed when the tool is ready to be implemented.

The discussion on the accessibility of the tool also relates to knowledge sharing and the availability of information among different stakeholders, to collectively facilitate the transition to smart mobility. The conversations with various policy makers indicated the need for knowledge sharing among parties involved. At the moment, most data available is collected by analysing the results of pilots. However, as discussed with Respondent J, not all pilots require effect measurements; some are exploratory in nature, and focus more on the technological innovation rather than the exact measurement of effects. According to Respondent K, pilots are often funded on a project-basis, meaning that solely the project itself and the evaluation are funded. This could lead to an increasing amount of stakeholders questioning the relevance of pilots.

In order to facilitate scaling up after the pilot phase, knowledge transfer is necessary to start the operations in other parts of the country as well (van Winden & van den Buuse, 2017). For projects funded by the European Commission, the proposals must include plans for knowledge sharing as that is a prerequisite for replication (van Winden & van den Buuse, 2017). While the metropole region of Amsterdam works from a platform specifically set up for project on smart mobility, a similar collaboration is not common everywhere. These government policy makers all acknowledged the current lack of communal learning and knowledge sharing, but also reinforced the efforts taken by various parties to improve this.

The most important initiative is the Krachtenbundeling Smart Mobility, set up by the national government, provinces, G5, metropole and traffic regions (Overleg, 2019). However, it would be recommended to include commercial parties in this initiative as well, as most information is with them responsible for the research and development on smart mobility projects.

10 Conclusion and recommendations

This conclusion includes general findings of the study and the limitations of research. Following the conclusion, suggestions are made on further development of the tool as well as for future research.

10.1 Conclusion

The conclusion consists of the general findings of the study and reflects on the level of answering the subquestions and main research question. The general findings also disclose the most important limitations of research.

10.1.1 General findings

Developments such as population growth and climate change pressure the environment and require a change of the mobility system. Many technologies have been emerging to transform our cities to be smarter. In the mobility sector as well, data-driven technologies as well as more qualitative measures or platform changes are being introduced.

A first version of a tool that could quickly assess effectiveness and efficiency of smart mobility applications has been designed and developed for the present study. Some steps of the research have been finished, while other steps still need revision and expansion. Extensive conversations with policy makers were conducted to integrate their views into the design. The requirements were defined accurately, but could still be verified with the respondents.

The design takes a challenge-oriented approach to support policy makers in investigating potentially interesting smart mobility applications for their city. Based on that challenge, it suggests policy ambitions and smart mobility applications that could contribute to improving the mobility situation in a city. This approach was approved by the consulted policy makers and is therefore considered appropriate. On a more detailed level, the indicators used to determine the challenge were not yet complete.

By setting rules of thumb, determining the effects of smart mobility applications has been simplified. These rules of thumb make it possible to convert some of the existing pilot and measurement data to similar units. However, the list of rules of thumb is not sufficiently completed to convert all information. That would need an elaboration on the list or adding more indicators to the effects.

The tool answers to the user needs identified to take a challenge-oriented approach, and ensure the relevance for large as well as smaller cities. In this way, the tool is rather useful as initiation of a discussion on the possibilities with smart mobility in a city. A comparison of smart mobility applications based on their effects on different factors is not what the tool should be expected to do; the availability of information on effects and costs is too limited to provide truthful insights.

10.1.2 Answer subquestions

Four subquestions were formulated, which have been answered throughout the study. This section will answer all the subquestions and review the level of integration of these questions in the study.

The first subquestion is *What are the user requirements of the tool?*. The tool is developed to contribute to mobility policy in Dutch municipalities, therefore, it is important to consult policy makers on their needs and requirements for such a tool. Both experts and policy makers were consulted, first, on their views on smart mobility, and secondly, on the potential of a tool that would assess smart mobility applications. The user requirements were collected through these informal interviews and transformed into functional and non-functional requirements. These requirements served as the basis for the conceptual design of the tool in this study.

The second subquestion is *Which smart mobility applications should be included in the tool (and at which level of detail)?*. Smart mobility is a term that is interpreted differently in literature, by experts and by policy makers. Which applications to include was therefore an important question. The literature section reviewed the variety of smart mobility technologies, but also, perhaps even more important, the different ways of categorizing these technologies. Although some policy makers indicated that their municipality regarded smart mobility as only those applications that are very technical, for this study, the decision was made to interpret the term quite broadly. In this way, all applications that could be considered smart mobility applications were included and could be assessed by the developed model. In order to account for the difference in technological character among the applications, the tools were divided into five categories, with multiple subcategories. The final list of applications and their categorization can be found in Appendix A2.2.

The third subquestion was formulated as *What are the effects of existing and future smart mobility applications?*. This question regards determining the effects of applications, which was the main objective of the third unit of the tool. The unit design for this unit argued that it is possible to determine the effects of smart mobility applications by using standard indicators. The present study set 6 different indicators within four different themes, that are relevant factors to assess when implementing smart mobility. To get to the value of these indicators for each application, rules of thumb were formulated, based on combining existing pilot results, factsheets and research papers. These rules of thumb enable the conversion from expected effects in some unit to the unit of the standard indicator. This means, however, that some information is needed to calculate the effects of an application on all the standard indicators. For existing smart mobility applications, this would not be a problem, but for future smart mobility applications, it could become a bit more difficult. The integration of the tool with regular transport models to simulate the effects could be a solution here, but depends on the innovation of those transport models to rightfully model the dynamics of smart mobility solutions, as explained in 9.3.2.

The last subquestion is *How do experts and policy makers assess the tool?*. The tool has been validated with two different policy makers, who both considered the tool to have potential to be a valuable contribution to policy making in the mobility sector. It would, however, still need revision and expansion to be ready for implementation. One of the recommendations from the user tests was to include more background information, e.g. sources, calculations and factsheets, to provide the user of the tool with a more substantive analysis, rather than only showing the results. Another important recommendation was to include not only positive effects in the tool but add potential negative impact of a smart mobility application as well.

Although these subquestions may not seem to directly comprise the study and main research question, they could easily be connected to the modules of the design. The first subquestion regards the user requirements; one of the most important and perhaps surprising user requirement was the focus on the challenge of a city regarding their mobility policy, rather than focusing solely on the impact of effects. This user requirement was incorporated in the first unit by defining the city profile. The second subquestion required the definition of the list of applications, which was the basis for the second unit, suggesting suitable applications for a mobility policy ambition. As already said, the third subquestion concerns the design of the third unit. The fourth subquestion focused on the validation of the tool with the experts and policy makers, which was an important part of the evaluation of the tool in this study.

10.1.3 Answer main research question

The main research question formulated in section 1.2 was:

What is a useful tool for policymakers to quickly assess effectiveness and efficiency of smart mobility applications?

Starting with consulting experts and literature, the design possibilities for a tool assessing smart mobility solutions were explored. In order to effectively assess smart mobility solutions, the tool shall take a challenge-oriented approach. This means that the tool shall not focus primarily on the variety of smart mobility applications available, but shall rather focus on the mobility challenge a city faces, and try to complement that challenge by assessing smart mobility solutions that would contribute to that challenge. In this way, smart mobility becomes interesting not only for large municipalities, but also for smaller ones, with less budget available for piloting and innovation.

The research question does not only concern effectivity, but also efficiency. This study finds that it would be most efficient to have a tool serve as a quick scan, rather than building a complex model that attempts to capture the versatility of smart mobility. This has been described in detail in section 9.3.2. The tool would have to be deployed by experts to facilitate an initial discussion between the expert and the client, and the results of the tool would be part of a more integral advice.

10.2 Recommendations

Based on the discussion, conclusion and limitations, recommendations can be done on both the tool as the research behind it. Section 10.2.1 describes the suggestions for further development of the tool, directed mostly at Witteveen+Bos. Section 10.2.2 concerns recommendations for future academic research.

10.2.1 Suggestions for further development of tool

The present study can be considered an exploration of a design for a tool that provides insight in the effects of smart mobility. Although the tool already functions and does not provide any errors, it shall not be considered ready for implementation. In addition to further verifying the content of the tool with users and experts within the sector, this section includes practical suggestions for further development of the tool.

1. Extra units

Suggestions for this would be to include for example a unit on best practices, with details on existing pilots and implementations of solutions. As suggested by Respondents I, K and L, some information on best practices could be useful to link municipalities to each other and encourage knowledge sharing. Hence, it could be considered to include a tab that visualizes the pilots throughout the country as well as contact information of the party responsible for the pilot. Another unit that could be added would be one that guides a Cost-Benefit Analysis for an application. Preferably this would be as customizable as possible, and hence specific to each city. A first step could be to include existing CBA studies as exemplary information.

2. Review indicators for the city profile

The current indicators used for the city profile only consider three of the five themes defined. The main reason for this was limited availability of variables on the database used. Especially an indicator on Efficient spatial use & infrastructure would benefit the information level of the tool. As explained earlier, a sensible indicator would be the amount of cars per square kilometre. This information is not available on waarstaatjegemeente.nl, but could be subtracted from CBS. There are two indicators for Comfort, health, safety and ethics, but both only relate to safety. There are two indicators for Sustainability & energy, and one for Efficient mobility & accessibility. The indicators used for Sustainability & energy can be considered sufficient, as they capture the most important pollution measurements. The indicator on Efficient mobility & accessibility is now set to total average distance to the train, but could be replaced by one of the other accessibility indicators in the database, e.g. average distance to the hospital. The recommendation would be to look into other databases that may contain more information on mobility on a city level, so the list of indicators for the city profile can be improved.

3. Review the indicators for the effects

First of all, the effects currently used relate to the theme but do not fully capture it. For some themes, it is therefore necessary to add more indicators to fully capture the theme. For example, for Comfort, health, safety and ethics, the amount of traffic accidents and pollution are used as an indicator. This indicators, however, merely relates to safety and health, and not to comfort and ethics. Secondly, at the moment, the effects unit focuses on the positive effects of smart mobility applications. As Respondent H rightfully pointed out, smart mobility could also have negative effects. Some examples of negative effects were mentioned in section 8.2. Including these negative effects would benefit the comparability of different smart mobility.

4. Same units for the effects and the city profile

Different indicators are used for the city profile and for the effects. In order to fully integrate the objectives of the different units, it would be best to synchronize the indicators for these two units. That means, it is recommended to use the same indicators for the city profile and the effects. In that way, the policy maker is guided even more in exploring the smart mobility applications that could contribute to solving the mobility challenge in the municipality.

5. Add factsheets or calculations

At the moment, the front-end of the tool only shows the outcomes of all transformations and calculations that were executed on the back-end. To make the tool and its output more intuitive and helpful, calculation documents or factsheets could be added to the units through a download link. By doing this, the user of the tool is provided with additional information in the form of calculation sheets or factsheets that can be downloaded.

6. Provide follow up options

As explained earlier, a situation-specific estimation of effects is difficult. A rough estimation or quick scan could be added in the tool, but a more thorough estimation would have to be studied in the context of the specific municipality. For the users that are interested in implementing smart mobility in their municipality, the option could be added to request an intake meeting with one of the engineers at Witteveen+Bos and discuss the options for a more detailed study.

7. Expand the city profile

More variables could be added, to capture the themes even better. On top of that, the real values could be added to the unit as well, on top of the noramlized scores. That would mean that, for example for Amsterdam, it would not only include the normalized score of 0.9121622 on the variable CO2-uitstoot autoverkeer exclusief auto(snel)wegen , but also the actual value of 4900 tonnes per 1000 inhabitants. Lastly, it would be recommended to change the dropdown to select a municipality into a checkbox, so municipalities can also be compared among each other.

8. Review the challenge in the first unit

At the moment, the first unit defines the challenge as one of the themes. This is determined by evaluating which indicator has the lowest score, and then, seeing which theme that indicator belongs to. This means that at the moment, ambitions are suggested for a challenge on quite a broad level, meaning that ambitions relating to health could be suggested when safety is a challenge - as both are included in the theme Comfort, health, safety and ethics. It could be considered to define a challenge on a more specific level. The challenge could also be the indicator with the lowest score; in this case, however, the ambitions would also have to be related to the variables instead of the themes. This would therefore require a change in both the definition of the challenge and the relations between the ambitions and themes.

9. Increase the amount of applications in the effects unit

At the moment, the amount of applications in the third unit, which is the unit on effects, is limited to seven applications. This was due to both the limited amount of data available and the limited added value for this study to add more applications, as explained in earlier sections. To make the tool more complete and hence, more relevant, the third unit shall be expanded to include the effects of more applications than only these seven.

10. Improve the rules of thumb

At the moment, the rules of thumb are very much simplified. At the moment, these rules have only been verified with a number of sources. As smart mobility is currently being piloted by different parties, more information on the effects will become available to verify the rules of thumb. On top of verifying the rules, they may be improved by slightly improving complexity of the system and adding more independent variables.

11. Automate conversion to indicators

The reference sheet at the moment only takes values for the set indicators. That means that conversions to those units have to be executed by hand. This could be made easier by providing automatic conversion from a larger amount of possible variables to the indicators. An extra Excel sheet could be added for this in the reference sheet.

10.2.2 Recommendations for future research

The current study has developed a concept to quantify the effects of smart mobility applications. Both measuring and testing smart mobility has proven difficult in practice and in research. More specific recommendations for future scientific research to improve this are done in this section.

1. Effect measurements of smart mobility implementation

In general, it can be stated that knowledge on the effects of smart mobility measures is limited. In order to improve the knowledge base, pilots and exploratory effect studies are being executed. On top of that, (scientific) research on measuring and modelling effects would be relevant (Centraal Planbureau, 2018). Research could for example be conducted on technologies to innovate transport models, and in this way, make them suitable to simulate smart mobility solutions as well. It could also investigate the feasibility of using rules of thumb to generalize effects of smart mobility for a variety of applications.

2. Difference smart mobility and normal transport projects

Normally, the feasibility of infrastructure projects is evaluated through a Cost-Benefit Analysis. Policy makers assess CBA as a very useful tool to compare different options and choose the most suitable one. For smart mobility, however, executing a CBA is more difficult than for a regular project. Additional research on the applicability of CBA to smart mobility projects could provide more insight in the relevant and non-relevant aspects of this analysis method, and perhaps suggest a guideline for usage of this method on smart mobility projects. An initial analysis of a monetization scheme for the calculated effects is included in Appendix A2.4. This Appendix also includes a suggestion on the valuation numbers to use when monetarizing the effects by the themes set in this study. Lastly, the Appendix describes the current societal costs on the themes, indicating the order of magnitude benefits could apply to.

3. Effectivity of pilots

As discussed in 9.3.2, the effectivity of pilots to boost smart mobility has been questioned by stakeholders. More research would be suggested on the effectivity of pilots in the past, in the mobility sector as well as other sectors. An interesting approach could be to set conditions on the process of a pilot and the follow-up to ensure its effectivity.

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Appendix

A1 Interviews

Interviews were conducted on smart mobility in general (A1.1), the user requirements for the tool (A1.2) and the validation of the developed tool (A1.3). In A1.4 the notes on the interviews with the respondents can be found.

A1.1 Policy ambitions

The interview questions are posed in Dutch, as all consulted experts are Dutch-speaking. Translations of all questions are included.

1. Hoe zou je smart mobility omschrijven? - How would you define smart mobility?
2. Aan wat voor toepassingen denk je bij smart mobility? - What kind of solutions/applications do you consider to be smart mobility solutions?
3. Welke effecten kunnen smart mobility toepassingen hebben en welke effecten zouden zij moeten bereiken? - Which effects could smart mobility solutions have and which effects should they have?
4. Welke effecten vind jij het belangrijkst? - Which effects are most important to you?
5. Welke effecten zijn juist onwenselijk? - Which are undesirable side effects of smart mobility applications?
6. Welke smart mobility toepassingen lijken het meest geschikt? - Which smart mobility solutions do you consider most useful?
7. Waarom zou je smart mobility toepassingen willen implementeren? - Why would you want to implement smart mobility solutions?
8. Wat houd je momenteel tegen om smart mobility toepassingen te implementeren? - What prevents you from implementing smart mobility solutions at the moment?

A1.2 User requirements

Prior to posing the questions below, the context of the problem and tool was explained. The consulted experts and policy makers know that the idea is to design a tool that connects smart mobility solutions to their effects.

9. Wat zijn de voornaamste problemen (of uitdagingen) met smart mobility voor beleidsmakers? - What are the main issues with Smart Mobility for policy makers?
10. Hoe zou een tool de besluitvorming kunnen helpen voor smart mobility? - How could a tool support decision making for Smart Mobility?

11. Wat zou deze tool moeten kunnen om effectief te zijn? - What should this tool offer in order to be effective?
12. In welke vorm zou je deze tool het liefst zien? - In what form would you prefer to see the tool?
13. Welke input zou relevant en beschikbaar zijn voor een tool? - Which input for such a tool is useful and available?
14. Hoe belangrijk is het om de effecten uit te drukken in financiële waarden? - How important is it to express the effects in financial values?
15. Hoe belangrijk is het om effecten met elkaar te kunnen vergelijken? - How important is it to be able to compare effects among each other?
16. Hoe belangrjik is het om smart mobility oplossingen onderling te kunnen vergelijken? - How important is it to be able to compare solutions among each other?
17. Op welk detailniveau zou je effecten willen kunnen analyseren (per weg, per buurt, per stad)? - At which level of detail would you like to assess effects (per road, per neighborhood, per city)?
18. Wie zou er toegang moeten hebben tot de tool? - Who should have access to the tool?

A1.3 User test

1. Hoe zou je je eerste indruk van de tool omschrijven? - How would you describe your first impression of the tool?
2. Wat beviel je het beste aan deze tool? - What did you like the most about using this tool?
3. Wat beviel je het minst aan deze tool? - What did you like the least?
4. Is er iets wat je verbaasde aan het gebruik van de tool? - What, if anything, surprised you about the experience?
5. Is er iets wat je frustreerde aan het gebruik van de tool? - What, if anything, caused you frustration?
6. Is de tool intuïtief in gebruik? - Is using the tool intuitive?
7. Past deze tool binnen jullie mobiliteitsvisie? - Does the tool fit your mobility vision?
8. Wat moet er nog veranderd worden om van meer waarde te zijn? - What should be changed in the tool to be of larger value?
9. Zou je de tool aanbevelen aan collega's of andere gemeenten? - Would you recommend this tool to colleagues or other municipalities?
10. Wanneer en hoe vaak zou je de tool gebruiken? - When and how frequently would you use this tool?

A1.4 Interview notes

All interviews were conducted in Dutch, hence the notes are in Dutch as well. These notes are a combination of the questions posed from A1.1 and A1.2. Line numbers are included to refer to the interviews in the main text.

Respondent C - 25/02/2020

Kijk naar het onderzoek voor Den Haag Innovation Center

Grote steden boksen steeds meer tegen elkaar op, in plaats van dat smart mobility verspreid over Nederland wordt toegepast

Misschien kan je beter regio's consulteren dan (uitsluitend) gemeenten

Mobiliteit wordt vaak verkeerd om aangepast, waardoor gewoontes al aangeleerd zijn. Buslijnen worden bijvoorbeeld pas later aangelegd in plaats van direct bij de bouw van een woonwijk.

Respondent E - 26/02/2020

Collega G heeft de fietsmonitor gebouwd. Deze geeft op basis van fietsdata inzicht in gebruik/gedrag. Dit is op basis van een raamovereenkomst met de gemeente Haarlem.

Voor de fietsmonitor wordt gebruik gemaakt van een herkomst- en bestemmingsdatabase. Het principe hiervoor is van data naar advies. Dus data gebruiken als basis voor je advies.

Simpelweg werkt de fietsmonitor als volgt: Het gebruikt een programmaatje om de breedte van fietspaden te bepalen. Dan wordt de gemiddelde en maximale capaciteit berekend van elk fietspad. Dat wordt vergeleken met herkomst-bestemming data. De vergelijking wordt gevisualiseerd en gepresenteerd aan de gemeente Haarlem.

Het waarderen van effecten is lastig. Dit heeft namelijk ook te maken met emotie. Je kan daarom beter beginnen met relatieve waarden.

Wat is de kwaliteit van de data die je gebruikt? Data an sich is niet genoeg, er is ook kennis nodig. Wat is op welke locatie belangrijk?

De communicatieve kant is ook belangrijk. Je moet zorgen dat anderen het ook snappen.

Gemeenteambtenaren kennen zelf hun stad het beste. Via een tool kan W+B ze een raamwerk bieden.

Deze tool zou inzicht moeten geven hoe gemeenten ervoor staan op het gebied van smart mobility per effect. W+B en gemeenten moeten samen beslissen wat smart mobility nou precies is.

Ook goed om te gaan praten met collega's die zich bezighouden met de fietsmonitor en dataverwerking

Hoe verkopen we een dergelijke tool aan gemeenten? De basis is het aller belangrijkst. In eerste instantie alleen een opstart maken, net goed genoeg om te laten zien. Dat moet het eerste inzicht bieden wat je iemand wil geven. Vervolgens op basis van commentaar de eerste opstart verder doorontwikkelen. Hiervoor heb je niet meer dan 3 gemeenten nodig, kwaliteit boven kwantiteit.

Kijk ook naar de structuurvisie van Haarlem: op welke manier komt smart mobility daarin terug?

Respondent G - 01/04/2020

Specificeer effecten aan de hand van rule of thumb, bijvoorbeeld verkeersgedrag.

Haarlem wil beter inzicht in fietsstromen in de gemeente, daarom is de fietsmonitor gebouwd.

Kijk ook naar het verkeersmodel voor Woerden, waarin de effecten van stedelijke ontwikkelingen en mobiliteitsmaatregelen gemodelleerd zijn. Dit was voor project 103130.

Collega kan meer vertellen voer vernieuwende mobiliteit.

Respondent H - 17/03/2020

H wil graag het resultaat van de tool zien.

De gemeente Den Haag heeft een mobiliteitstransitiebrief opgesteld, waarin onder andere hun mobiliteitsambities genoemd worden.

De gedetailleerdere mobiliteitsvisie komt eind april uit.

Respondent I - 18/03/2020

Vragen die gemeenten zichzelf stellen:

Waar begin je met implementatie van smart mobility toepassingen?

Wat gebeurt er in andere gemeentes?

Zou relevant zijn als de tool op deze vragen in zou spelen.

Respondent J - 20/03/2020

De kengetallen (of indicatoren) van smart mobility zijn vaak onbekend. Het is ook heel erg afhankelijk van menselijk gedrag. Dat maakt het lastig te vertalen naar een simpele tool.

Smart mobility is bij I&W als volgt georganiseerd:

- Beleid, uitvoering (RWS)
- Afdeling smart mobility bij wegen en verkeer
- Drie mobiliteitsdoelstellingen: Bereikbaarheid, veiligheid, duurzaamheid
- Ze houden zich bezig met twee ‘hoeken’, namelijk de kansen om aan die doelstellingen bij te dragen en de implementatie.
- Er is een hoop onzeker over smart mobility: effecten op systeem niveau
- Ook houden ze zich bezig met: toelatingskaders aanpassen, datasystem aanpakken (randvoorwaarden, verantwoorde implementatie)

- 4 actielijnen: verantwoorde toelating/certificering, inrichten van datasysteem/doorvertalen internationale cybersecurity eisen, infrastructuur/wegbeheer, efficiënte samenwerking met partners
- Vooral relevant voor masterscriptie is de 3e actielijn: MIRT verkenning, MKBA kunnen smart mobility maatregelen niet echt meenemen in investeringskeuzes
- Tot nu toe opereert verkeersbeleid heel lokaal, bijvoorbeeld om een knelpunt op te lossen. Smart mobility werkt niet lokaal.

De projecten die I&W draait op het gebied van smart mobility gaan vooral over uitvoering, soms over beleid. Er is bijvoorbeeld een samenwerking tussen de auto-industrie en het ministerie betreffende data over verkeersveiligheid. Ook worden er 7 MaaS pilots gedraaid.

Hoe beslis je wat een pilot wordt? MaaS is evident, gewoon een transitie die sowieso gaat plaatsvinden. Betreft het verknopen van modaliteiten. De effecten en implicaties zijn nog niet duidelijk. Voor zelfrijdend vervoer is de technologische transitie onvermijdelijk. De potentie is groot en de industrie is er al mee bezig. De pilots daarvoor zijn ofwel onderzoekend van aard, ofwel om de effecten te testen.

Eventueel nog contact opnemen met collega van I&W over kennisontwikkeling. Werkt veel samen met studenten van de TU Delft op het gebied van onderzoek naar de impact van ADAS.

Er wordt te weinig integraal afgewogen tegen andere alternatieven. Ook de effecten van maatregelen zijn te weinig bekend. Er zijn veel afhankelijkheden en menselijk gedrag is onvoorspelbaar.

Beste insteek zou kunnen zijn per type opgave: welke smart toepassingen dragen bij aan het oplossen van die opgave? Bij opgaven kan je denken aan bijvoorbeeld wegwerkzaamheden of luchtkwaliteit.

Bij lokale overheden is het vaak een probleem dat de data niet op orde is. Dat heeft niet met één losse actie te maken.

Beide lijnen (profiel en effecten) zijn nodig voor een goed inzicht. De eerste is wel eerst nodig, en de tweede komt daarbij. Het ministerie wil graag in samenwerking met decentrale overheden opgaven in kaart brengen.

De beschikbare info over effectiviteit is momenteel aan de hand van de eerste pilots die gedraaid zijn. In proeven en pilots is er vooral aandacht voor het technische aspect en niet voor aantonen van geclaimde effecten. Dit is iets waar I&W tegenaan loopt. Ze proberen dit op te lossen door kennisvragen mee te geven aan de projecten.

Als je effecten uitdrukt in bereikbaarheid, veiligheid en leefbaarheid, blijft het abstractieniveau vaak te hoog.

Smart mobility kan gedragsverandering makkelijker maken (bijvoorbeeld via een mobiele applicatie voor deelmobiliteit), dan heb je een effect.

Aan te raden om te werken op opgaveniveau in plaats van doelenniveau. Ook kan je beter kijken naar de oorzaak van ongevallen in plaats van het aantal.

Andere bestaande modellen om naar te kijken:

- Smartwayz tool
- TNO city model (vraag Jacqueline)
- SimSmartMobility

Respondent K - 08/04/2020

De toekomstradar heeft hetzelfde uitgangspunt als de tool die ik voor ogen heb.

K is thematrekker bij het smart mobility platform van MRA voor digitale en fysieke infrastructuur. Afgelopen jaar hebben ze binnen dit thema de toekomstradar ontwikkeld.

Vanuit MRA is er een smart mobility platform opgezet, maar binnen het platform is een groot onderscheid tussen koplopers en volgers.

De toekomstradar is begonnen vanuit het idee om Smart Mobility in te zetten om verkeersstromen te optimaliseren, met een Amsterdamse invalshoek. Op deze manier wilden ze verkeersmanagers helpen voor te bereiden op de toekomst.

De Toekomstradar is een soort Wikipedia die antwoord geeft op vragen. Momenteel bevat het een drietal assets om mee te beginnen, de bedoeling is om nog uit te breiden. Ze maken onderscheid tussen de toepassingen die nu al beschikbaar zijn en die later verwacht worden. Ook maken ze onderscheid tussen uitvoering en beleidsmatig.

Ze komen er nu achter dat de Toekomstradar misschien wel geschikter is voor beleidsmedewerkers van ‘volgers’ (steden die niet pionier zijn met betrekking tot smart mobility) dan voor verkeersmanagers.

Wat K aanspreekt aan mijn idee is het uitgaan van de opgave. Dat doen ze bij MRA ook als ze met gemeenten in gesprek gaan. Op die manier breng je ze naar een oplossing in plaats van dat je ze ‘een luchtkasteel’ voorschotelt.

Gemeente Gooise Meren gaf bijvoorbeeld aan Smart Mobility iets te vinden voor de grote stad. Dan is het beter eerst naar de mobiliteitsopgaven van de gemeente te kijken en vervolgens aan te tonen dat Smart Mobility een middel kan zijn om dat op te lossen.

Wordt de tool openbaar? Dit is natuurlijk ook een commerciële afweging. Hebben de gebruikers van de tool nog een expert nodig om vervolgens aan de slag te kunnen?

Het effectueren van smart mobility toepassingen kan ook gedaan worden aan de hand van losse aanvragen bij adviesbureaus en leveranciers per toepassing.

De provincie Noord Holland heeft een toolbox ontwikkeld over smart mobility oplossingen in grootonderhoudsprojecten. Die geeft weer welke oplossingen er zijn.

K is ook enthousiast over het invoegen van best practices. Relaties leggen tussen gemeenten is ook wat MRA nastreeft. Het is niet alleen interessant om te zien waar ze ook vergelijkbare dingen doen; de ene gemeente kan bijvoorbeeld ook beperken wat de andere wil stimuleren, dit zien we op het gebied van deelmobiliteit als we Amsterdam en Amstelveen vergelijken.

Adviseurs worden steeds opener over hun ervaringen. Leren van elkaar is essentieel, zowel over de implementatie (hoe) als over de effecten (is het het waard)

Pilots worden vaak projectmatig gefinancierd. Dat betekent dat er geld is voor de proef en de evaluatie. Daarna komt het vaak stil te liggen. Dat is de reden waarom de markt pilot-moe is. Pilots leveren op deze manier niet echt iets op.

2 jaar geleden is het initiatief Krachtenbundeling in Nederland gestart om fragmentatie tegen te gaan. Ze proberen pilots aan elkaar te koppelen en ervaringen te delen. Het is een samenwerking tussen het Rijk, de twaalf provincies, G5, de metropoolregio's en de vervoerregio's.

Ook commerciële partijen zijn betrokken bij de kennisontwikkeling rondom smart mobility. Zo heb je de zeven MaaS pilots van het ministerie van I&W, die zich betrekken op verschillende opgaven. Voor deze pilots is uitvraag gedaan aan de markt, en ongeveer 24 partijen hebben daarop geschreven. Alle zeven pilots zijn nu aanbesteed. De overheid kan de mobiliteitstransitie bevorderen, maar de markt moet zorgen dat het tot uitvoering komt. Marktpartijen werken samen omdat allen hun eigen specialisme hebben. De mobiliteitstransitie is zo groot en kent zoveel aspecten, dat er geen spelers zijn die het allemaal kunnen. De materie dwingt zo de markt tot samenwerking.

De beperkte kennisdeling geldt ook voor semi-overheidspartijen. NS doet bijvoorbeeld heel ingewikkeld over datadelen.

Overheden moeten zoeken naar hun rol in innovaties, bijvoorbeeld op het gebied van deelplatformen. Met airbnb waren overheden heel reactief. Bij deelfietsen en stepjes waren ze het wel voor, door het niet toe te staan tot het moment dat er regulering voor was.

De Toekomstradar is al wel online maar nog niet volledig. Daarnaast moet de website beheerd worden. Komende tijd gaan ze kijken naar scopeverruiming. De toolbox van de provincie Noord Holland zou onderdeel kunnen worden van Toekomstradar. Ook zou Martin ontwikkelingen door het platform bijvoorbeeld willen aanbieden op Toekomstradar.

Voor de toolbox van de pronvicie Noord Holland geldt ook: Als er geen expert opinie toevoegt, hoe waardevol zijn de oplossingen dan?

Hoe onderhoudt je zo’n dashboard? Je moet rekening houden met constant nieuwe ontwikkelingen, maar foutieve informatie is misschien wel schadelijker. Het onderhoud kost tijd en geld. Het beheer moet goed op orde om van waarde te zijn.

Niet alleen de data zelf maar ook de interpretatie van de data is aan ontwikkelingen onderhevig.

Respondent L 02/04/2020

Het is te veel werk om opties in te bouwen voor alle steden. Ga je specifieke steden kiezen of per categorie aan steden werken (metropolitaan, kleine steden?)

L is programmamanager smart mobility voor metropoolregio Amsterdam. Vanuit die rol werkt ze aan het platform smart mobility. Dit platform heeft tot doel te helpen in de mobiliteitstransitie, wat ze ongeveer gelijk stellen aan smart mobility. Ze willen kansrijke toepassingen aanjagen zolang ze bijdragen aan beleidsdoelstellingen. Smart Mobility is niet een doel op zich.

De drie doelen van het platform zijn aanjagen, kennis vergaren en delen, en partners verbinden. Ze vinden het belangrijk om leerervaringen te delen, zodat het wiel niet telkens opnieuw uitgevonden hoeft te worden.

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Ze werken met de volgende thema’s: digitale en fysieke infrastructuur (slimme wegen, iVRI), data, mobility as a service, logistiek, gebiedsontwikkeling.

De koplopers op deze thema’s zijn de gemeente Amsterdam, de provincie en de vervoerregio. Hiervoor heb je mensen nodig die zien dat het kansen biedt. De provincie is vooral bezig met infrastructuur, de vervoerregio met de openbaar vervoer concessies en MaaS, de gemeente in brede zin met logistiek, en ook met MaaS.

Onder de zoekende gemeenten kan je bijvoorbeeld scharen: Zaanstad, Haarlemmermeer, Haarlem, Gooi & Vechtstreek. Zij proberen ze te helpen door vanuit de opgave voor die gemeente te denken, niet direct vanuit de smart mobility toepassing.

MRA Amsterdam werkt vanuit de volgende ambities: veiligheid, duurzaamheid, leefbaarheid, bereikbaarheid.

Het gevaar bij het ontwerpen van een tool is dat het een leuk boekje wordt wat verder weinig toe te passen is. Zelf hebben ze bijvoorbeeld de leidraad gebiedsontwikkeling en smart mobility ontwikkeld.

Ook L is het er mee eens dat een tool die praktischer georiënteerd is, zoals een dashboard, relevanter zou zijn. Deze zou ook een link kunnen omvatten naar de best practices voor een bepaalde toepassing. Zo kan je mensen verder helpen, doorverwijzen.

Er zijn veel effectmetingen gedaan bij het MRA programma elektrisch en de praktijkproef Amsterdam. Deze gegevens blijven wel intern. Talking Traffic van I&W is ook een mooi voorbeeld, maar daar zijn geen metingen van.

Het is goed om onderscheid te maken tussen bijvoorbeeld kleine, middelgrote en grote steden. Wat is de problematiek die je daar ziet? In grote steden hebben ze vaak te maken met drukte in de stad, in de metropoolregio met het managen van bezoekersstromen, druk op de openbare ruimte, het draaiend houden van het netwerk, en de toegankelijk houden van het landelijk gebied.

Vervolgens kan je kijken waar smart mobility toepassingen effect op hebben, maar dit kan je beter kwalitatief houden. Daarna kan je kijken waar deze toepassingen al worden toegepast, identificeer best practices en link daar naar door.

A2 Lists of most important concepts

The most important concepts for the study are themes (A2.1), applications (A2.2) and ambitions (A2.3). These concepts can be related to each other. Relations between ambitions and themes are listed in A2.4, and ambitions and applications are cross-referenced in A2.5.

A2.1 Themes

THEMES
Efficient spatial use & infrastructure
Sustainability & energy
Efficient mobility & accessibility
Comfort, health, safety & ethics
Knowledge & data collection

A2.2 Applications

APPLICATIONS	CATEGORY	SUBCATEGORY
Application sharing rides	Data tool	consumer applications
Ordering MaaS	Data tool	consumer applications
Real time congestion avoidance	Data tool	consumer applications
Real time crowd at destinations	Data tool	consumer applications
Realtime information supply	Data tool	consumer applications
Roadworks on route planning	Data tool	consumer applications
Floating car data	Data tool	data collection
Geographic information systems	Data tool	data collection
Sensor movement/people/vehicles	Data tool	data collection
Sensor temp/noise/air pollution	Data tool	data collection
Automatic Incident Detection - AID	Data tool	driving assistance
Parking navigation system	Data tool	driving assistance
Systems for speed control and management	Data tool	driving assistance
Bicycle highway	Infrastructure	lanes
Bus rapid transport	Infrastructure	lanes
Tidal flow	Infrastructure	lanes
Charging stations electric cars	Infrastructure	parking & charging
Park and ride	Infrastructure	parking & charging
Intelligent infrastructure	Infrastructure	surroundings
Street lighting by sensor	Infrastructure	surroundings
Car free zones	Infrastructure	zones
Environmental zone	Infrastructure	zones
Shared space	Infrastructure	zones
Adapt schedules schools/public institutions	Policy measure	restructuring
Rethink spatial planning living/working/shopping	Policy measure	restructuring
Peak hour driving	Policy measure	subsidy
Peak hour public transport	Policy measure	subsidy
Stimulate working from home	Policy measure	subsidy
Subsidy autonomous driving	Policy measure	subsidy
Kilometre-based charge	Policy measure	tax
DRIP - Dynamic Route Information Panels	Traffic management	
ITS - intelligent transport systems	Traffic management	

iVRI - intelligent traffic lights	Traffic management	
Ramp metering	Traffic management	
Tidal flow	Traffic management	
Autonomous shuttles	Vehicle use	sharing
Shared autonomous cars	Vehicle use	sharing
Shared bicycle	Vehicle use	sharing
Shared cars	Vehicle use	sharing
Shared electrical bicycle	Vehicle use	sharing
Shared electrical cars	Vehicle use	sharing
Shared scooter	Vehicle use	sharing

A2.3 Ambitions

AMBITIONS
Become CO2 neutral city
Decrease amount of accidents
Efficient maintenance (road/infra/vehicles)
Encourage cycling
Encourage walking
Event transport management
Facilitate electric driving
Gain insight in traffic flows
Improve area access
Improve bicycle/pedestrian crossing over water/highway
Improve passenger experience
Improve residents' health
Increase road safety
Innovate/exemplary function
Make city centre accessible
Make mobility accessible to vulnerable groups
Make public transport more robust/reliable/user-friendly
Make village/rural area accessible, decrease travel time
Rearrange roads/streets more efficiently
Reduce emissions (incl CO2)
Save/earn money
Shorten traffic jams (highway/national roads)
Shorten travel time
Solve parking shortage (cars)
Control tourist flows (attract/discourage)
Control traffic demand
Temporarily redirect traffic
Understanding traffic nuisance

A2.4 Relations between ambitions and themes

AMBITIONS	**Efficient spatial use & infrastructure**	**Sustainability & energy**	**Efficient mobility & accessibility**	**Comfort, health, safety & ethics**	**Knowledge & data collection**
Become CO2 neutral city		X			
Decrease amount of accidents				X	
Efficient maintenance (road/infra/vehicles)	X				
Encourage cycling	X	X		X	

Encourage walking	X	X		X	
Event transport management			X		
Facilitate electric driving		X			
Gain insight in traffic flows					X
Improve area access			X		
Improve bicycle/pedestrian crossing over water/highway	X				
Improve passenger experience				X	X
Improve residents' health				X	
Increase road safety				X	
Innovate/examplary function	X	X	X	X	X
Make city centre accessible	X		X		
Make mobility accessible to vulnerable groups				X	
Make public transport more robust/reliable/user-friendly			X		
Make village/rural area accessible, decrease travel time			X	X	
Rearrange roads/streets more efficiently	X				
Reduce emissions (incl CO2)		X		X	
Save/earn money	X		X		
Shorten traffic jams (highway/national roads)	X				
Shorten travel time				X	
Solve parking shortage (cars)	X				
Control tourist flows (attract/decourage)			X		X
Control traffic demand	X				
Temporarily redirect traffic			X		
Understanding traffic nuisance					X
Amount of ambitions in theme	11	6	9	11	5

A2.5 Relations between ambitions and applications

Ambition	**Application 1**	**Application 2**	**Application 3**	**Application 4**
Become CO2 neutral city	Charging stations electrical cars	Environmental zone	Kilometre-based charge	Stimulate working from home
Decrease amount of accidents	Automatic Incident Detection - AID	Systems for speed control and management	Autonomous shuttles	ITS - intelligent transport systems
Efficient maintenance (road/infra/vehicles)	Roadworks on route planning	DRIP - Dynamic Route Information Panels	Realtime information supply	
Encourage cycling	Bicycle highway	Shared bicycle	Car free zones	
Encourage walking	Car free zones	Shared space	Rethink spatial planning living/working/shopping	
Event transport management	Real time congestion avoidance	Automatic Incident Detection - AID	Roadworks on route planning	Realtime information supply
Facilitate electric driving	Charging stations electrical cars	Environmental zone	Shared electrical cars	
Gain insight in traffic flows	Floating car data	Real time congestion avoidance	Geographic information systems	

Improve area access	Rethink spatial planning living/working/shopping	Car free zones	Shared space	
Improve bicycle/pedestrian crossing over water/highway	iVRI - intelligent traffic lights	Shared electrical bicycle	Shared bicycle	Bicycle highway
Improve passenger experience	Application sharing rides	Roadworks on route planning	Real time congestion avoidance	
Improve residents' health	Environmental zone	Shared bicycle	Car free zones	
Increase road safety	Sensor movement/people/vehicles	Systems for speed control and management	ITS - intelligent transport systems	Autonomous shuttles
Innovate/examplary function	Floating car data	Intelligent infrastructure	Autonomous shuttles	
Make city centre accessible	Rethink spatial planning living/working/shopping	Car free zones	Shared space	
Make mobility accessible to vulnerable groups	Application sharing rides	Autonomous shuttles	Shared space	Car free zones
Make public transport more robust/reliable/user-friendly	Bus rapid transport	Autonomous shuttles		
Make village/rural area accessible, decrease travel time	Bicycle highway	Bus rapid transport		
Rearrange roads/streets more efficiently	Shared space	Rethink spatial planning living/working/shopping		
Reduce emissions (incl CO2)	Charging stations electrical cars	Environmental zone	Kilometre-based charge	Stimulate working from home
Save/earn money	Peak hour driving	Peak hour public transport	Kilometre-based charge	
Shorten traffic jams (highway/national roads)	Peak hour driving	Stimulate working from home	Tidal flow	Ramp metering
Shorten travel time	Intelligent infrastructure	ITS - intelligent transport systems		
Solve parking shortage (cars)	Real time crowd at destinations	Parking navigation system	Park and ride	Shared cars
Control tourist flows (attract/decourage)	Realtime information supply	Real time crowd at destinations		
Control traffic demand	Realtime information supply	Real time congestion avoidance	Peak hour driving	Stimulate working from home
Temporarily redirect traffic	Real time congestion avoidance	Roadworks on route planning	Realtime information supply	Real time crowd at destinations
Understanding traffic nuisance	Real time congestion avoidance	Realtime information supply	Floating car data	

A3 Calculations of effects

In 6.3, the effects for smart mobility applications are listed. This appendix further describes the actual calculations of these effects per application.

A3.1 Park and ride

There are different types of Park and Rides, one important distinction being between destination P+R and origin P+R. This study assumes the building of a origin P+R, meaning that the P+R is located closer to the origin than to the destination, and that the largest part of the journey is now taken by public transport. When determining the effects of a P+R, variables that could affect the outcomes are the possibilities to park your car at the destination, the extent of congestion on the route and the public transport connectivity from the P+R (Rijkswaterstaat, 2019).

The average capacity of a park and ride is 150 parking spots, of which on average 60% is occupied (Rijkswaterstaat, 2019). That means that a Park and Ride would have

$$0.6 * 150 = 80$$

spots occupied.

Efficient mobility & accessibility: The rule of thumb is that each parked car at a P+R equals one congestion avoidance (Rijkswaterstaat, 2019). An average of 80 parked cars means approximately 80 congestion avoidances, which equals 16 vehicle hours saved per day when applying the rule of thumb. That means, on a yearly, basis,

$$16 * 365 = 5840$$

vehicle hours saved.

Sustainability & energy: Each parked car saves 13.7 kg CO2 per day (Rijkswaterstaat, 2019). This means that on average for all spots,

$$80 * 365 * 13.7 = 400{,}040$$

kg CO2 is saved on a yearly basis.

Comfort, health, safety & ethics: One car parked rather than driving saves 0.0097 kg NOx per day and 0.0006 kg PM10 per day (Rijkswaterstaat, 2019). That yields a reduction of

$$80 * 365 * 0.0097 = 283$$

kg NOx and

$$80 * 365 * 0.0006 = 17.5$$

kg PM10 per year.

Regarding safety, using Table 13, it can be calculated that implementing a Park and Ride reduces the amount of injured victims due to traffic incidents by

$$0.00013 * 5840 = 0.7592$$

victims per year, and the amount of deathly or hospitalized victims by

$$0.000032 * 5840 = 0.1869$$

victims per year.

Efficient spatial use & infrastructure: It is assumed that all 80 cars that occupy spots on the Park and Ride would otherwise be driving. Following the information from Figure 9, the spatial use reduction can be estimated at

$$80 * (140 - 20) = 1600$$

m2.

A3.2 Car sharing

Car sharing can be implemented in various forms. The municipality of Wageningen implemented a business-to-consumer model, for which an external company put shared cars on fixed spots in the city, available 24 hours per day. However, it would also be possible to have a free-floating system, where cars do not have to be returned to the location of pick-up. The data used for these calculations do not differentiate between these two; the surveys conducted refer to car sharing in general, not in a specific system. It is important, though, to note that the type of system does affect the impact of car sharing. A system that is easy to use and integrated in other mobility policy in the city, with cars at close distance, has proven most successful. The rule of thumb for car sharing is that one shared car replaces approximately 6 possessed cars (Rijkswaterstaat, 2019). One shared car is estimated to serve by 15 to 18 users (Natuur & Milieu, 2019).

Efficient mobility & accessibility: People drive on average 1600 km less per year when they started car sharing compared to before that (Planbureau voor de Leefomgeving, 2015). Using the estimations in Decisio (2012), gives total reduction in VVU per introduced shared car of

$$15 * 1600 * 0.01 = 240.$$

Efficient spatial use & infrastructure: Rijkswaterstaat (2019) estimates that one shared car saves 36-38 m2. However, using the rule of thumb on spatial use, our estimate would be higher:

$$6 * 20 = 120$$

m2. The difference between these estimates is in the estimated space taken by one parked car. While Rijkswaterstaat solely considers the exact dimensions of a parking spot, the 20 m2 from the rules of thumb is an estimation on the actual space taken.

Sustainability & energy: Reducing the amount of kilometres driven equals CO_2 savings per person of 90 kg CO_2 per year. When also including the long term reduction of the amount of cars on the road, the CO_2 reductions would be 220 kg CO_2 per person per year. Per introduced shared car, that would mean

$$220 * 15 = 3300$$

kg CO_2 saved per year (Planbureau voor de Leefomgeving, 2015).

Comfort, health, safety and ethics: Using the rule of thumb for pollution, introducing one shared car saves between

$$96 * 0.00075 = 0.18$$

and

$$240 * 0.0015 = 0.36$$

kg PM_{10}, and between

$$240 * 0.0065 = 1.56$$

and

$$240 * 0.0130 = 3.12$$

kg NO_x per year.

For traffic accidents, the amount of injured victims can be estimated by

$$240 * 0.00013 = 0.03$$

per introduced shared car, and the amount of deathly or hospitalized victims by

$$240 * 0.000032 = 0.01$$

per introduced shared car.

A3.3 Congestion avoidance

Congestion avoidance can be used either to prevent major delay in case of maintenance or to improve bottleneck-situations on highways. It mainly entails personal invitations change to their transport behaviour to contribute to reducing congestion. Due to the accepted motions in Dutch parliament, congestion avoidance by means of financial incentive and using ANPR cameras is only allowed in case of large maintenance. As camera registration has proven most effective, it only makes sense to calculate the effects for a limited time period (Rijkswaterstaat, 2019).

Efficient mobility & accessibility: The 10 congestion avoidance projects resulted on average in 3.700 congestion avoidance per day. An average congestion avoidance project spanned a period of 160 days. Taking into account the ratio of participants as well as the congestion avoidances per participants, 70 congestion avoidances can be achieved per 1000 cars on the road by these projects. As one congestion avoidance equals approximately 0.2 saved vehicle hours,

$$0.2 * 160 * 3700 = 118{,}400$$

vehicle hours are saved over the average period of a project.

Efficient spatial use & infrastructure: One project prevents 118,400 VVU over 160 days. That equals

$$\frac{118400}{160} * 5 = 3700$$

m2 on average during the duration of the project.

Sustainability & energy: On sustainability, congestion avoidance projects would yield a reduction of 2.1 kg CO2 per congestion avoidance (Rijkswaterstaat, 2019). Assuming a project of comparable size to the executed projects, i.e. 3700 congestion avoidances per day over 160 days, one project would yield

$$2.1 * 3700 * 160 = 1{,}243{,}200$$

kg CO2 savings.

Comfort, health, safety and ethics: On NOx, the emissions would be reduced by 0.0024 kg per congestion avoidance and for PM10 by 0.00027 kg per congestion avoidance. That can be converted to emission reduction of

$$0.0024 * 3700 * 160 = 1420.8$$

kg NOx per average project,

and

$$0.00027 * 3700 * 160 = 159.84$$

kg PM10 per average project.

Regarding traffic safety, one average project leads to

$$0.00013 * 118.400 = 15.39$$

fewer injured victims, and

$$0.000032 * 118.400 = 3.79$$

fewer deathly or hospitalized victims.

A3.4 Bicycle highway

The effects of improvement of the bicycle infrastructure does not cause major changes in the amount of people traveling by car or by bicycle. It does, however, have a larger impact on the satisfaction of cyclists that were already using the cycling infrastructure. On top of that, the effects of improving cycling infrastructure are dependent on the location, and on the extent of infrastructure adaptations. Creating missing links in the cycling paths would have a larger effect than improving the asphalt layers. The effects calculated are based on the effect measurements of the construction of the Rijn-Waalpad, a bicycle highway between Nijmegen and Arnhem.

Efficient mobility & accessibility: The average bicycle highway is around 10 kilometres long and results in approximately 150 congestion avoidances per day, or

$$150 * 365 = 54750$$

congestion avoidances per year (Rijkswaterstaat, 2019). With one congestion equal to 0.2 saved vehicle hours, that means

$$0.2 * 54750 = 10950$$

vehicles hours saved per year.

Efficient spatial use & infrastructure: By taking into account that driving cars take up more space than parked cars, the savings in spatial use can be estimated at an area of

$$\frac{10950}{365} * 5 = 150$$

m2. For now, we are assuming no reductions in car possession but only a change in usage.

Sustainability & energy: For now assuming use by only regular bicycles and no e-bikes for simplicity, each congestion avoidance reduces emissions per day by 1.1 kg CO2 (Rijkswaterstaat, 2019). Assuming the project concerns an average bicycle highway, emissions reductions would be

$$1.1 * 54750 = 60{,}225$$

kg CO2 per year.

Comfort, health, safety and ethics: With the same assumptions as for Sustainability & energy, each congestion avoidance saves 0.0013 kg NOx and 0.00015 kg PM10 (Rijkswaterstaat, 2019). That yields total reductions of

$$0.0013 * 54750 = 71.2$$

kg NOx per year and

$$0.00015 * 54750 = 8.2$$

kg PM10 per year.

Regarding safety, a bicycle highway would reduce the amount of injured victims in accidents by

$$10950 * 0.00013 = 1.42$$

and the amount of deathly or hospitalized victims by

$$10950 * 0.000032 = 0.35.$$

A3.5 iVRI

iVRI is the abbreviation of the Dutch term ‘intelligente verkeersregelinstallaties’, or intelligent traffic lights. Intelligent tranffic lights include software optimizations to improve traffic flow, as well as experimenting with dynamic control programs.

Efficient mobility & accessibility: In Noord-Holland, iVRI led to a reduction of 4.5 VVU per crossing per workday (Ministerie van Infrastructuur & Waterstaat, 2015). Even more promising are the results of the implementation of iVRI in Helvoirt, between Den Bosch and Tilburg. At crossing N65-Torenstraat, waiting times and travel times have been reduced significantly, leading to a decrease of 632 VVU, from 2509 to 1877 lost vehicle hours per week (Goudappel Coffeng, 2018). Being conservative, the first results are being used to estimate standard results. 4.5 VVU per crossing per workday would equal a reduction of

$$4.5 * 5 * 52 = 1430$$

VVU per crossing per year.

Efficient spatial use & infrastructure: Less congestion leads to less spatial use by cars. This reduction can be estimated at:

$$\frac{1430}{365} * 5 = 20$$

m2 on average.

Sustainability & energy: No specific research is conducted on the effects of iVRI on sustainability, but by using the rule of thumb that one VVU leads to approximately 5.5-18.5 kg CO2 reduction, the effect can be estimated between

$$1430 * 5.5 = 7865$$

kg CO2 savings, and

$$1430 * 18.5 = 26455$$

kg CO2 savings per year.

Comfort, health, safety and ethics: Using the rules of thumb, the emissions of PM10 are expected to be reduced by

$$1430 * 0.00075 = 1.07$$

kg to

$$1430 * 0.0015 = 2.15$$

kg PM10. For NOx, the expected reduction is between

$$1430 * 0.0065 = 9.30$$

and

$$1430 * 0.0130 = 18.59$$

kg NOx per year.

Regarding safety, the reductions in injured victims can be estimated at

$$1430 * 0.00013 = 0.19$$

per year and the deathly or hospitalized victims are expected to decrease by

$$1430 * 0.000032 = 0.05.$$

A3.6 Real-time travel advice

Real-time travel advice helps travelers to find the optimal route, leaving time and mode of transportation at any given time. The results used to determine the effects are based on measurements of multiple private parties (Ministerie van Infrastructuur & Waterstaat, 2015).

Efficient mobility & accessibility: Real-time travel advice could result in 5000 congestion avoidances per day (Ministerie van Infrastructuur & Waterstaat, 2015). Using the conversion factor, that would save

$$0.2 * 5000 = 1000$$

VVU per day. On a yearly basis, that could mean

$$1000 * 365 = 365000$$

VVU.

Efficient spatial use & infrastructure: Real-time travel advice improves traffic flow and hence spatial use by congestion. The reduction in spatial usage can be estimated at:

$$\frac{365000}{365} * 5 = 5000$$

m2.

Sustainability & energy: On real-time travel advice, no specific estimation for CO2 savings is known. Using the rule of thumb, gives CO2 savings in the range of

$$365000 * 5.5 = 2{,}007{,}500$$

kg, and

$$365000 * 18.5 = 6{,}725{,}500$$

kg per year.

Comfort, health, safety and ethics: Air pollution can be estimation with the rules of thumb defined. On PM10, it could yield a reduction between

$$0.00075 * 365{,}000 = 273.75$$

and

$$0.0015 * 365{,}000 = 547.5$$

kg PM10 per year. For NOx, the reduction is expected to be in the range of

$$0.0065 * 365{,}000 = 2372.5$$

and

$$0.0130 * 365{,}000 = 4745$$

kg NOx per year.

For traffic safety, real-time travel advice could reduce the amount of injured victims in traffic accidents by

$$0.00013 * 365{,}000 = 47.45$$

and the amount of deathly or hospitalized victims by

$$0.000032 * 365{,}000 = 11.68.$$

A3.7 Bicycle sharing

Many different sharing systems have evolved in the past years. The most important differences between those systems regard registration, return possibilities, accessibility, amount of locations and type of locations. In Rijkswaterstaat (2019), the effects have been split up and determined for multiple different sharing systems, based on expert judgements and assumptions. The calculations in this section work with bandwidths instead, capturing the variety of the different systems.

Efficient mobility & accessibility: The effect of bicycle sharing is 0.1 - 0.6 congestion avoidances per shared bicycle per day (Ministerie van Infrastructuur & Waterstaat, 2018), depending on the chosen type of system. Using the rule of thumb to convert congestion avoidance to VVU, that would mean between

$$0.1 * 0.2 = 0.02$$

VVU reduction, and

$$0.6 * 0.2 = 0.12$$

VVU reduction per day per shared bicycle. Per year, the reduction in VVU could be estimated at between

$$0.02 * 365 = 7.3$$

and

$$0.12 * 365 = 43.8$$

per shared bicycle.

Efficient spatial use & infrastructure: As bicycle journeys mainly replace other bicycle journeys, the effect on spatial use is negligible. The difference between spatial use of a car and a bicycle is too big for replacement of bicycles to be significant.

Sustainability & energy: Using the rules of thumb, it can be calculated that one shared bicycle saves between

$$5.5 * 7.3 = 40.15$$

and

$$18.5 * 43.8 = 810.30$$

kg CO2 per year.

Comfort, health, safety and ethics: By using the values from Table 13, one shared bicycle can be estimated to save at least

$$7.3 * 0.00075 = 0.0055$$

kg PM10, by taking the lowest value of the bandwidth of both PM10 per VVU and the amount of VVU,

and at most

$$43.8 * 0.0015 = 0.0657$$

kg PM10 per year, by taking the highest value of both bandwidths. Using the same approach, the emissions of NOx are expected to decrease with between

$$7.3 * 0.0065 = 0.0475$$

and

$$43.8 * 0.0130 = 0.5694$$

kg per year.

Finally, the reduction in amount of traffic injuries can be estimated at between

$$7.3 * 0.00013 = 0.00095$$

and

$$43.8 * 0.00013 = 0.00569,$$

per year, and the reduction in amount of traffic deaths between

$$7.3 * 0.000032 = 0.00023$$

and

$$43.8 * 0.000032 = 0.00140.$$

A4 Cost-Benefit Analysis

One of the recommendations is to investigate the use of Cost-Benefit Analysis for smart mobility solutions. The following rules of thumb would be suggested if a Cost-Benefit Analysis would be included in the developed tool.

A4.1 Valuation numbers

Regarding **accessibility**, the valuation of time spent in a car depends on the travel motive. Travellers in congestion which falls in their work schedule, are more expensive than travellers outside of working hours.

Table 17 Valuation numbers accessibility (euros per lost vehicle hour) (Ministerie van Infrastructuur & Milieu, 2015)

Lost vehicle hours	**Costs**
Personal transport	9.00
Business transport	42.20
Average	15.64

For the sake of simplicity, the present study will assume the valuation number for accessibility always at 15.64 euros.

In current transport models, traffic flow is financially valued by the Value of Time (VoT) spent in a vehicle. The assumption to this VoT used to be that time spent in traffic is lost time. When the usage of autonomous driving vehicles gets standardized, the VoT changes. Time spent in a vehicle could now be used to eat, work, sleep or relax. Lost time could in this way become productive time (Rigo, 2019). Because autonomous cars are not expected not be fully operational soon, VoT from Table 17 are used.

For the monetization of **environmental** effects, the Ministry refers to the guide on environmental prices (Handboek Milieuprijzen) (CE Delft, 2017). The following relevant valuation numbers are taken from this guide for emissions to air in euros per kg emission (2015 price level):

Table 18 Valuation numbers environment (euros/kg emission, 2015 price) (CE Delft, 2017)

Gas	**Lower boundary**	**Middle value**	**Upper boundary**
CO2	0,014	0,056	0,057
NOx	24,1	34,7	53,7
PM10	31,8	44,6	69,1

An important remark regarding the environmental effect is that the valuation of CO2 savings depends on the realized emissions and ambitions scenarios in the coming decade (Centraal Planbureau & Planbureau voor de Leefomgeving, 2016). However, at the moment, the middle value can be assumed for the sake of simplicity. When further advancing these calculations, this remarks shall be considered.

The valuation numbers for **traffic safety** are described by Rijkswaterstaat (2016) and noted in the table below:

Table 19 Valuation numbers traffic safety (millions of euros per victim, 2009 price) (Rijkswaterstaat, 2016)

Victim category	**Costs per victim**
Traffic deaths	2.612
Severe traffic casualties	0.281
Light casualties	0.0086
Other casualties	0.0049

However, in case the severity of injuries and material damage are unknown, Rijkswaterstaat (2016) argues to use the valuation numbers in Table 20, which account for these factors.

Table 20 Rules of thumb valuation numbers for traffic safety (Rijkswaterstaat, 2016)

Rule of thumb	**Costs per death (in mln euros)**	**Costs per severely injured (in mln euros)**
Per death	17.0	-
Per death and injured	2.612	0.53

The suggestion would be to apply the most relevant table of the two, depending on the level of detail available on victims and damage due to the traffic accidents.

Lastly, if the average **spatial** acquisition costs are 1370 euros per m2 and an average period is 20 years, the yearly spatial costs would be approximately 70 euros per year per m2 (Decisio, 2017).

A4.2 Null scenario

To start a Cost-Benefit Analysis, it is important to know what the current situation is regarding those factors that are assessed in the analysis. This current situation, the null scenario, can then be compared to the projected situation after implementation of a measure. In Deltaplan 2030, Mobiliteitsalliantie (2019) summarizes the current societal costs of mobility on the themes described before.

Regarding **accessibility**, the societal costs relate to congestion and lost time in traffic. The direct costs for congestion on the main road network summed up to 2.8-3.7 billion euros in 2016. In the future scenario with high economic growth and high population development (WLO, 2015), this could increase to 3.5-4.7 billion euros. Public transport delay amounts to approximately 500 million euros.

According to Planbureau voor de Leefomgeving (PBL), the total **environmental** costs for mobility, excluding air traffic and shipping, are approximately 7 billion euros in 2015.

The costs for traffic **safety** amount to approximately 14 billion euros in 2017, according to SWOV. This number is calculated based on approximately 600 traffic deaths (13% of costs) and 21,000 heavily injured (45% of costs). If no policy measures are taken, the amount of traffic deaths is estimated at 470-580 in 2030 and the amount of heavily injured at 29,000-32,000. That would be a decrease and increase respectively (Mobiliteitsalliantie, 2019).